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Recovery and Conservation of the West Runton Elephant

The outcrops of fossil-bearing sediments that are exposed on the north east Norfolk coast are well known to both amateur and professional palaeontologists for the diversity of terrestrial and freshwater fossils that are occasionally revealed after storms and high tides. The West Runton Freshwater Bed, which forms part of the Cromer Forest Bed is internationally renowned to scholars of Quaternary mammals in particular and represents the 'type site' for the Cromerian Interglacial, a period when Britain was connected to continental Europe by a broad land bridge.
The climate at that time is known to have been similar to today but the local fauna included many exotic species including bears, giant elk, rhinos, hyenas and elephants. There is no evidence for human occupation of Britain at this time, approximately 600,000 years ago, the earliest finds of human bone occurring 100,000 years later at Boxgrove.
The initial discovery of the elephant was made by amateurs in December 1990, while walking on the beach at West Runton near Cromer. A gale the previous day had eroded the base of the cliff revealing what proved to be the pelvis of a very large elephant. An astragalus or ankle bone found nearby suggested that more bones belonging to the same elephant might be lieing in the same vicinity. A 2½ week excavation undertaken by staff of the Norfolk Museums Service in January 1992 successfully located and removed approximately 25% of the skeleton, individual bones being encased in supporting plaster jackets before being lifted from the site. At least one large bone was known to still lie deeper in the Freshwater Bed but considerations of safety required that this, and any other parts of the skeleton remained buried at the foot of the cliff.
The bones recovered between 1990 and 1992 proved to be as important and unique as they were spectacular. Although the Forest Bed had been famous for over 170 years for its fossil mammal specimens, until 1992 there had been no find of a complete or even partial skeleton. Furthermore, elephant bones were almost unknown from this deposit until this most recent spectacular discovery. Equally important was the excellent state of preservation of the elephant bones. Although fragile and crushed by the weight of the overlying sediment, the surface details of the bones were remarkably well preserved, clearly showing muscle attachments, surface porosity and even the teeth marks of hyenas. The presence of hyenas as scavengers was confirmed by the presence of droppings or coprolites in the sediment close to the bones.
Following the 1995 excavations and the recovery of part of the skeleton in 1992, and its removal to the Castle Museum, study of the bones began in earnest. Examination of the lower jaw established the species as *Mammuthus trogontherii*, ancestor to the smaller woolly mammoth that roamed East Anglia in the Later Ice Age. From the pelvis recovered in 1990 it was determined that the specimen was a mature male with a shoulder height estimated at 4 metres and a weight of 9 to 10 tonnes, making the West Runton elephant the largest and oldest elephant yet discovered in Britain.
Because of its international importance, and in the light of the intense interest shown by the media and general public alike, the recovery of the remaining skeleton was seen as imperative, particularly since coastal erosion presented a continuing threat to the find spot. In late 1995 following a successful bid to the Heritage Lottery Fund and further support from local businesses, a controlled and systematic excavation of the elephant site was undertaken by the Norfolk Archaeological Unit assisted by the Swedish archaeological consultancy Arkeologikonsult and staff of the Norfolk Museums Service. This entailed the removal of over 17 metres of cliff overlying the excavation area, amounting to thousands of tonnes of sands, gravels and clay. In addition to the recovery of the remaining elephant bones, an ambitious programmme of environmental and scientific analyses of the sediment containing the bones was undertaken by an international team of specialists. More than 10 tonnes of soil samples were retained for later sieving, from which thousands of small mammal, amphibian and fish bones are anticipated to be recovered to add to the dozens of bones and teeth from bison, horse and deer found during excavation of the elephant.
Systematic samples for pollen analysis and sedimentological study were also taken.

Lifting the bones

Although the preservation of the elephant bones was remarkably good, the condition proved to be another matter. Fine details of structure and morphology were clearly visible on visual inspection of the bones and study of histological features in polished sections showed that there had been remarkably little secondary mineralization of the specimens. Apart from the dark brown colouration of the bones they appeared to be unaltered. However, loss of the structural protein collagen over thousands of years of burial had robbed the bone structure of much of its mechanical strength and as a consequence the majority of bones were penetrated by a network of cracks and breaks. Counter intuitively, these cracks were more numerous in the mid-shafts of long bones with the spongy ends appearing to retain more of their original integrity.
The surfaces of the bones were also easily marked by abrasion so wherever possible plastic or wooden tools were used to loosen sediment around the bones. Thus the elephant bones were far from the popular image of fossil bones as hard stony lumps. Rather the conservators were faced with the prospect of lifting very large, very heavy and potentially very fragile bones from West Runton beach in late autumn weather. Because of the cold, damp conditions 'high tech' encasement techniques involving glass-fibre reinforced resins and plastics, foams etc. were ruled out since they were considered too costly, time consuming and unreliable. The bones lifted in 1992 were each successfully lifted after encasement in a 'cast' of plaster of Paris reinforced with linen bandage and scrim. A parting layer of tissue protected the surfaces of the bones from direct contact with the plaster.

Plaster jacketed tusk prior to removal from site.

Plaster of Paris has the advantage of being relatively cheap, quick setting and above all reliable. Once the remainding plaster in the mixing bucket is hard one can be assured that the rest of it on the bone has also set. A large block of polyurethane foam may be hard to touch on the outside but may remain un-cured on the inside for many hours or days. A modified version of the standard plaster jacket was adopted for use at West Runton. Several layers of damp tissue-paper compress were stippled onto the bone surface using a stiff brush. This was followed by one or more layers of aluminium kitchen foil. Aluminium foil has the advantage of retaining its shape to a certain extent after crushing so that even undercuts could be successfully protected. The tissue served to prevent any wet plaster carried under the foil by surface tension forces from contaminating the surface of the bone. The tissue and foil parting layers were followed by successive applications of plaster-wetted bandage cut into approximately 50 cm lengths. Once the bone was well covered in plaster bandage the thickness of the jacket was built up with plaster of Paris and broad scrim. In order to create an effective jacket and one which would not allow the bone to drop through the bottom when lifted, the sediment surrounding the bone was excavated so that it stood proud of the surrounding surface on a pedestal of soil. This was not always easy since many bones rested one on top of the other. However, once the plaster jacket was protecting the bone it was possible to excavate tunnels through the supporting pedestal and beneath the bone, allowing plaster bandages to be passed over and under the mid-shaft. Additional rigidity was conferred to the plaster jacket by including shaped sections of expanded steel mesh (available from builders' merchants) within the outer layers of the plaster. This expanded mesh has the advantage of being

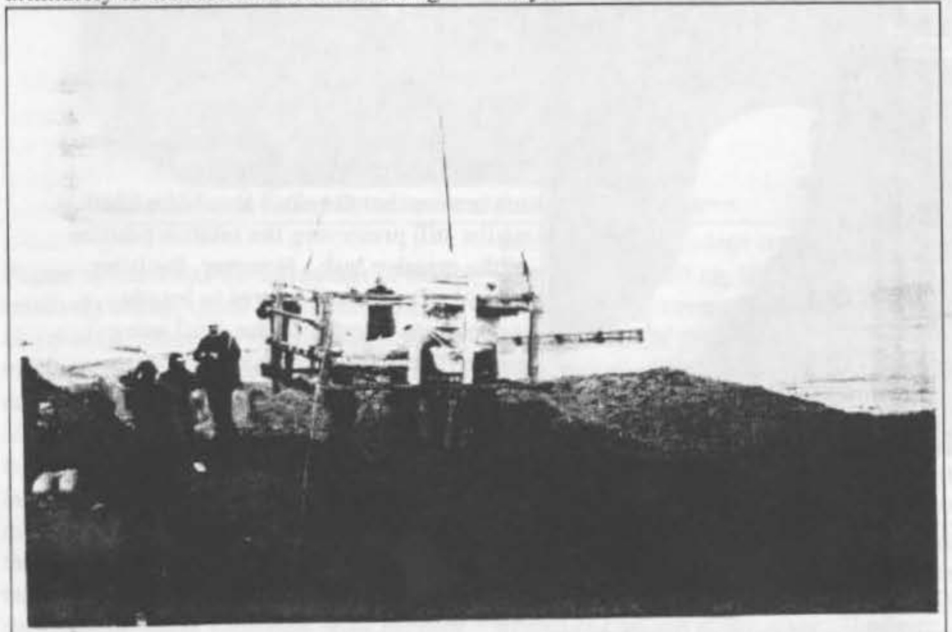
readily stretched and bent into complex shapes but becomes very rigid when the holes are filled by solid plaster.

Aluminium foil covering before application of top coat of plaster of paris

Once the bones were safely jacketed the pedestals supporting them could be progressively removed until the plaster jackets could be gently rocked from side to side, demonstrating that they were free of the ground. The bones were each lifted (by many hands) and placed 'sediment side up' on standard pallets. Bubble-pack rolls or polystyrene bean-bags were used to cushion the finds and the bones were secured to the pallets with scrim tapes. The palletted samples were removed from the beach using a half-tracked vehicle.

Because of the nature of the work and the weather conditions, latex gloves were worn throughout the excavation and for lifting of most of the bone finds. This had the additional advantage of limiting possible human contamination of material that may later be subject to analysis for residual biomolecules. Water collected as run-off from the cliff face was used to wet down exposed bones to prevent potential cracking of their surfaces and when applying tissue or plaster, partly for convenience and partly in an attempt to preserve the chemical integrity of the bones.

Discovery of a large portion of skull with one intact tusk stretched the ingenuity of the conservation team to its limits. Clearly for such an important find it was imperative that the skull should be lifted whilst still preserving the relative position of the massive tusk. However, the latter proved to be several metres in length. Attempts to 'block lift' the skull using polyurethane foam and a wooden crate were ruled out for the reasons outlined above. Furthermore, such an approach ran the risk of destroying undiscovered bones hidden beneath the skull or tusk. The tried and tested formula of plaster bandage was adopted whilst a suitable cradle was devised. As sections of the skull and tusk were exposed by careful excavation, they were systematically supported and protected by a plaster jacket. Those parts that became undercut as sediment was removed were given some additional support by infilling the void with foaming polyurethane from aerosol cans. Similarly, tunnelled undercuts beneath sections of the tusk were supported by replacing the sediment with foam. Small fragments of skull and other bones revealed by the removal of surrounding sediment were planned, recorded and lifted. It soon became clear that small pieces of bone could be lifted on a pedestal of sediment simply by crushing large pieces of aluminium foil around them and gently squeezing the aluminium to shape. Lightweight, channelled, rolled steel section was used to build a scaffolding around the skull and tusk to support them during the final stages of excavation and ultimately to cradle the structure during jacket securely to the steel/plywood cradle. Eventually, when both skull and tusk were supported at all points, the remaining sediment was carefully dug away by hand to release the structure from its parent soil. Nylon lifting straps shackled to the top of the cradle then allowed the complex to be lifted free from the Forest Bed and onto the waiting half-track. Preparing the skull for lifting was undertaken in less than four days.


Lifting the elephant using carne and rolled steel scaffolding

lifting. This steel section could be readily cut to length on site using a hacksaw and could be joined using a wide range of differently shaped clamps and couplings, held rigidly together by standard bolts. Additional support was provided by shaped pieces of perforated steel sheet and a plywood box for shuttering around the skull. In each case, two-part foaming polyurethane was used to bond the plaster

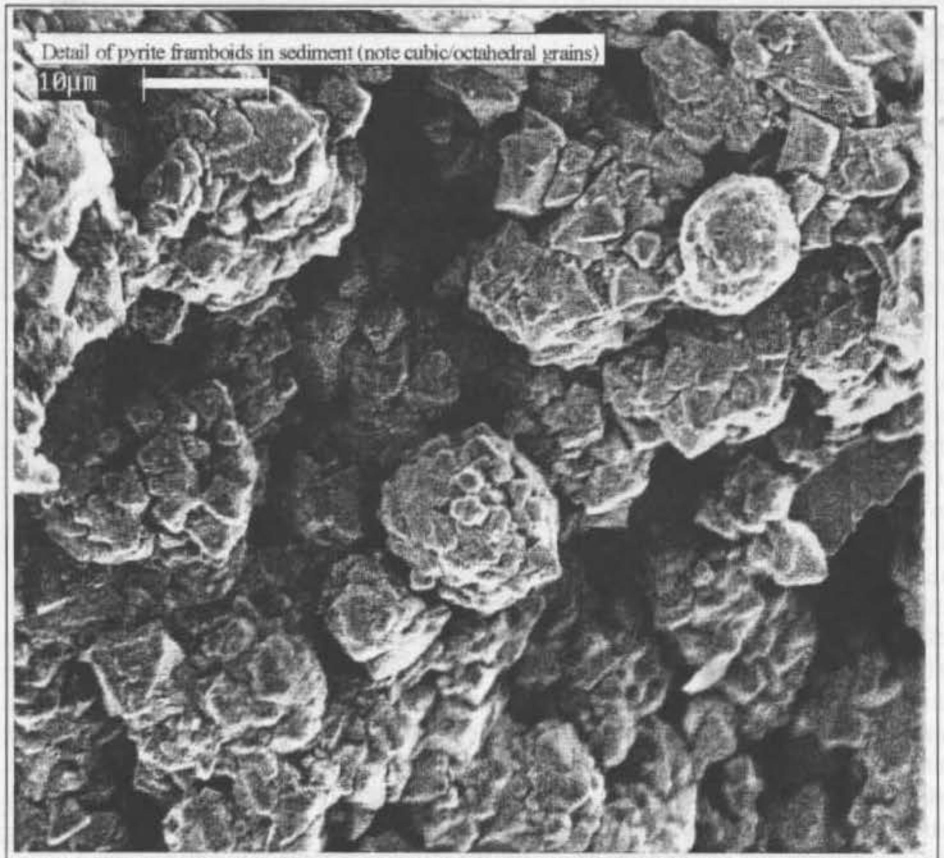
The original finds of the pelvis and astragalus were treated with PVAc emulsion in an attempt to stabilize the bone both structurally and against post excavation chemical change. The bones excavated by staff of the Norfolk Museums Service were consolidated with Paraloid B72 in acetone as they were revealed following removal of the plaster jackets in the natural history laboratory. Although

both groups of bones were clearly stable and robust, visually they were very shiny and many of them had the appearance of resin replicas. Furthermore, as palaeontological specimens any resin filling the pores and obscuring the surface at a microscopic level left them compromised as far as future scientific analysis was concerned.

Wholesale consolidation of the bone was decided against, either on site prior to lifting or after removal to the conservation laboratory. On-site consolidation of bone lying in damp soils is rarely successful since colloidal dispersions and emulsions have poor penetration (if at all) in such circumstances and solvent based consolidants are precluded by the presence of water filling the pore spaces in the bone. Although acrylic dispersals have been espoused for the lifting of fragile bone, this is only practical in arid conditions where the pore spaces are empty and high evaporation rates guarantee curing of the resin. Laboratory examination of an elephant rib and several fragments of skull and tusk recovered from strata above the elephant skeleton revealed several interesting features of the fossil bones from this part of the Forest Bed. Firstly, there had been very little secondary mineralization on the bone (an observation confirmed by later X-ray diffraction) with pores and voids within the bone only loosely filled with sediment. This sediment could be readily blown out of the voids using a weak blast of compressed air from an airabrasive unit. Secondly, where the bone or tusk had been cracked and splintered shortly after deposition, the displaced fragments were secured by massive pyrite formation. Those areas of bone unaffected by crushing (by the overburden) seemed reasonably strong and in no need of consolidation. This seemed an important observation since from an ethical as well as practical viewpoint, the less foreign material introduced into the structure of the bone (in the form of consolidant) the better. Subsequent experiments with the fragmented elephant rib and other bone fragments demonstrated that, for moderately-sized specimens at least, the bones could support their own weight without recourse to consolidating resins. Fragments were mechanically cleaned of sediment using compressed air. Where old breaks were concreted with iron pyrites it was possible to clean back to the broken surfaces by adding aluminium oxide powder (airbrasive powder #3) to the air stream. Joins were then secured using cellulose nitrate adhesive (HMG).

Close inspection of these samples during cleaning showed no evidence for salt efflorescence resulting from exposure to sea spray. This was consistent with observations made on site. Up to the time of their excavation the bones had been effectively sealed under many tens of metres of cliff face. Furthermore, the surrounding sediment was extremely compact with very little obvious permeability, the slow colour change exhibited by freshly cleaned surfaces resulting from fresh oxidation of reduced species in the soil. Even on those days when it was not raining hard, the direction of any flow of water through the Forest Be was undoubtedly downwards. Examinatio of the lifted bones several weeks after their removal from the site did result in some cause for concern. Some small areas of dried tissue paper and patches of the plaster jackets were discoloured by rust-coloured stains. Samples of tissue paper were tested for pH and Fe ions and the results of 3.5 and strong positive respectively, indicated the oxidation of pyrite and subsequent release of Fe^{3+} and H^{-} ions. White crystals were seen following the line of a drying front on some bones.

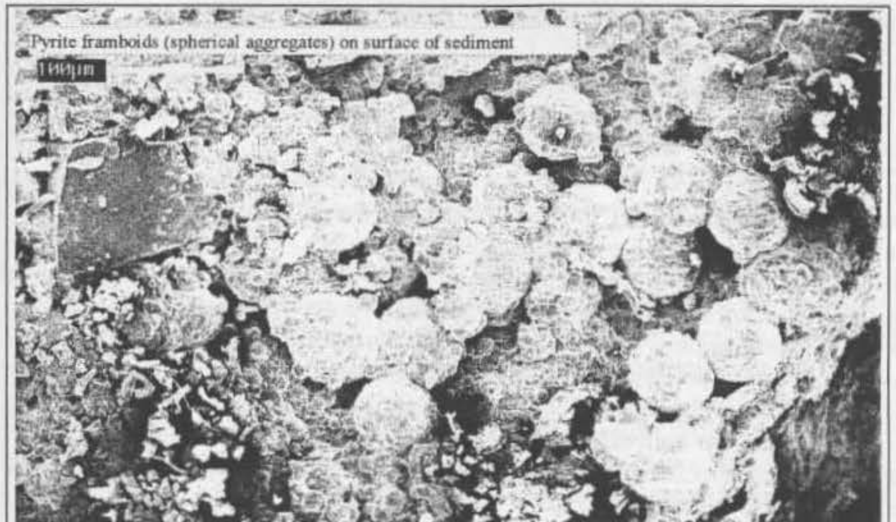
Microscopic, histological and X-ray diffraction studies of several samples readily revealed the presence of both massive pyrite and finely-divided framboidal pyrite within the fine pore structure of the bone. Sediment closely associated with the bones was also examined microscopically and proved to be full of densely-packed framboidal pyrite. The white, powdery crystals were identified as gypsum and almost certainly derive from the reaction between sulphuric acid liberated by pyrite decay and bone apatite. Accelerated ageing experiments (100% relative humidity/70°C/Ag foil) of bone, ivory and sediment samples graphically demonstrated the rapid oxidation of pyrite in the sediment. The bone and ivory samples however reacted much more slowly or not at all, possibly reflecting the lower reactivity of massive pyrite or the



High magnification SEM image of pyrite framboids in sediment showing details of structure

buffering capacity of bone mineral. XRD studies of the bone showed only modest peak sharpening of the expected bone apatite spectrum, indicating little remodelling of the bone during burial. Scanning electron microscopy of polished bone sections had already demonstrated very little microfocal destruction by micro-organisms.

Electron microscopy was also used to investigate the effects of airabrasive cleaning on the surfaces of bone and ivory. Several different types of powder were tested on small samples and the resulting surface textures examined at high magnification. Airbrasive powder #3 (aluminium oxide) was extremely aggressive and with a Moh's hardness of over 9.5 rapidly etched the surface of bone, removing any fine details. Another commonly used powder, #9 (glass beads) was less aggressive than aluminium oxide and did not destroy the fine surface detail of the bone but left a burnished texture, giving the surface a lacquered appearance. Experiments with various powders led to the choice of superflow sodium bicarbonate (airbrasive powder #4A) for general cleaning of bone and removal of superficially adhering sediment. This had no discernible effect on the original surface even at high magnification (figure 1). Pyritic concretions could be airabraded away using crushed glass (airbrasive powder #10) which was less aggressive than aluminium oxide and yet did not leave a burnished surface to the bone or ivory. Considerable discretion had to be exercised in the choice of pressure and powder flow to achieve good results, with the lowest possible settings being selected for most applications. Low air pressure and progressively higher powder flow rates were found to give the best results, rather than high pressures and low powder flow.



Electron micrograph of sediment removed from surface of elephant bone showing numerous pyrite framboids.

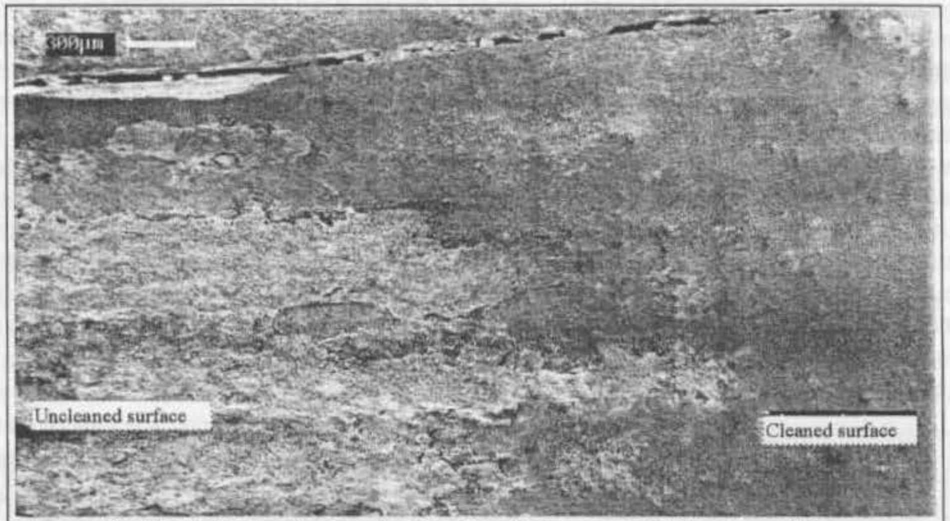


Figure Surface of ivory fragment. Results of experimental cleaning with airbrasive powder #4A (sodium bicarbonate)

Future work

Experimental work is continuing into the chemistry, structure and stability of the West Runton bones and work has begun on exposing and cleaning one of the large limb bones to determine how best to overcome the practical problems involved in handling and manipulating heavy, fragile finds. A purpose-built airabrasive cabinet has been constructed in the Castle Museum workshops so that large bones may be cleaned safely and effectively. Arrangements are also being made with suitable specialists to investigate the possibility of ancient proteins and biomolecules surviving in skeletal material from the Forest Bed.

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Book Review

Storage of Natural History Collections: a preventive conservation approach. Carolyn L Rose, Catherine A Hawks, Hugh H Genoways (Eds) volume I 1995. Published by the Society for the Preservation of Natural History Collections, Iowa USA.
ISBN 0-9635476-1-5. Obtainable from Julia Golden, Dept of Geology, The University of Iowa, 121 Trowbridge Hall, Iowa City, Iowa 52242-1379, USA ($46 inc. airmail). 448pp

This is actually the first volume of 'Spinach' books on the care of natural history collections, the second having been originally published in 1992. Both are now available printed on alkaline paper as A4 hardbacks. A review of the 1995 reprint of volume 2 "Ideas and practical solutions" will follow sometime in the future.
The preventive conservation volume is divided into five sections:

1. creating and managing storage facilities
2. creating and monitoring storage environments
3. selecting and testing storage equipment and materials
4. storing archival collections and collection documentation
5. funding for collections care

For museums setting up new storage facilities this book shows how to 'get it right the first time' from a museum professional's point of view - the structure and planning of a storage facility. For both new ventures and for those who wish to update their present stores, essential aspects such as security, fire protection and emergency preparedness are discussed with other topics ranging from air quality to ultra-cold freezer storage. Using the expertise of their huge membership, the SPNHC have compiled the ultimate in printed natural history museum curatorship; the society members extended into the fields of organic conservation, ethnography and some archaeology. Apart from sections about atmospherics and types of wood used for making storage cabinets there is little material specifically for geologists in this volume: minerals are mentioned as salts in degrading photographic materials or as corrosion products.
The section on fluid preservative storage by John Simmons outlines the biochemistry of fixation by formaldehyde, glutaraldehyde and compounded fixatives, the use of alcohols as preservatives and the correct procedure for transferring specimens from one type of fluid to another. He covers types of storage jars, internal labels and inks that will or won't survive prolonged immersion, ideal storage environments and hazards relating to fluid fixatives/preservatives - all the basic but essential information that curators require. There follows a useful appendix of fluid preservatives suitable for various plant and animal taxa, although users of some of the less well-known preservatives, cf. Dowicil, Pampel's (Pampl's) fluid, should beware since these fluids have been known to cause dissociation of tissues in the long term. The old problem arises of no long-term testing (or non-availability of results) from anyone who has used these fluids for storage periods longer than 20 years.
The section on pest management by Wendy Jessup, is equally comprehensive covering daily/weekly routines: a tightly written section of preventative conservation. Other sections cover storage equipment including the correct materials used in their construction, down to such important details as chemical resistance and hardness, types of wood used and their suitability, the incorporation of synthetic polymers and the correct storage for archival collections and documentation, including photographic materials and video tapes.
Fund raising is an unfortunate but necessary part of most museum curators' remit: the book concludes with a chapter suggesting the best fundamental approaches for raising