Real-time Survival Rates for Treatments of Archaeological Iron

SUZANNE KEENE

> I there behelde the bones of a man . . . and round about him . . . such nailes were found, wherefore I coniectured them to be the nailes of his coffin. . . . I caused some of the nayles to bee reached vp to mee, and found under the broad heades of them, the olde wood, skant turned into earth. . . . I reserued one . . . but the nayle lying drie, is by scaling greatly wasted.
>
> —John Stowe, *Survey of London,* 1603

Since the 1970s, a series of excavations in London has uncovered a mass of archaeological evidence for life in the capital from pre-Roman times onward. During the short-lived property boom of the mid-1980s, there was an exponential increase in new building and redevelopment in the city of London. The museum was fortunate in persuading many developers to fund excavation on these developments. It was found that progressive land reclamation and revetment along the north bank of the Thames, the main trade route, had resulted in large, stratified dumps of rubbish from the Roman and medieval city. The waterlogged and anaerobic conditions in these sites ensured the survival of the objects contained there, including an unparalleled number and range of objects made of iron.

The Nature of the Problem

The stabilization of archaeological iron presents difficult problems. Iron is a relatively reactive metal, and in the presence of an electrolyte such as ground water, it mineralizes to a greater or lesser extent. The minerals formed will vary depending on burial conditions (Turgoose 1982b). In aerobic conditions, objects often corrode out entirely, although their form can remain embodied within the corrosion products (and can sometimes be recovered by skilled conservators). In anaerobic conditions, corrosion may proceed to a much lesser extent. Such objects often appear extremely well preserved and are sometimes assumed to be stable. Experience has shown, however, that such is not the case.

Whatever the apparent condition of the objects when excavated, they actually consist of a highly complex metal-and-mineral system. Many of the minerals are only stable within the particular burial environment—with its specific redox potential, pH, and so on. When brought above ground, these conditions no longer exist, and different minerals begin to form, due either to changes in the original minerals, or to fresh corrosion at the metal-corrosion interface (Turgoose 1982b).

Because they are so well preserved, these objects are an excellent source of evidence for their manufacture and use. London iron is often decorated by tooling or shaping; it can be tinned or inlaid; tool marks from manufacture or sharpening are preserved in surfaces. But unfortunately for the conservator, most of this detail is contained in the mineral layers, as John Stowe observed nearly 400 years ago. If objects recorrode, fresh mineralization at the metal surface pushes off these delicate surfaces, leaving only the familiar powdery red rust.

Existing Knowledge

The work of Turgoose (1982a, 1982b, 1985) and others (Gilberg and Seeley 1982) has done much to explain the corrosion mechanisms sustained by archaeological iron after excavation. However, developments in treatments to stabilize this material have lagged behind theoretical understanding to some extent.

The “Holy Grail” of iron conservators has been removal of every trace of chloride from the corrosion and metal. Until the 1970s, there was a meager choice of treatments for iron: boiling in purified water, reduction using electrolysis, or soaking in sodium carbonate. These methods were widely found to be unsuccessful; objects treated in this way frequently recorroded within a few years. Other methods have been more recently introduced: hydrogen reduction, chemical reduction, and gas plasma reduction. These are very aggressive treatments, however, and all of them place at risk the delicate corrosion surface of the objects or the metallurgical evidence that they embody, both of which are prime reasons for preserving the objects. Some of them rely on heat, which compromises the metallurgical evidence (Tylecote and Black 1980).

Other measures that do not depend on chloride removal are desiccated storage, storage in an atmosphere of vapor-phase inhibitor (VPI), and storage in atmospheres of nitrogen or with an oxygen scavenger. However, treatments not involving chloride removal, such as corrosion inhibitors, have scarcely been seriously explored.

In the United Kingdom at least, there is a strong body of opinion that treatments for iron are no more effective than simply storing objects at a low relative humidity. Turgoose (1982b) identified 15% RH as the level at which all water will be removed from iron minerals, thus preventing alteration. Therefore, many conservators in the United Kingdom have adopted storage at, or as close as possible to, 15% RH as their preferred procedure for stabilizing this material.

The Reason for This Study

Conservators at the Museum of London were faced with an influx of beautifully preserved but unstable objects, as shown in Figure 1, but no clear professional con-

FIGURE 1. *Well-preserved iron objects from Swan Lane, treated using various methods.*

sensus on the most effective treatment for them. Excavation funding included an element for conservation, but this was project-based and only available for a fixed time; decisions could not be deferred.

In 1983–84, in order to gather some objective evidence, a study of iron previously treated by the author was undertaken and published (Keene and Orton 1985). The results of this study suggested that all the treatments that were assessed improved the stability of the objects. Since then, the policy of the Museum of London has been to actively treat iron destined for its collections. The museum also considered it desirable to keep this policy under review. Therefore, in 1983, anticipating an eventual formal assessment, finds from a particular site (Swan Lane, SWA 81) were divided into four batches, and each batch was treated using a different procedure. The objects have since been stored and handled in exactly the same way as are other objects in the museum's collections.

ASSESSMENT DESIGN AND PROCEDURES

The present study is based on empirical observations of the stability of excavated iron treated in various ways and untreated. The aim was to establish whether any of the treatments that are used confer greater stability than no treatment or storage at RH lower than 15% (desiccated storage).

The sample in the assessment summarized in Table 1 may be described as follows: (a) four batches of iron from the Swan Lane site, treated at one time; (b) iron from the same excavation, not treated and stored in desiccated and ambient conditions; (c) iron from other Museum of London sites, some batches stored in desiccated conditions, some in ambient environments; and (d) iron from completely different areas and types of sites (excavated by the Passmore Edwards Museum), stored using the best practicable means to maintain a low RH.

TABLE 1. *Summary of the data from the assessments of the batches of objects.*

Excavation code and date	*Treatment or storage type*	*Year treated or stored*	*Number in batch*	*Years since treatment or start of storage*																							
				2			*3*			*5*			*6*			*7*			*8*			*9*			*13*		
				Mis	*Sta*	*Uns*	*Mis*	*Sta*	*Uns*	*Mis*	*Sta*	*Uns*	*Mis*	*Sta*	*Uns*	*Mis*	*Sta*	*Uns*	*Mis*	*Sta*	*Uns*	*Mis*	*Sta*	*Uns*	*Mis*	*Sta*	*Unc*
a. Museum of London, Swan Lane site: treated batches																											
SWA 81	NaOH	1983	24	0	24	0				0	24	0							1	22	1						
SWA 81	Alk. sulf.	1983	19	0	19	0				0	19	0							5	13	1						
SWA 81	Water/VPI	1983	31	7	27	2				4	18	7							3	16	3						
SWA 81	Electrol.	1983	17	6	10	1				3	6	6							2	6	4						
b. Museum of London, Swan Lane site: batches stored without treatment																											
SWA 81	Ambient	1983	31																			0	10	21			
SWA 81	Dessicated	1983	10																			0	3	7			
c. Museum of London, other sites: batches stored without treatment																											
OPT 81	Dessicated	1982	32																			0	23	9			
OPT 81	Ambient	1982	33																			0	13	20			
BWB 83	Dessicated	1984	17													0	9	8									
MOG 86	Dessicated	1986	15							0	2	13															
MOG 86	Ambient	1986	15							0	2	13															
BOY 86	Dessicated	1986	15							0	6	9															
BOY 86	Ambient	1986	20							0	3	17															
d. Passmore Edwards Museum: batches stored without treatment																											
WA/AM 78	Dessicated	1978	164																						0	8	156
BA 85	Dessicated	1985	47										0	10	37												
TF 88	Dessicated	1988	72					0			22		50														
TF 89	Dessicated	1989	26		0			20			6																

Notes: 1. An object is only counted unstable once, and is thereafter omitted from the table.
2. If an object was missing from an assessment but is found at a later one to be stable, it is counted as stable in the earlier assessments.
3. In this table, an object may be considered missing at one assessment but observed as unstable at a subsequent one.
See Table 2 for further details of these points.

The treatment procedures, detailed in Appendix 1, may be summarized as follows:

Water/VPI: Soaking in deionized water with dissolved vapor phase inhibitor (Dichan, dicyclohexyl ammonium carbate, marketed as Shell VPI 260)
Alkaline sulfite: Soaking in changes of alkaline sulfite, followed by changes of deionized water
Sodium hydroxide: Soaking in a dilute solution of sodium hydroxide
Electrolysis and soaking: A short period of electrolytic reduction followed by soaking in water/VPI as above

Objects were allocated to the four treatments in rotation by their accession number; those that were heavily corroded, very delicate, or had tinned or decorated surfaces were not treated with alkaline sulfite nor with sodium hydroxide. Electrolytic reduction was not used as it usually is—to strip away all corrosion to the metal—but rather to loosen corrosion layers in order to make it easier to expose fine detail. In this, it was very successful. The selection for treatment was similar therefore to any typical selection process and was not completely random. A higher proportion of delicate and heavily corroded objects are typically allocated to treatments either by electrolysis or by using water with VPI, although there is no reason to assume that such objects are inherently more or less prone to corrosion. These treatments are summarized in Table 2.

After treatment, the objects were stored at 15% RH in sealed boxes containing silica gel, according to normal practice. Their condition was reviewed in 1985, 1988, and 1991: two, five, and eight years after treatment. The most recent review included untreated objects from the same site stored in the ambient environment but not treated, and a similar sample that had been stored at 15% RH.

To provide further data, objects both from other Museum of London sites and from a completely different context were also examined. A neighboring museum, the Passmore Edwards, has a climate-controlled chamber operated at 18–20% RH. Hygrothermograph records confirm that these conditions were maintained throughout the period of study. Excavated iron has been stored within this chamber in sealed boxes containing completely desiccated silica gel monitored with indicator strips since 1982. The objects have thus been doubly protected. Prior to that time, silica gel in sealed boxes alone was used to create desiccated conditions. The museum is therefore an excellent exponent of the technique of desiccated storage.

In assessing instability, as in the earlier study, an object was graded "unstable" if there was the slightest sign of fresh corrosion or lifting of mineral layers. In the current review of Museum of London iron, microscopic examination was used to settle doubtful cases, and this resulted in regrading a few objects from "unstable" to "stable."

In most cases of treated iron, instability consists of one or two very small flakes or cracks, as shown in Figure 2. Often, however, untreated iron has almost disintegrated, as shown in Figure 3.

FIGURE 2. *A treated iron object, above, slightly unstable.*

FIGURE 3. *An untreated iron object, right, almost disintegrated.*

DATA AND ANALYSIS

A total of 588 objects were examined. The data from these assessments are summarized in Table 1. Table 2 shows an example of the data for one batch, which was treated using water and VPI. For each object, the following data were available: year

TABLE 2. *Observations for the batch treated using water/VPI.*

Date of assessment (treated in 1983)	*April 1985*	*October 1988*	*July 1991*
Registration number: SWA 81			
462	m	x	out of trial
463	[o]	[o]	o
468	[o]	[o]	o
470	m	m	x
472	o	[o]	o
474	o	o	o
506	[o]	[o]	o
656	o	m	x
657	o	[o]	o
695	[o]	[o]	o
780	m	x	out of trial
926	o	[o]	o
946	o	m	m
1045	m	x	out of trial
1362	x	out of trial	
1530	x	out of trial	
1591	o	o	o
1739	[o]	[o]	o
1762	[o]	o	m
2230	[o]	o	x
2239	[o]	[o]	o
2240	m	x	out of trial
2313	o	o	o
3068	o	x	out of trial
3079	o	m	x
3091	o	o	o
3273	[o]	o	o
3382	[o]	[o]	o
3388	m	x	out of trial
3863	[o]	[o]	o
3951	m	x	out of trial
Totals:			
Number entering interval (= number from last interval minus number then unstable)	31	29	22
Missing	7	4	3
Newly unstable	2	7	3

Key: m = missing; o = observed stable; [o] = inferred stable from later re-appearance; x = newly unstable of excavation; year treated or storage begun; stable, unstable, or not present on one or more occasions after treatment; years elapsed from start date to examination.

In the precursor to this study (Keene and Orton 1985), the probability of recorrosion and the related parameter of half-life were also calculated. It was not necessary to use this sophisticated technique again, since the new data were considerably simpler. However, complications did arise. On first sight, in fact, it was difficult to determine how to extract all the information these data obviously contained. Batches of objects had been examined at different points in time; some objects were not present for assessment but were found on subsequent occasions when others were missing.

A very similar research situation exists in medicine when clinical trials are undertaken to compare survival rates for different treatments. Patients may survive, or they may die of the disease being treated or from another cause. They may miss checkups, then subsequently return. It was found that the techniques used to assess test results with these kinds of variables could also be applied to the "survival" of archaeological iron. The techniques are described fully in Mould (1981:65–69). Data similar to those available for the iron objects are used to construct "Life Tables." A Life Table for the batch treated using water with VPI is shown in Table 3; the headings summarize the method.

What is calculated is the probability that an object will "survive" (be stable) at any given year after it was treated or stored. The probabilities for different batches of objects can then be compared (Fig. 4, Table 4). These survival probabilities are, in fact, familiar figures, often quoted in press reports for treatments. A probability of 0.33 can be expressed as "one in three will survive beyond *x* years," or as "a 30% chance of survival" (Fig. 5).

RESULTS

The question being examined is: Does treatment confer greater stability than no treatment or than desiccated storage? This can be expressed as a null hypothesis: At a given year *T*, there is no difference between the probability of survival for an iron

TABLE 3. *Life table for the batch treated using water/VPI.*

Year	*Interval number*	*Years since treated*	*Observed unstable*	*Missing*	*Number entering interval*	*Number at risk* ($li - \frac{1}{2} wi$)	*Prob. of instability at interval* i	*Prob. of surviving*	*Prob. of surviving to Year T*
	i	*T*	*di*	*wi*	*li*	*ni*	$qi=di/ni$	$(1-qi)$	$PT=(1-qi)(1-qi)$ (percent)
1983	0	0	0	0	31	31.00	0.00	1.00	100
1984	1	1	0	0	31	31.00	0.00	1.00	100
1985	2	2	2	7	31	27.50	0.07	0.93	93
1986	3	3	0	0	25	25.00	0.00	1.00	93
1987	4	4	0	0	25	25.00	0.00	1.00	93
1988	5	5	7	4	25	23.00	0.30	0.70	65
1989	6	6	0	0	19	19.00	0.00	1.00	65
1990	7	7	0	0	19	19.00	0.00	1.00	65
1991	8	8	3	3	19	17.50	0.17	0.83	53

FIGURE 4. *Survival probabilities compared for batches of objects treated in different ways, and batches stored untreated. Lines for the stored batches are straight because they are calculated from one assessment in year 9, while those for treatments are the result of three sequential assessments (see Table 4).*

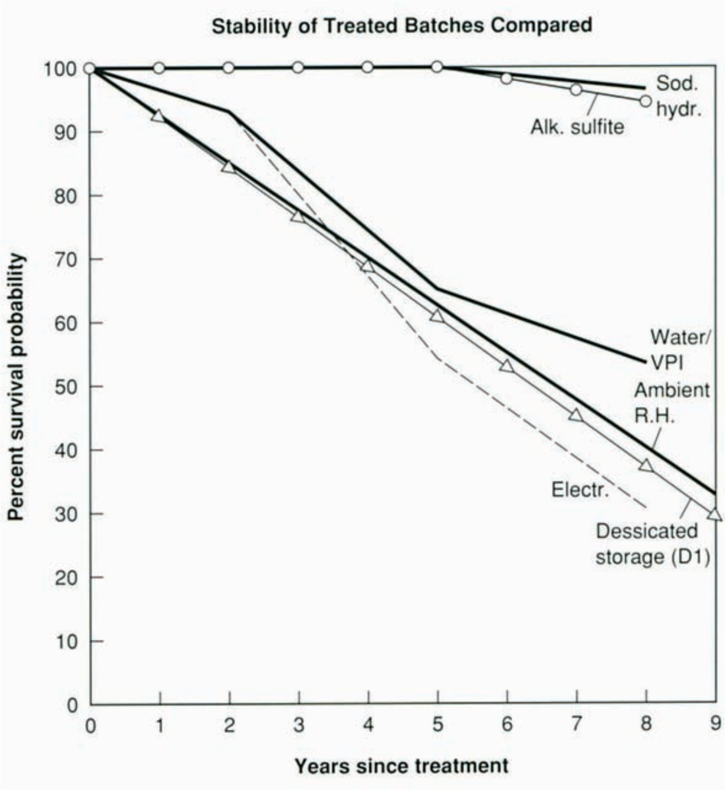


TABLE 4. *Percent survival probabilities at Year* T *for all the assessed batches.*

Year since treatment/ storage	*Treated iron: Swan Lane, SWA 81* Sodium hydroxide	Alkaline sulfite	Water/ VPI	Electrol./ soak	*Stored at ambient RH* Site codes: MOG 86	BOY 86	SWA 81	OPT 81	*Stored at 15% RH* Site codes: TF 89	TF 88	MOG 86	BOY 86	BA 85	BWB 83	SWA 81	OPT 81	WA/AM
(Year *T*)																	
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—	—
2	100	100	83	94	—	—	—	—	77	—	—	—	—	—	—	—	—
3	100	100	83	94	—	—	—	—	—	31	—	—	—	—	—	—	—
4	100	100	83	94	—	—	—	—			—	—	—	—	—	—	—
5	100	100	65	52	13	15	—	—			13	40	—	—	—	—	—
6	100	100	65	52			—	—					21	—	—	—	—
7	100	100	65	52			—	—						53	—	—	—
8	96	94	61	26			—	—							—	—	—
9							32	72							30	39	—
10																	—
11																	—
12																	—
13																	5

object, whether it is treated, stored in desiccated conditions, or simply stored in the ambient environment.

The comparative survival probabilities at the different assessments of the Swan Lane batches are compared in Figure 4. Survival probabilities at the end date (year 8) are compared in Figure 6, showing a very considerable difference between the best treatments (soaking in sodium hydroxide and alkaline sulfite), which more than doubled the probability of survival over storage at ambient RH and over electrolysis

FIGURE 5. *The percentage of stable objects compared for batches of untreated stored objects.*

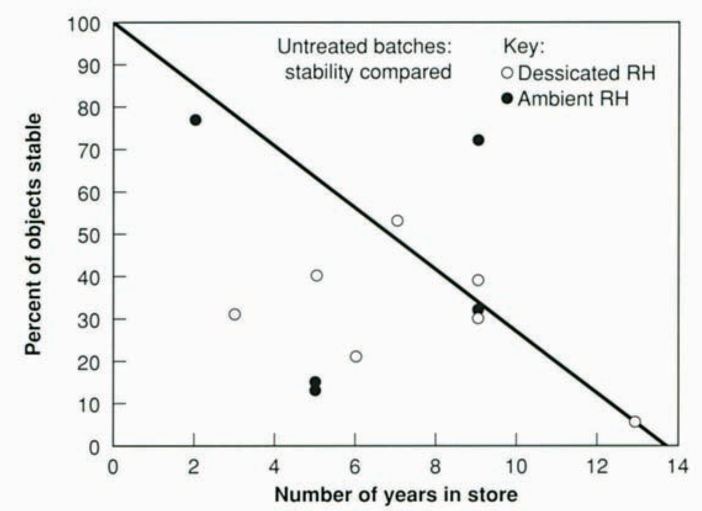
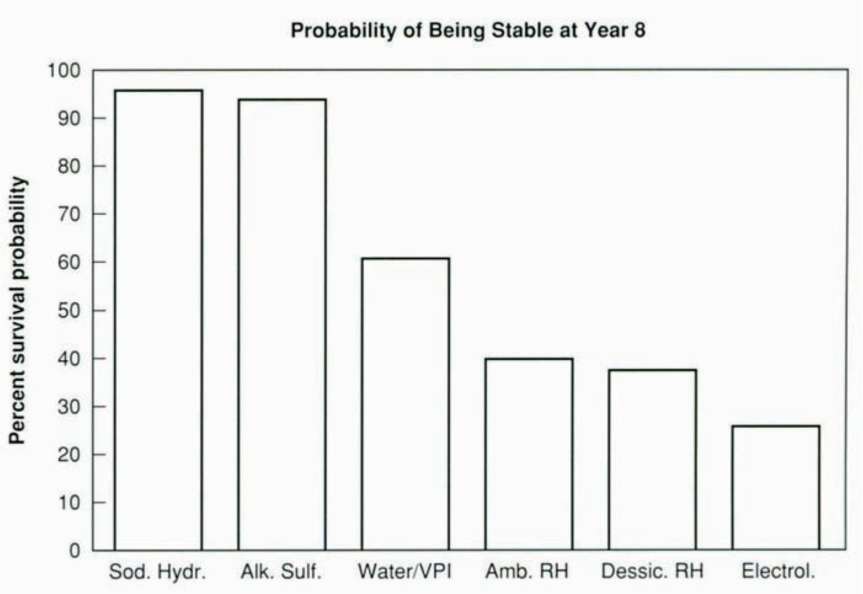


FIGURE 6. *The probability of being stable at year 8: outcome of treatments and storage compared.*



followed by soaking, which in this study gave the worst survival rate of all. Soaking in deionized water with VPI doubled the survival chance over that of untreated iron. The interpretation of these results is discussed later.

But are these differences only apparent? The chi-squared test of significance was applied to a table of numbers of objects, stable and unstable, for the treatment batches compared to the untreated iron (all for the Swan Lane site, to reduce variables). The results were significant at the 0.5% level, and so the null hypothesis can be rejected; there is a real difference between active treatment and storage alone. Further tests of significance (binomial tests) show that electrolysis is significantly worse than the average of the other three treatments, and that water with VPI is probably worse than sodium hydroxide and alkaline sulfate.

The results for the batches that were not treated but stored in different ways are equally interesting. In order to compare results with those for the treated batches, the simple percentages of objects stable at the year of inspection were calculated (Fig. 6). The result for the batch longest in storage (also the largest batch by far), from which the percentage of objects surviving is very small, has been used to plot the line in Figure 6, which gives a notional average. If objects in desiccated storage survived longer than objects stored at ambient RH, then the markers for these batches would be located in the upper right-hand part of Figure 6. But they are, in fact, randomly distributed, as are the markers for batches stored at ambient RH.

Because the batches were assessed at different numbers of years after storage, it was not possible to carry out a chi-squared test of significance for the untreated objects. Other possible tests do exist, but they are complex, and it is likely that the differences would not be statistically significant.

INTERPRETATION

Instability in iron has a number of contributing factors, as Turgoose and others have shown (Turgoose 1982a, 1982b, 1985). Given these factors—the chemical nature of the iron's corrosion, particularly perhaps the chloride content; the physical nature (thickness and impermeability) of the mineral layers; and the relative humidity and oxygen content of the storage environment—it is difficult to evaluate the success of treatments as well as explain the causes of failure.

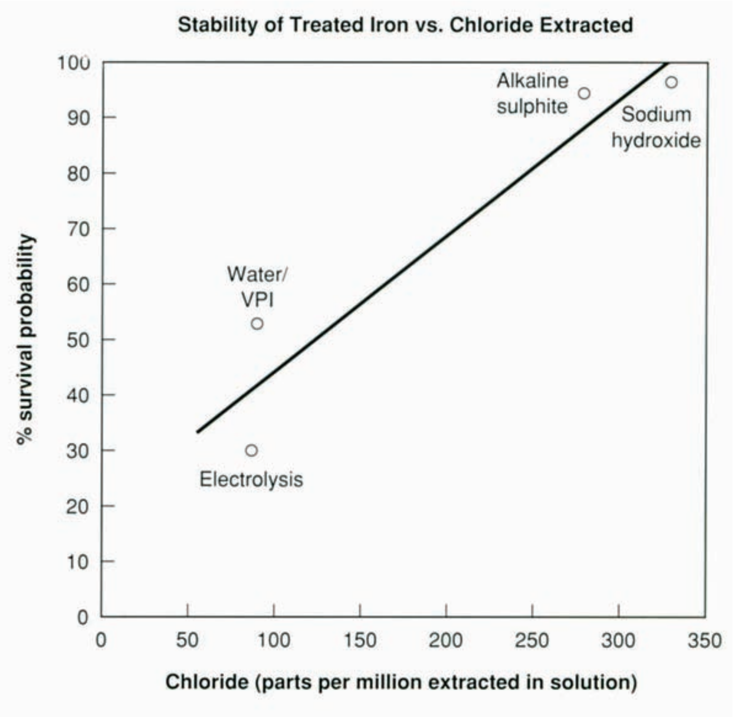
The nature of the object is one consideration. Watkinson (1983) has shown that if an object is completely mineralized, then it is not likely to recorrode. The Museum of London anaerobic iron does not fall into this category; the objects each have a relatively thin corrosion layer and a metal core. It seems that little of the dry-site iron from the Passmore Edwards Museum is protected by this factor either, but time will show whether, for example, the few remaining objects from the batch longest in storage (thirteen years) will eventually break down.

Iron from the Museum of London was from wet, anaerobic sites. Results for these batches are no different from those for the Passmore Edwards dry-site iron (Tables 1, 4), although the mineral layers on the objects look very different. In this case, the burial context of the objects has not had a strong influence on their survival.

The concentration of chloride ions is another factor. There is a correlation between the amount of chloride ion removed during treatment and the probability of stability, as illustrated in Figure 7. The comparative chloride-extraction rates for the different treatments have been confirmed in measurements made by other conservators at the Museum of London in the course of treating other batches of objects, as well as by Rinuy and Schweizer (1981), and North and Pearson (1975, 1978). In iron conservation, one questions the basis for any assumption, but it is widely assumed that if sufficient chloride can be removed from an archaeological object, then the object will be stable. An empirical test by Rinuy and Schweizer (1981) did indicate that iron does not corrode in the complete absence of chloride, even at elevated relative humidities.

It is quite surprising that sodium hydroxide alone produced such a good result. The treatment was tried as a result of North and Pearson's article discussing its use on marine iron (1978). The ill effects subsequently predicted by Turgoose seem not to have occurred (1985a:14). It was tried because it prevented obvious corrosion and was less disruptive than alkaline sulfite to mineral layers.

FIGURE 7. *The probability of being stable at year 8 plotted against the amount of chloride extracted during treatment.*



Pretreatment using electrolysis had a markedly adverse effect on the stability of the objects. This procedure was used to make the corrosion layers separate more easily for cleaning delicate, decorated surfaces; and it accomplished this purpose very effectively. It was postulated that electrolysis would make the mineral layers more porous and allow soluble chloride to escape more easily during subsequent soaking. Perhaps this pretreatment also allows oxygen and humidity to penetrate more easily during subsequent storage. If this is the course of its lack of success, then it may be possible to prevent this effect by consolidating the corrosion layers.

The results from this study seem to indicate that the storage environment has much less influence on the stability of iron than had been supposed—a great deal less than do most treatments. There may be an explanation for this. Even if a desiccated environment is maintained, as it was for the Passmore Edwards material, the phenomenon of interstitial condensation may mean that pockets of high humidity are formed in the plentiful pores and cracks in the mineral coatings of the objects (Schreir 1976). Any free water will leach out soluble salts, such as chlorides, and concentrate them in these small areas.

Should it be confirmed that desiccated storage has no real advantage over storage in ambient conditions, this information will have far-reaching consequences for the techniques used to store archaeological iron. Many more samples need to be assessed, however.

CONCLUSIONS

These results reinforce the tentative conclusions from the first study that, in real-time assessments after long periods in storage, active treatment improves the survival chances of iron. Treatment appears to have a much greater effect than does controlled storage at low relative humidity. The most effective treatments are those that remove the greatest quantity of chloride, but this study cannot demonstrate cause and effect here.

Following the first study and the encouraging early results of the second, the Museum of London has continued to treat its archaeological iron, using the procedures outlined in Appendix 2. These include soaking in the corrosion inhibitor triethanolamine, as suggested by Argo (1985:31). This method has not yet been formally assessed, although it has been observed that quite a large amount of chloride is extracted in this way. The museum will revise its standard treatments again to take account of present findings, and and will also consider whether to use sodium hydroxide rather than alkaline sulfite, should it be less disruptive to the mineral layers.

The effects of treatment on the objects' surfaces are also being studied by Dana Goodburn Brown, using the scanning electron microscope to record surface detail before and after treatment. At present, selected objects are being carefully cleaned, and silicone-rubber molds (Dow Corning 9161) are being taken of the surfaces before and after treatment. The four different treatments described in Appendix 2 are being assessed; and, in addition, a treatment is being developed at the Institute of Archaeology at University College, London. The same area of each object will be examined in order to evaluate the effect each treatment has on the surface.

Further work is suggested. Turgoose is currently engaged in a collaborative research project under the European STEP initiative at the University of Manchester Institute of Science and Technology, assessing the corrosion potential of archaeological iron. In parallel with this work, studies based on the real-life assessment of actual objects are clearly useful. Accelerated aging tests in high relative humidity for mineralized iron are likely to introduce other complications arising from the nature of the mineral layers and will not give convincing results. Some of the protocols set out for clinical trials in medicine, described by Mould (1981), might be adopted.

The development of more effective treatments—including less aggressive ones, perhaps not involving chloride removal—should also be encouraged. It is tantalizing to read abstracts of published work on the effects of silicates and corrosion inhibitors (Art and Archaeology Technical Abstracts 27-815, 27-907), and discussions of the use of corrosion inhibitors (Turgoose 1985b). It is encouraging to report that Ahmed al Zaid, at the Institute of Archaeology at University College, London, is researching the use of silane products on iron.

APPENDIX 1. TREATMENT PROCEDURES USED IN THE TRIAL

MECHANICAL REMOVAL

Mineral layers overlying the original surface were first removed using mechanical means: a scalpel or power pen. For ease of comparison of treatments, each batch consisted of iron objects totaling approximately the same weight, and all soak baths contained 1 L of solution. The temperature of all the treatment baths was maintained at 50 °C in a laboratory oven. Sealed polythene boxes, completely filled with liquid, were used to keep oxygenation to a minimum.

Alkaline Sulfite

For general discussion of this method, see North and Pearson (1975). Only relatively robust objects with no tinning were selected for this treatment, since tin will dissolve in alkaline solutions. The procedure was as follows:

1. Chloride removal: Objects were immersed in four successive baths of 0.5 M alkaline sulfite (Na_2SO_3 + NaOH). The duration of each bath was one week.
2. Removal of alkaline solution: Objects were immersed in changes of deionized water and Dichan VPI until no more chloride could be detected. There were fifteen solution changes. The total time of treatment was twenty weeks.[1]

Sodium Hydroxide

For a discussion of the benefits of using washing solutions at raised pH, and especially sodium hydroxide, see North and Pearson (1978). Only relatively robust objects with no tinning were selected for this treatment, since tin will dissolve in alkaline solutions. The procedure was as follows:

1. Chloride removal: Objects were immersed in five successive baths of 0.5 M sodium hydroxide (NaOH).
2. Removal of alkaline solution: Objects were immersed in changes of deionized water with 0.5% w/v Dichan VPI until no further chloride could be detected. There were thirteen solution changes. The total time of treatment was nineteen weeks.

Electrolysis Followed By Deionized Water

The procedure was as follows:

1. Corrosion softening: The electrolyte was sodium carbonate. A low density current was passed until the corrosion layers had softened and separated sufficiently for easy removal.
2. Chloride removal: Objects were soaked as a batch in changes of deionized water with 0.5% w/v Dichan VPI until no more chloride could be detected. There were fifteen changes of solution. The total time of treatment was twenty weeks.

Deionized Water and VPI Soaking

The procedure was as follows:

Chloride removal: Objects were soaked in changes of deionized water with 0.5% w/v Dichan VPI until no more chloride could be detected. There were fifteen changes of solution. The total time of treatment was twenty weeks.

Drying and Protection

After treatment, objects were dewatered through two changes of industrial methylated spirits and coated with two coats of Incralac lacquer.

APPENDIX 2. DESALINATION TREATMENTS IN CURRENT USE

Desalination treatments for iron currently used as standard at the Museum of London involve a choice of method as follows:

ALKALINE SULFITE

This method of chemical reduction makes corrosion more porous and allows Cl^- to diffuse out. It also extracts the most chloride and appears not to damage silver or copper (black deposit on the latter can be scraped off).

Contraindications: Alkaline sulfite dissolves tin, weakens adhesives, and can disintegrate fragile, heavily mineralized objects. It may also damage original surfaces.

SOAKING IN TRIETHANOLAMINE (TEA) SOLUTION

TEA is thought to react with iron oxychlorides, freeing chloride ions. It has the next best chloride extraction rate after alkaline sulfite. TEA is a corrosion inhibitor, so it inhibits flash rusting. It seems not to damage silver or copper (copper may stain) and does not damage fragile objects. It is possibly suitable for organics such as bone.

Contraindications: TEA damages tin. It is less damaging to adhesives than is alkaline sulfite.

SOAKING IN DEIONIZED WATER WITH CORROSION INHIBITOR (DICHAN VPI)

The corrosion inhibitor prevents rusting during the soak; this may enhance chloride removal. It is possible that traces remaining in the object will confer some corrosion protection. Deionized water with VPI does not damage nonferrous metals, adhesives, or leather.

Contraindications: Do not use this method with wood or iron composites, as the VPI soaks into the wood and produces quantities of crystals as it dries.

TANNIC ACID

This is used as a surface coating for "maintenance" of unstable objects.

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NOTE

1. North and Pearson recommend neutralizing the sodium sulfite using barium hydroxide. Simply soaking to remove it was judged preferable, since barium hydroxide can leave unsightly white deposits.

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BIOGRAPHY

Suzanne Keene qualified in conservation at the Institute of Archaeology in London. She worked in the Winchester Research Unit on the material from the well-known excavations there. After a period in private practice, she became head of Archaeological Conservation at the Museum of London, then head of the Department of Conservation there. She now works as head of Collections Management at the Science Museum of the National Museum of Science and Industry in London. Her research interests include conservation information and the stabilization of archaeological iron.