1

The Conservation and Restoration of the Copper Scroll from Qumran

Régis Bertholon, Noël Lacoudre and Jorge Vasquez

Introduction

The 23 cylindrical segments of the Copper Scroll are the result of the cutting up of the two rolls of sheets of copper discovered in 1952 in a cave near the Dead Sea. So that the text on these sheets of copper could be read, all involved had to resign themselves to the inevitability of the rolls being cut. After nearly 2000 years, the metal of these rolls was completely oxidized.

Remarkable work of consolidation was undertaken in 1955 and 1956 in the laboratory in Manchester both before and after each roll was submitted to the thin blade of the saw. Then about 40 years passed during which the materials used in consolidating the scroll aged and successive handling of the segments resulted in new breaks that were 'repaired' with products that were sometimes less than adequate. With some sense of urgency a highly skilled assessment of the state of the document became necessary. Then the work of conservation began, using methods that recent research had put at our disposal. This involved removing surface adhesives and putting back together and consolidating the fragmented segments with more stable materials that were often less obtrusive. At the request of the Hashemite Kingdom of Jordan and thanks to the coordination of the Institut Français d'Archéologie du Proche-Orient and of the École Biblique et Archéologique Française, Electricité de France (EDF), in the form of its technological and scientific wing, offered its help in undertaking this ambitious programme.

The work was done between 1994 and 1996 at the Laboratoire EDF–Valectra, which is at the heart of EDF's Groupe des Laboratoires de l'Exploitation du Parc Nucléaire. There, experts with competence in the behaviour of metals could lend their support: metallurgists with their electron microscopes, X-ray diffractometers and analysis by fluorescence; chemists for the microanalysis of all kinds of treating solutions; and those who would assess the non-destructive X-ray images, which had never been attempted before on the segments of this text whose copper had totally disappeared.

It was possible not only to establish for each of the 23 segments, recto and verso, an extremely detailed 'status report', but also to contribute some unpublished information concerning both the engraved text and the inner structure of the material of which the Copper Scroll is constituted. Supported by the technical expertise of the laboratories of EDF's Direction des Études et Recherches, other work was undertaken at the same time, such as the digital treatment of the radiography images at Saint-Denis. These analyses enabled us to give the fragmentary document an appearance close to that of the original and to restore its inscribed text with the greatest possible feasibility.

All the important moves in the restoration process were presented step by step to the competent authorities of the Jordanian Department of Antiquities, who also gave their agreement to the solution for the final support of these precious shells. In a similar way, the reassembly of certain fragments was achieved with the endorsement of Émile Puech (CNRS—Centre national de la recherche scientifique), the epigraphist responsible for the new reading of the manuscript.

Forty Years of Conservation and Handling of This Unique Document

The status reports have enabled us to redress the balance sheet after 40 years of conservation and to determine the causes of various damage that has occurred since the treatment of 1955–56 (Table 1.1; Fig. 1.1). This damage is tied up with the aging of the products used, with the continuous handling of the scroll, and with the conditions under which it was stored and presented. This has provided an opportunity for learning about the consequences of the choice of treatment in 1955–56, notably with respect to the interventions made for consolidation, and for evaluating the behaviour of resins, some of which are still used today.

At the time of each status report it was important to document and conserve a faithful image of the segments before any intervention. Numerous photographs have been taken in conjunction with the observation of the segments and the analysis of the materials. Each segment has likewise been subjected to radiography from several angles which has allowed us to form a complete radiographic covering of the scroll before any intervention.

Table 1.1. *Summary of treatments of the Qumran Copper Scroll before 1992*

1955–56: Treatment in the laboratory in Manchester (Baker 1956, Baillet *et al*. 1962)

For each of the 23 segments:

- mechanical cleaning of dust and concretions from the outer surface;
- mounting on a steel axle and sealing with plaster;
- removal of traces of cellulose resin by washing with acetone;
- consolidation with an epoxy resin lightly diluted in toluene (Araldite 102/hardening Araldite 951), heating to 40°C;
- gluing of the fragments with cellulose nitrate (Durofix);
- gluing of strips of reinforcement of methyl polymetacryl (perspex) by cellulose nitrate (Durofix) and reinforcement with a layer of epoxy resin (Araldite);
- cutting by circular saw at high speed;
- cleaning with a nylon brush;
- mechanical cleaning of the products of corrosion from the inner surface;
- consolidation of the surface with a solution of methyl polymetacryl (Perspex) in chloroform;
- photographs;
- construction of a support for the Amman Museum.

1977: Technical appraisal (Oddy 1977)

Undated: Pinpoint regluing of fragments, placing reinforcements of green linen.

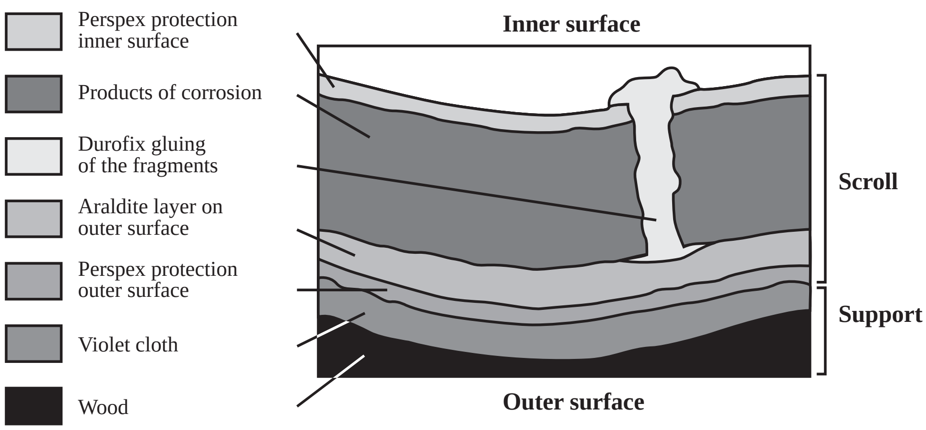

Fig. 1.1. *Transverse cut of a segment with its support after the treatment of 1955 and at the time of its storage at Amman Museum*

The principal ascertainable changes are:

- the fragmentation of the majority of the segments;
- non-adjoining gluings, either in the wrong places or simply unaesthetically;
- the presence of blue-green efflorescence, possibly indicating active corrosion;
- the peeling of the layer of Araldite from the consolidation of the outer surface;
- the relative insolubility of the perspex film of the consolidation of the inner surface;
- the adhesion of violet fabric from the support of the segments and the presence of brown traces on the outer surface of the segments.

Except for the peeling of the layer of Araldite, all the changes had already been noticed by A. Oddy[1] at the time of an earlier status report in 1977, about 22 years after the original treatment (Oddy 1977).

The diagnoses completed in 1977 and 1994 have come to practically the same conclusions:

- The great fragility of the segments was the cause of the fragmentation observed since 1956. This fragility had not inhibited the handling of the segments. The peeling of the layer of Araldite was not implicated here because the fragmentation was taking place without any differentiation in areas of both adherence and of peeling; however, the solidity of the layer of Araldite appeared insufficient.
- Although some non-adjoining gluings or those in the wrong place date from the treatment of 1955–56, numerous others are undoubtedly the result of later interventions that are undocumented but were intended to remedy accidents from the handling of the segments. The yellowing, which was due to the aging of the Durofix glue based on cellulose nitrate used in 1955, was responsible for the unaesthetic appearance of the gluings. However, the mechanical grip of the glues was good and the solubility of the Durofix seemed unchanged.
- The analysis of the blue-green efflorescence, done in 1994, indicated that it was principally a question of copper hydroxychlorides

1. We thank Andrew Oddy for kindly communicating the result of his assessment to us.

(atacamite and paratacamite). The efflorescence was localized on fractures, in fissures and at places where the cleaning of 1955 had made a layer of brown-coloured corrosion appear. Rather than being an active corrosion brought about by a rapid transformation of the metal, which in fact does not exist any longer in the entirely oxidized segments, it seemed to us that it was a question only of the transformation of the copper chlorides (nantokite) into copper hydrochlorides. This transformation could have been generated by mechanical constraints, particularly at the heart of cracks, which had facilitated the cracks' propagation (Bertholon 1995a).

- The changes in the resins used in 1955 were probably due to the combined action of light and humidity. The solubility of the film of perspex (methyl polymetacrylate, PMMA) was noticeably different according to whether it was acting as a protecting film on the inscribed (and exposed) inner surface or on the outer surface (cf. Fig. 1.1). The latter remained soluble in solvents of PMMA (Horie 1992) at the same time as the protecting film on the inner surface had become soluble in acetone only with difficulty. The detachments visible on the two surfaces no longer presented the same features: whitening of the accumulation of resins present in the hollows and lack of suppleness for the inner surface, but tearing on the outer surface. In both cases the film of perspex no longer seemed to play any role in protecting or consolidating the surface.

There was another very important element in the status report. The examination conducted in 1955 had concluded that the original surface (the surface of the segments at the time of their abandonment, which is nearest to the inscribed surface) should be located near a brown layer, still actually very visible and composed of a layer of red copper oxide (cuprite): 'a distinctive film of dark-brown colour covers what is now the base material' (Baker 1956). In spite of this remark, the cleaning of 1955 had not intended to eliminate the products of corrosion situated above this layer but to remove various accretions and some products of corrosion just at the green layer of hydroxilated copper, that is, well above the original surface. The deep imprint of the inscriptions meant that the document was very legible without cleaning down to the original surface.

The examination and analysis done in 1994 through the spectrometry of the florescence of X-rays coupled with observation through scanning with an electron-microscope enabled us to establish that the original surface was situated at the heart of the layer of cuprite at the interface of a brown-to-black layer and the upper cuprite layer. This ability to locate the original surface rests, among other things, on the presence of inclusions composed of silica or calcium coming from the buried layer situated just above the original surface and of certain elements of the original alloy of tin, belonging to the layer situated just below the original surface. This seems to corroborate the observations made in 1955.

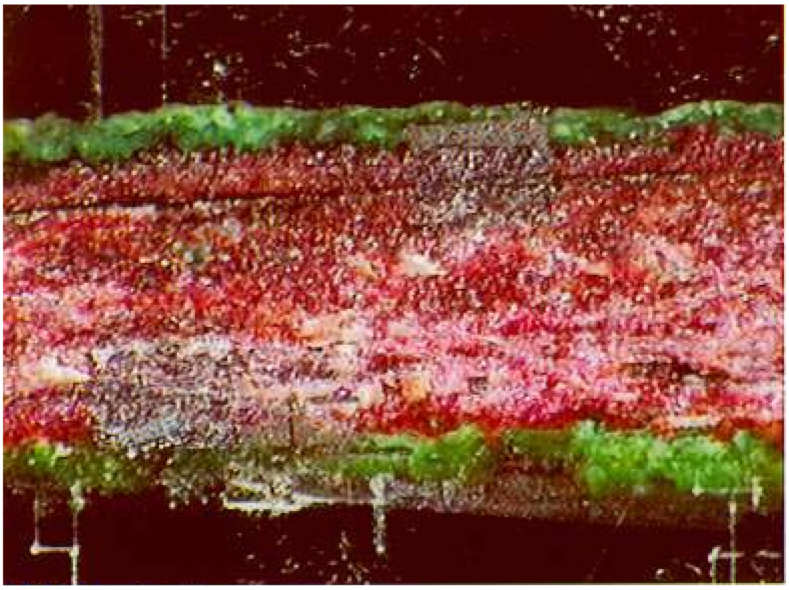

Fig. 1.2. *Stratigraphy of the layers of corrosion in the Copper Scroll after a transverse cut of a segment*

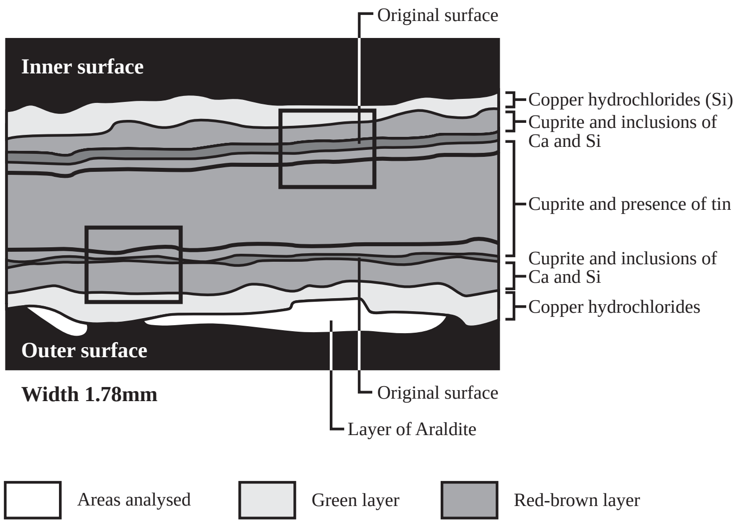

Fig. 1.3. *Transverse cut of a segment indicating the stratigraphy of the layers of corrosion visible on Fig. 1.2*

Objectives of the 1994 Conservation and Restoration

Diagnosis had shown that the intrinsic fragility of the scroll was the principal cause of its deterioration, together with it having been handled numerous times. It was important to give the scroll adequate cohesiveness and mechanical resistance sufficient to allow its conservation for the long term.

The consolidation of the scroll itself had to be compatible with the treatments already given in 1955 so as not to introduce heterogeneity into the cohesiveness and chemical behaviour of the materials applied on the segments. At the same time it was essential to use very stable materials so as to prevent for as long as possible the expiry of any new and always very delicate intervention. As far as possible, in any intervention it was also important to provide for some reversibility.

These objectives have been pursued through taking care to intervene as minimally as possible so as not to jeopardize the future of the document, but to allow for its natural aging, and that of the strengthening products too. Also, to enable the manipulation of the segments without danger, given the necessities of the study, an important part of the consolidation was brought about through the construction of individual supports and a customized packing case.

The objectives of the conservation and restoration of the segments also involved the readability of the inscription (after remounting and cleaning). With the same care taken not to jeopardize the future of the document through too much intervention, its cleaning was deliberately limited.

Interventions for Conservation and Restoration in 1994–1995

The improvement of the mechanical holding of the segments necessitated the redoing of the consolidation of 1955. The partial removal of the layer of Araldite led to heterogeneity in the mechanical resistance of the segments and so was a source of fragmentation. To remove the layer entirely appeared to put the segments at considerable risk. It was possible to re-establish a certain homogeneity by completing the layer with something similar, a layer of Araldite AY103/ hardener HY956 of a type very close to that used in 1955 and which ages in a similar way (Down 1984, 1986). To enable reversibility, this new layer is isolated by a film of Paraloïd B72, which involves some difference in adhesion but does not change the rigidity of the layer (Fig. 1.4).

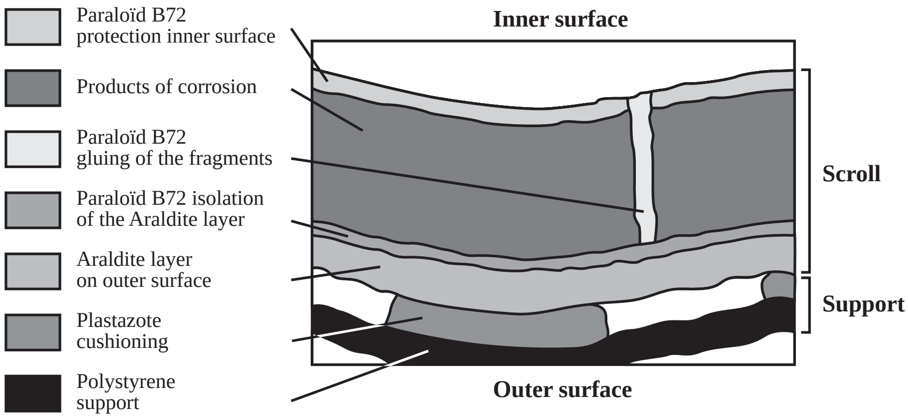

Fig. 1.4. *Transverse cut of a segment after the treatment of 1994*

This redoing of the consolidation was completed by the important work of the support of the segments. The characteristics of this support are the following:

- support of the whole surface of each segment by a rigid base of heat-formed polystyrene;
- intermediary cushioning between the segment and the base with a foam of polyethylene-reticulated Plastazote, to relieve the effects of shocks and vibrations;
- the fixing of each segment and the conceiving of the base to allow usual holding and manipulation of the segment by its base;
- the removable fixing of the segment by Plexiglas screwed hooks that allow for the holding of the segment itself in exceptional circumstances (e.g. for the study of the reverse);
- the use of long-term stable materials (polyethylene, polystyrene, acrylics);
- the presentation of the different segments at the same height in a Plexiglas box conceived to that effect;
- the making of a cushioned case for transportation (see Fig. 1.5).

The individual bases allowed for the handling of each segment in good conditions of safety, thus facilitating the study of the document.

The gluing together was redone with Paraloïd B72 so as to permit reversibility and to improve aging (Koob 1986).

It was decided not to proceed with cleaning down to the original surface but to limit this to certain areas that still had deposits of dirt or where further study was needed because the detail of certain letters was hidden. Because of the depth of the inscription, this minimal intervention for cleaning was entirely compatible with presenting the document as legible; however, certain details relating to the preparation of the document (such

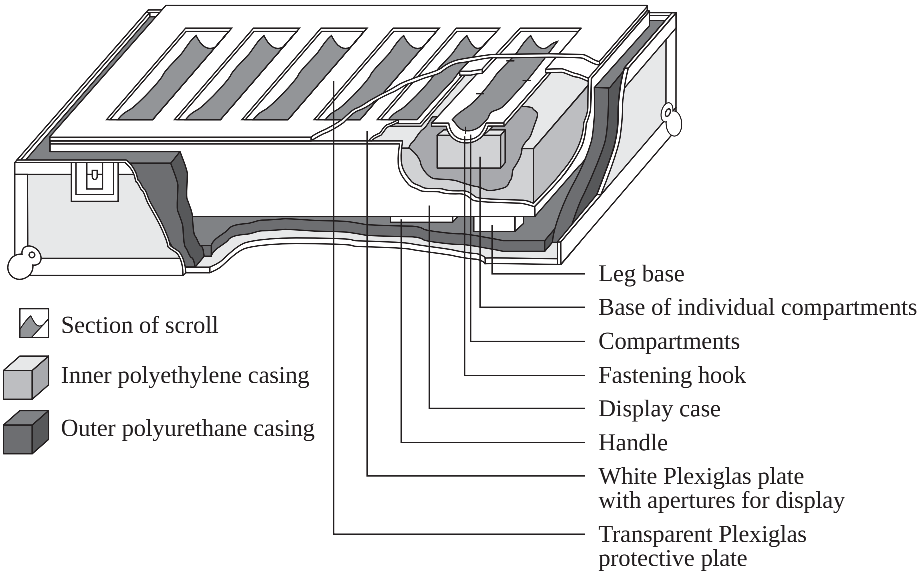

Fig. 1.5. *View of the transportation case containing the presentation box within which are placed the segments, each on its individual base*

as engraved lines) are not always visible on the surface of the products of corrosion. Various criteria were taken into account when deciding on cleaning being limited to certain areas:

- the minimization of the risks inherent in every cleaning technique (mechanical, chemical, or both) on the delicate sheets, which are deeply mineralized;
- the possibility of recovering hidden information (such as engraved lines) thanks to the exploitation of the X-ray images and their treatment;
- a refusal to modify the 'image' of the scroll, that is, a concern to conserve its appearance as familiar to the interested public and to retain its representative antiquity.

The complete list of interventions for conservation and restoration is presented in Table 1.2. The photographs of segments after treatment show only faint changes to the general appearance of the scroll.

Minimal intervention for conservation and restoration always allows for the better safeguarding of the integrity of a document. Such intervention has been undertaken on the Copper Scroll from Qumran because the technical means available at present offer other possibilities for the improvement of the legibility of the document. Conjointly the treatment of the digitized X-ray images and the flat reproduction of the scroll by galvanoplasty based on the casts of the segments were achieved.

Table 1.2. *Treatment of the Qumran Copper Scroll completed in 1994*

- Survey of the data of the cutting of 1955.
- Partial elimination of the 1955 materials of consolidation: elimination of the perspex films from the inner and outer surfaces and dismantling of the Durofix gluings by immersion in acetonitric, pinpoint mechanical elimination of the layer of Araldite, removal of the small plates of supporting Plexiglas.
- Pinpoint mechanical cleaning of the calcareous accretions masking certain characters.
- Stabilization of the corrosion by immersion in a partial vacuum in benzotriazol at 3 per cent in ethanol.
- Gluing of the fragments with Paraloïd B72 at 60 per cent in xylene.
- Insulation, consolidation, protection: insulation of the gluings and of the outer surface by Paraloïd B72 at 20 per cent in acetone, lining on the outer surface by a film of Araldite, protection of the inner surface and of the layer of Araldite on the external surface by a film of Paraloïd B72 at 5 per cent in acetone.
- Continuation of the data of the cutting of 1955 on each segment.
- Support:
  - the taking of a plaster imprint of each segment which allowed the making of a counter-image imprinted in plaster;
  - the making of shells through the heat treatment of sheets of polystyrene on the counter-images;
  - adjustment of each segment on its shell through cushioning with a polyethylene foam (Plastazote);
  - fixing of the segments on their shells.
- Presentation, storage and transport: the making of presentation and storage boxes in Plexiglas, the making of cases for transportation with a cushion of polyethylene foam.

Applying the X-rays and Digitized Images to the Epigraphy of the Copper Scroll

The X-rays of the segments enable an easier reading of the scroll and reveal certain inscriptions that have been difficult to see because of the roughness of the surface due to disturbances brought about by corrosion. They have also contributed to the elaboration of the status report by making apparent the cracks and various superimpositions of fragments that have been difficult to ascertain by visual examination. The digitization of the rolls of copper was undertaken in order to make a new and more feasible copy of the text; until now this has been a very intricate task because of the scroll's deformities and the uneven relief of the surface of the segments. On the basis of the radiography of the segments, the engineers of the Direction des Études et Recherches of EDF have been able to digitalize the inscriptions as the curves and deformities were made flat and as the displaced fragments were readjusted with the help of Émile Puech (École Biblique). Thus, thanks to the assembly of different images by computer, a new vision of this document has been obtained that will lead to its renewed epigraphic study.

Moulding and Reproduction by Galvanoplasty

Each of the 23 segments was moulded with a stretchable silicone. The negatives obtained in this way were flattened and put alongside one another to enable, for each of the three riveted sheets, the making of a positive in plaster that would constitute a faithful flat replica (with a variation in measurement of less than 2 per cent, that is, a character of 5 mm is reproduced with a length of 4.98 mm).

The new mould then makes a second negative obtainable in silicon, which now reflects the totality of the sheet. A positive in copper is then made by galvanoplasty (the deposit of metal by electrolysis), after the silicone sheet has been rendered conductible through the application of a fine layer of graphite. The facsimile in copper obtained for each of the three sheets of the document allows a new reading of the document inasmuch as it is a close representation of its original state.

Conclusion

The work of conservation and restoration of the Copper Scroll from Qumran undertaken by the Valectra laboratory was conducted simultaneously in several different directions:

- (Re)restoration compatible with the work done in Manchester in 1955 and minimal intervention for cleaning so as not to change fundamentally the appearance of this unique object of the world's heritage: it is the only Dead Sea scroll on copper.
- Creation of individual supports for each segment, intended to facilitate their handling by researchers and conservators, and the construction of boxes for presentation and for transport in order to minimize risk of further deterioration resulting from human handling.

- Creation and digitalization of X-ray images, and the making of galvanoplasty moulds that offer henceforth new presentations of the text that might satisfy the requirements of the epigraphists. The different reproductions are complementary: the revelation by the X-rays of movements of the scribe in the metal, the evocation of the complete document on the basis of the connecting of the digitized images and the faithfulness of the model in the smallest detail to the mould of the inscribed surface of each segment. The digitized X-ray images are capable of being broadcast widely within the scientific community. The copper replicas made through galvanoplasty also offer opportunities for museums and for the education of the general public because this document now appears in a state close to that of the original.

This discreet (re)restoration guided by the principles of reversibility and of minimal intervention will enable, we hope, the improvement of the scroll's conservation and presentation for the long term. Let us recall that the (re)restoration of this unique document was made possible thanks to pertinent choices being made concerning the treatment and the quality of materials used in 1955; these had good aging properties. We hope that our work reduces the chance that the scroll will need further restoration soon, and we also hope that any future restorers will come to their task facilitated by the choices we have made today.

BIBLIOGRAPHY

Baillet, M., J.T. Milik and R. de Vaux

1962 *Les 'petites grottes' de Qumrân* (DJDJ III; Oxford: Clarendon Press, 1962).

Baker, H. Wright

1956 'Notes on the Opening of the "Bronze" Scrolls from Qumran', *BJRL* 39: 45-56.

Bertholon, R.

1995a *Rouleau de cuivre 3Q15 de Qumrân: Rapport d'expertise technique et projet de conservation-restauration*, internal report of Electricité de France, No. D5711/RB94.2003/BTO.

1995b 'De nouvelles approches de la lecture du rouleau de cuivre de Qumrân: re-restauration minimale, radiographie X et traitement d'image, moulage et galvanoplastie', in R. Bertholon *et al.*, *Restauration, dé-restauration, re-restauration: Colloque sur la conservation restauration des biens culturels* (Paris: Association des restaurateurs d'art et d'archéologie): 295-306.

1998 'Corrosion du rouleau de cuivre de Qumrân et localisation de la surface originelle', in R. Bertholon, L. Robbiola and N. Lacoudre (eds.), *Metal 98* (London: James and James): 125-35.

2001 ‘Characterisation and Location of Original Surface of Corroded Metallic Archaeological Objects’, *Surface Engineering* 17.3: 241-45.

Down, J.L.

1984 ‘The Yellowing of Epoxy Resin Adhesives: Report on Natural Dark Aging’, *Studies in Conservation* 29: 63-76.

1986 ‘The Yellowing of Epoxy Resin Adhesives: Report on High-intensity Light Aging’, *Studies in Conservation* 31: 159-70.

Horie, C.V.

1992 *Materials for Conservation, Organic Consolidants, Adhesives and Coatings* (Oxford: Butterworth, 1992).

Koob, S.P.

1986 ‘The Use of Paraloid B72 as an Adhesive: Its Application for Archeological Ceramics and Other Materials’, *Studies in Conservation* 31: 7-14.

Oddy, W.A.

1977 *Report on the Scientific Examination of the Copper Scroll from Qumran in the Archaeological Museum, Amman* (unpublished report kindly communicated by the author).