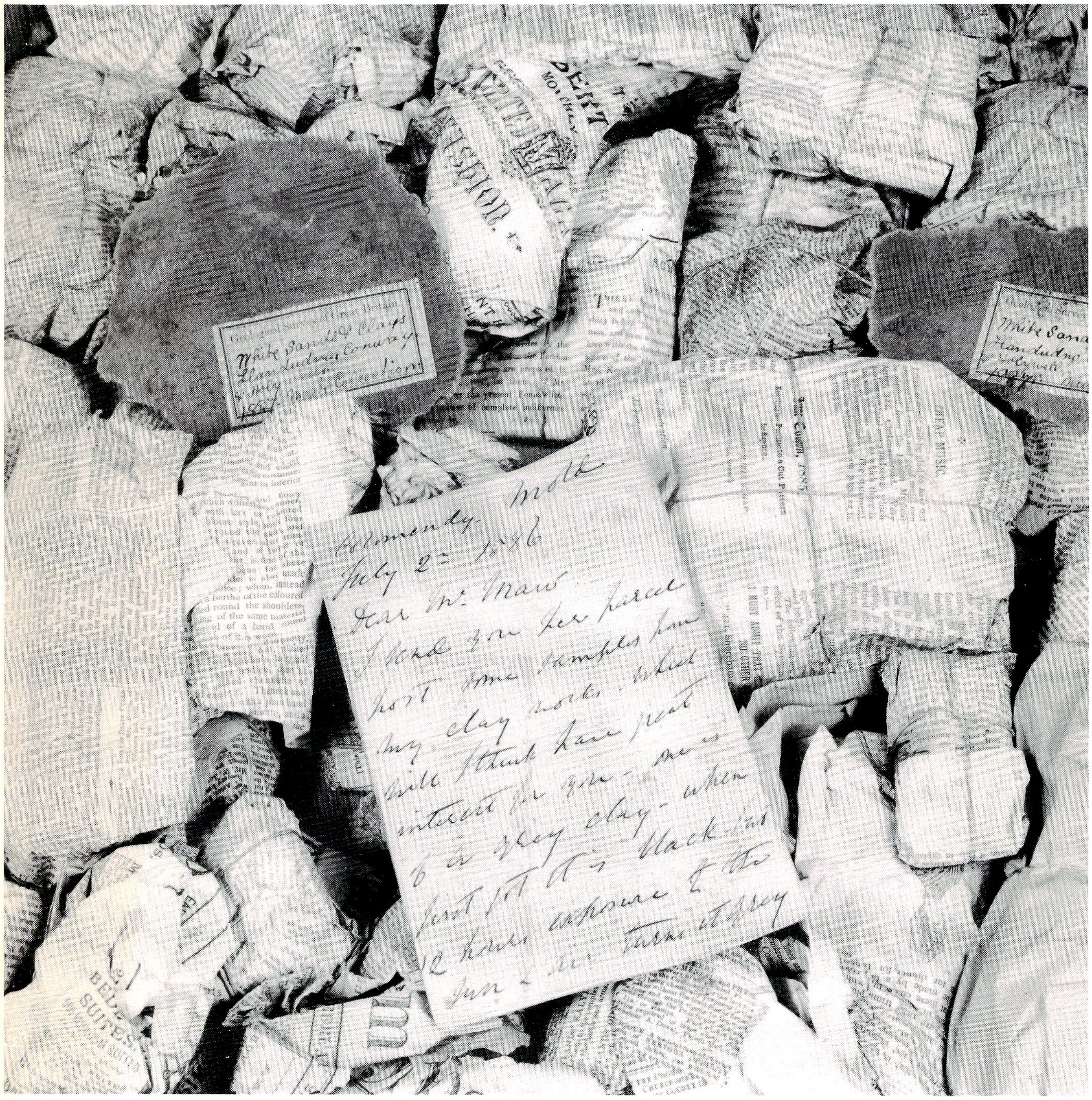
GCG

THE GEOLOGICAL CURATOR

VOLUME 4 No. 7 Issue 1 for 1986



Colomendy. Mold
July 2nd 1886
Dear Mr Maw
I send you per parcel
post some samples from
my clay works - which
will I think have great
interest for you - one is
of a grey clay - when
first got it is black - but
12 hours exposure to the
sun & air turns it grey

EDITED BY P.R CROWTHER AND C.J COLLINS

THE CONSERVATION OF GEOLOGICAL MATERIAL

GEOLOGICAL CURATORS' GROUP

The Group is affiliated to the Geological Society of London. It was founded in 1974 to improve the status of geology in museums and similar institutions, and to improve the standard of geological curation in general by:

- holding meetings to promote the exchange of information.
- providing information and advice on all matters relating to geology in museums.
- the surveillance of collections of geological specimens and information with a view to ensuring their well being.
- the preparation of a code of practice for the curation and deployment of collections.
- the advancement of the documentation and conservation of geological sites.
- initiating and conducting surveys relating to the aims of the Group.

1987 COMMITTEE

Chairman	Michael F. Stanley, Deputy County Museums Officer, Derbyshire Museums Service, John Turner House, Parkway, Darley Dale, Matlock, Derbyshire DE4 2FW (Tel. 0629 733226).
Secretary	Geoffrey Tresise, Keeper of Geology, Liverpool Museum, William Brown Street, Liverpool L3 8EN (Tel. 051 207 0001/5451).
Treasurer	Tom Sharpe, Department of Geology, National Museum of Wales, Cathays Park, Cardiff CF1 3NP (Tel. 0222 397951).
Editor	Peter R. Crowther, Curator of Geology, City of Bristol Museum and Art Gallery, Queen's Road, Bristol BS8 1RL (Tel. 0272 299771).
Recorder	Donald I. Steward, Assistant Keeper, Department of Natural History, City Museum and Art Gallery, Hanley, Stoke-on-Trent ST1 3DW (Tel. 0782 202173).
Minutes Sec.	Diana M. Smith, Curator, Bath Geological Museum, 18 Queen Square, Bath BA1 2HP (Tel. 0225 28144).
Public Relations	Hugh Torrens, Department of Geology, Keele University, Keele, Staffordshire ST5 5BG (Tel. 0782 621111).
Committee	Michael J. Benton, Department of Geology, The Queen's University of Belfast, Belfast BT7 1NN. Christopher J. Collins, Assistant Keeper Conservation, Leicestershire Museums Service, 96 New Walk, Leicester LE1 6TD (Tel. 0533 554100). Wendy Kirk, Department of Geology, University College London, Gower Street, London WC1E 6BT (Tel. 01 387 7050). Simon J. Knell, Area Museum Service for South Eastern England, c/o The Geological Museum, Exhibition Road, London SW7 2DE (Tel. 01 225 1733). Monica T. Price, Department of Mineralogy, Oxford University Museum, Parks Road, Oxford OX1 3PW (Tel. 0865 272590)

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COVER. Part of the George Maw Collection of British rocks, originally amassed in the 1860s by the famous tile manufacturer of Ironbridge, Shropshire, and presented by Maw to the Jermyn Street Museum of the Geological Survey of Great Britain in 1887. The collection of approximately 500 specimens was returned to Ironbridge in 1985 by the British Geological Survey as a gift to the Ironbridge Gorge Museum; the Maw Collection forms one of several conservation and curation projects undertaken by the West Midlands Area Museum Service's Peripatetic Geologist, Rosemary Roden, who provided this 'first view' of the material still in its 1887 wrappings. Photograph courtesy of Ironbridge Gorge Museum Trust.

THE GEOLOGICAL CURATOR

VOLUME 4 NO.7

THE CONSERVATION OF GEOLOGICAL MATERIAL

Edited by PETER R. CROWTHER and CHRISTOPHER J. COLLINS

Proceedings of the GCG Conference
British Museum (Natural History), London
23-24 January, 1986

CONTENTS

GEOLOGICAL CURATORS' GROUP

February 1987

REFERENCES TO THIS ISSUE

It is recommended that reference to the whole or part of this issue be made in one of the following forms, as appropriate:

Crowther, P.R. and Collins, C.J. (eds.). 1987. The conservation of geological material. Geol. Curator, 4(7), 375-474.

Howie, F.M.P. 1987. Safety considerations for the geological conservator. Pp. 379-401. In Crowther, P.R. and Collins, C.J. (eds.). The conservation of geological material. Geol. Curator, 4(7), 375-474.

PREFACE

'The Conservation of Geological Material' was an international conference organised by the Geological Curators' Group, in association with the British Museum (Natural History). Held in the BM(NH)'s Department of Palaeontology, 23-24 January 1986, the conference's primary aim was to improve the state and status of geological conservation within the UK (Collins 1986). The two-day programme attempted to cover the major aspects of geological conservation and thereby encourage discussion about current techniques and potential future developments. The inclusion of archaeological and arts conservators in the programme was intended to give those involved with the conservation of geological material insights into unfamiliar attitudes and techniques and to highlight the potential for fruitful interdisciplinary cooperation.

The physical state of the UK's material geological heritage has long been a major cause for concern. The documentation of this long term neglect by the museum community was seen as a major objective of the newly formed Geological Curators' Group in 1974. The grim catalogue, as compiled by Doughty (1981) remains a national scandal - and is proving with further investigation to be an underestimate of the problem (M.A. Taylor, S.J. Knell, pers. comm.). Examples of, and the reasons for, such widespread neglect have been regularly recorded in the pages of the Newsletter of the Geological Curators' Group and its successor, the Geological Curator. Today, there are at least some signs of hope for the future; particularly encouraging is the help now being provided to smaller museums by the growing number of peripatetic geologists employed by Area Museum Councils in curatorial and conservatorial roles.

One inevitable result of such long term and widespread neglect is that the development over the last few decades of subject specific conservation skills, techniques, research and personnel within most of the major museum based disciplines has largely passed geology by. The very few centres of excellence in this area, such as the BM(NH), serve to emphasize the absence of facilities available to the vast bulk of museum collections. This gross inadequacy is just another facet of the general malaise that has particularly (but not exclusively) affected provincial geological collections since their nineteenth century heyday. There is in effect no such profession as that of geological conservator: compared with the tremendous strides made by other museum disciplines, such as archaeology or the fine arts, published literature is minimal, active research is confined to just a handful of workers, and specialist training does not exist.

Our perception of just what constitutes geological specimen conservation (and what does not) is still a major source of debate. Some geological curators would doubt the necessity to distinguish conservation from curation at all. Certainly, the distinction between preparation and conservation will always be difficult to define in geology; it is often only a matter of viewpoint, and sometimes even semantics. The technical and laboratory skills required for modern preparatory techniques are those of the conservator; for example, the 'preparation' of vertebrate material by acid dissolution for research or display can equally be its 'conservation' in terms of ensuring the material's status and integrity for the future.

At the other extreme from our doubtful curators, some professional conservators from allied disciplines expect the traditional standards and codes of practice of their own specialisms (which in their case result from long tradition) to be instantly transposed to geology. In an ideal world they would be right, but the real world is one of dwindling resources, conflicting priorities, and the absence of any true conservation tradition within museum geology, so their dogmatism is more likely to discourage the establishment of geological conservator posts. Compromise and pragmatism are the more likely routes to success for geological curators attempting to fight the conservation cause with those who control the purse strings.

The conservation of the UK's geological collections will not be helped by providing already hard pressed curators with a 'recipe book' of techniques with which to dabble. In our view the solution to the problem lies in creating specialist, laboratory based geological conservators, to whom curators can go for both advice and technical skills. Authorities charged with caring for the larger collections must aim to add a conservator of geology to their existing conservation departments, while smaller museums should be able to call on a regional facility (probably best coordinated through the Area Museum Councils). Geological conservation as a respected discipline ranking alongside those already long established cannot be achieved overnight: the will to establish and resources to fund new posts and properly equipped facilities must be created within museums and Area Museum Councils; training courses in geological conservation must be established (a start has been made here by the Institute of Archaeology); much more research is needed into the stability of geological specimens in the museum environment and into the applicability of new techniques and materials to the problems encountered; and, of course, a freely available body of knowledge must accrue via regular publication.

Returning to the GCG conference, CJC has reported the bare events of the two days elsewhere (Collins 1986) and there is little to add here regarding the programme itself. The papers that follow are expanded versions of those given at the time and they will hopefully provide a useful addition to what literature exists. All the contributions have been independently refereed and subjected by PRC to the standard editorial and (somewhat primitive) production procedures of the Geological Curator (described by Crowther 1986).

The organisation and sponsorship of the conference was coordinated by CJC, with much sound advice and practical help coming from Peter Whybrow of the Palaeontology Laboratory, British Museum (Natural History). The topics chosen for the two day programme, and the choice of speakers invited to expound upon them were also CJC's responsibility. The GCG would like to express its thanks to the International Centre for Conservation in Rome (ICCROM) for providing a substantial grant towards conference expenses and this publication, and to the Geological Society of London for defraying some conference expenses. The Group is indebted to Dr H.W. Ball (then Keeper of Palaeontology), Peter Whybrow and all the staff of the Palaeontology Laboratory, British Museum (Natural History) for both hosting the conference and providing practical demonstrations of many of the techniques discussed in the formal sessions.

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Peter R. Crowther
City of Bristol Museum and Art Gallery
Queen's Road, Bristol BS8 1RL

and

Christopher J. Collins
Leicestershire Museums, Art Galleries
and Records Service
96 New Walk, Leicester LE1 6TD

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SAFETY CONSIDERATIONS FOR THE GEOLOGICAL CONSERVATOR

BY FRANCIS M.P. HOWIE

INTRODUCTION

Every laboratory and workshop user will be exposed regularly to a range of physical and chemical hazards during his or her working life. The experienced laboratory worker or workshop technician will, irrespective of formal training, have gained experience and expertise in the handling and use of chemicals and practice of hazardous techniques.

Perhaps contrary to popular belief, the majority of accidents in laboratories are not caused by mishaps with chemicals. J.M. Harrington (1976, cited in Pal 1985) suggested that, based on surveys of accidents in medical and university laboratories, the majority (over 60%) were caused by cuts and abrasions from glassware, knives, scapels, etc. Chemical accidents, poisoning, gassing and explosions caused less than 5% of accidents and the balance of 30% were caused by slips, falls and faulty handling and lifting methods.

Comparisons of accident severity, however, show a different picture, with chemical accidents being far more dangerous than other groups. Acute effects caused by lacerations, trips and falls can, in many cases be predicted and therefore avoided by the simple expedient of, for example, using protective clothing, the correct handling equipment or lifting technique. Similarly, fires and explosions with hazardous materials and the acute harmful effects of chemicals can be avoided by employing a little foresight and adequate protective equipment. When things do go wrong, however, the effects can be disastrous.

The chronic or long-term effects of exposure to relatively low concentrations of medium to high toxicity chemicals have not been thoroughly investigated in the laboratory context, and in general are not considered seriously enough by laboratory workers. Evidence from industrial occupational epidemiology (the study of the statistical links between exposure to hazards and development of occupational disease) has clearly demonstrated that regular exposure to a number of substances (including vinyl chloride, benzene, hard wood dust, mercury and arsenic compounds, asbestiform minerals, hydrofluoric acid and organo-phosphorus insecticides, to name but a few) causes chronic disablement and even premature death.

The evidence from studies of laboratory and workshop personnel is far less conclusive, but Dewhurst (1983) deduced from a limited survey of laboratory accidents that 40% of all laboratory fatalities were due to chemical accidents. Herman (1984) detailed ongoing studies into the mortality of professional chemists in the UK by the Royal Society of Chemists; preliminary results indicated that there are pockets of employment (as yet unspecified) where excess deaths have occurred. It would therefore be prudent to consider that working in laboratories and workshops with chemicals and proprietary materials is, at the very least, a medium to high risk activity. Riedmiller et al. (1984) described some of the major chemical hazards encountered in the geotechnology laboratory; Brunton et al. (1985) outlined in general terms the range of hazards the geological conservator may be exposed to during his or her work.

What materials or physical hazards should be of particular concern to conservators and preparators of geological material, and what precautions are required to minimize the risks to health? It is not possible to give here more than very incomplete answers to these questions. My intention is to outline the broad categories of risk and, with the aid of the bibliography, provide a basis for further informed investigation of the current occupational safety and health literature as the basis for the development of safe working systems in geological laboratories and workshops.

All institutions in the UK employing more than five people must, under the Health and Safety at Work, etc. Act (1974), produce and keep up to date a statement outlining their safety policy. This statement is the core safety document for the organization. The policy statement should set out in clear terms the plan for safety which employer, management and employee should adopt. The onus is primarily upon the employer through management to provide employees with safe systems of work, information and training. All too often this is not done or not carried out effectively. Each employee has the duty to take care of himself and those working around him or herself, and to make use of any safe systems provided by the employer. Unfortunately few institutional employers realise the extent of their duties under HASAWA, leaving their employees to fend for themselves as best they can. Holt (in press) discusses in detail the application of safety policy in Museums and similar organizations.

CHEMICAL HAZARDS

Mentioned in this volume are a number of resins, solvents, acids and proprietary materials which have been used and are recommended for the preparation and conservation of geological specimens. In addition, some specimens may have inherent risks for handling because of the toxic substances they contain. The hazards presented by the chemicals and materials used in geological laboratories can be divided into six categories, with a seventh for the specimens themselves:

1, fire and explosion risks
2, chemical incompatibility
3, acute effects of solvents and corrosives
4, chronic effects of chemicals
5, toxic dusts
6, allergenic materials
7, toxic minerals

The hazards considered can, of course, occur in areas other than laboratories, and the dangers presented by the use of chemicals outside the laboratory environment (e.g. in the field or in a curatorial area) can be far greater because adequate facilities and/or experienced staff may not be available.

Fire and explosion from chemicals

Risks. Fires and explosions involving solvents cause a considerable number of incidents and accidents in laboratories of all types, ranging from ignition of flammable solvents by hot plates, bunsens, static and cigarettes to explosions of oil mists and high flash point solvents through faulty technique or in poorly maintained equipment. These accidents are usually avoidable providing the operator is aware of the risks involved.

Table 1 illustrates the flash points, ignition temperatures and explosive limits in air for solvents commonly used in geological conservation. Obviously, the lower the flash point and ignition temperature the greater the risk, but the solvent's vapour pressure, vapour density, diffusion rate in air and rate of evaporation must also be considered. For example, although xylene has a far higher flash point (42° C higher) than acetone, it is rated just as great a fire risk because it has an ignition temperature almost identical to acetone and has a lower explosive limit in air. Ether, on the other hand, is a severe fire risk because of its low ignition temperature of 150°C (about the same temperature as the surface of a hot light bulb) and high vapour pressure. Ether vapour, in addition, flows rapidly along benches and can ignite metres away from the liquid solvent container, flash back and cause a very severe explosion; few solvents are quite as great a fire risk. Note however that carbon disulphide, which has been used in palaeobotanical preparation and mineral cleaning, can be ignited by a hot cup of tea!

Precautions. Situations to avoid when handling flammable organic solvents include the use of electric stirrers (non-explosion proofed) for the preparation of consolidants; the use of consolidants near microscope lamp transformers (including fibre-optic light sources); and never use a hot plate or sand bath or oil bath to heat flammable organic compounds (note that acetic and formic acid vapours can ignite even when evolved from hot dilute aqueous solutions).

Dilute aqueous solutions of ethanol and isopropanol also have very low flash points. Avoid storage of organic solvents in domestic refrigerators; the build up of vapour in the fridge can be ignited by the thermostat or interior lamp contacts. Fatalities and serious injuries have been caused by the fridge door blowing across the room or impacting the person opening it. Solvent soaked tissues and rags in open bins are a common cause of fire. Always use closable type metal bins (several proprietary types are available but expensive - a small all-metal dust bin is adequate). Only use small amounts of solvents in the open laboratory: the less on the bench, the less likely it is for a serious fire to develop. Never smoke or allow visitors to smoke in your laboratory.

Incompatible chemicals

Risks. Many types of chemical reaction do not require any heat, light or catalyst to initiate them; simply mixing certain liquids, gases or even solids may cause fire, explosion or serious injury. Accidental mixing of incompatible materials can be avoided as long as one is aware of the likely consequences. Conservators and restorers in several disciplines often have their favourite 'cocktail' of solvents for cleaning or preparing consolidants; during preparation, sequential treatment of material with acids, peroxides, etc. can be hazardous, especially where specimens are not washed between treatments. Bretherick (1986) gives details of many of the known chemical incompatibilities; note, however, the reaction of fine-grained pyrite material with hydrogen peroxide - this reaction can be so exothermic that the mixture boils, and as the product is strongly acidic there is the risk of severe burns.

Precautions. Good practice dictates that mineral acids should be stored away from organic solvents, and both should be stored away from peroxides including polyester catalyst. Table 2 lists some of the incompatible chemicals likely to be encountered in geological laboratories.

Table 1. Flammability and hazard data for some solvents used in geological conservation.

Notes: On small fires only, BCF or Halon type extinguishers can be used in ventilated areas, BCF will react with some solvents.

*TWA(STEL) values are 10 minute time weighted averages (TLVs) for short term exposure limits (see HSE EH40 - 1986 and text).

^{c}Denotes that exposure to substance above this limit is not to be exceeded and is governed by a control limit (see HSE EH 40 - 1985 and text).

Substance	Flash point °C	Ignition Temp °C	Vap. Press. mm Hg	Flamm. range % by vol in air	Extinguisher to use	Special risks	TWA* (STEL)
Acetone	-20°	538°	226 @ 25°C	3-13%	Dry powder/ CO_2/foam		1250 ppm
Propan-2-ol	12°	399°	44 @ 25°C	2-13%	Dry powder/ CO_2		1225 ppm
Ethanol	13°	423°	50 @ 25°C	3.3-19%	Dry powder/ CO_2	Flammable when diluted	1000 ppm
Butan-2-one	7°	474°	-	2-11%	Dry powder/ CO_2/foam		300 ppm
Diethyl ether	-45°	170°	440 @ 20°C	2-48%	Dry powder/ CO_2	Formation of peroxides	1580 ppm
Petroleum ether	-57°	250°	-	1-8%	Dry powder/ CO_2		500 ppm
Toluene	4°	536°	30 @ 20°C	1-7%	Dry powder/ CO_2/foam		150 ppm
Xylene	25°	500°	10 @ 20°C	1-7%	Dry powder/ CO_2		150 ppm
White Spirit	22°-45°	220°-260°	10@ 25°C	1-5%	Dry powder/ CO_2		125 ppm
Ethylacetate	4°	524°	100 @ 25°C	2-12%	Dry powder/ CO_2		35 ppm
Acetic acid	43°	428°	12 @ 25° C	4-10%	Water spray/ CO_2		15 ppm
Ammonia (vapour)		651°	$7.6x10^3$ @ 25°C	16-25%	Water	Explodes with chlorite and hypochlorites	35 ppm
Styrene	31°	490°	5 @ 25°C	1-6%	Foam/dry powder		^{c}250 ppm
Carbon disulphide	30°	100°	360 @ 25°C	1-45%	Dry powder/ CO_2		^{c}10 ppm
Dichloro-methane		660°	440 @ 25°C	15-65%			^{c}250 ppm
70% Ethanol in water	19°	423°	-		Dry powder/ CO_2	Highly flamm.	
30% Ethanol in water	29°	423°	-		Dry powder/ CO_2	Highly flamm.	
MEK peroxide (used as Polyester catalyst)	50-90°	Unstable at 60°	Low		Water spray (fire brigade only)	Explosive	1.5 ppm
Formic acid (90%)	50°C	433°C	-	18-57%	Dry powder/ CO_2	Explodes with hydrogen peroxide	5 ppm
Cellulose nitrate	-	160°C	-		Water spray	Spontaneous combustion	-

Table 2. Some incompatible chemicals.

Substance	Reaction with : producing
Acids, e.g. Acetic, formic, nitric, hydrochloric, sulphuric	hypochlorites : chlorine nitrites : nitrous oxides peroxides : oxygen, exothermic chlorates : chlorine oxides, exothermic sulphides : hydrogen sulphide alkalis : exothermic reaction organic solvents (+ mineral acids) : fire risk
Acetic acid	ethylene glycol : exothermic reaction permanganates : fire
Acetone	chloroform : explosion conc. acids : explosion
Ammonia	hypochlorite : chlorine oxides
Copper/brass	ketones : explosive ketinides
Ethanol	conc. acids : fire risk peroxides : fire risk
Ether	peroxides : explosion risk
Chlorinated solvents	hot plates, cigarettes, etc : highly toxic phosgene ketones : explosion risk aluminium (unoxidised) : explosion risk
MEK peroxide Peroxides	cobalt napthanate (accelerator) : fire risk solvents and acids : fire risk
Propan-2-ol	peroxides : explosion risk chlorates : fire risk conc. acids : fire risk
Pyrite (finely divided)	hydrogen peroxide : exothermic reaction
Resins	peroxides and conc. acids : fire risk
Hydrocarbon solvents, e.g. toluene, xylene, white spirit	peroxides : fire risk chlorine/hypochlorites : fire risk

Acute health effects of solvents and corrosive chemicals

Risks. As can be appreciated from Table 1 some of the highly flammable solvents are of low toxicity. However, there are many circumstances when the use of moderately to highly toxic organic compounds is unavoidable, particularly since many proprietary materials contain mixtures of often undisclosed chemicals. Where data is lacking or scanty it is wise to treat such materials as hazardous. Recently, however, the Health and Safety Executive has published guidelines on the provision of information for the use of substances at work (Health and Safety Executive 1985). Recent and proposed legislation on labelling and control of substances used at work should help to remove many of the doubts and deficiencies in this area.

Table 3 shows some of the acute hazards of many of the solvents, resins and acids, etc. now used in conservation and preparation. No one has yet come up with a satisfactory method of expressing on a simple scale of measurement the relative toxicity and risk of chemicals. LC_{50} and LD_{50}(lethal inhalation concentration and lethal oral dose test results from animal experiments) have been commonly used to classify toxic substances, thus:

very toxic : LD_{50} (rat)$<$25 mg/kg : LC_{50} (rat)$<$ 0.5 mg/litre/4 hours
toxic : LD_{50} (rat) 25-200 mg/kg : LC_{50} (rat) 0.5-2 mg/litre/4 hours
harmful : LD_{50} (rat) 200-2000 mg/kg : LC_{50} (rat) 2-20 mg/litre/4 hours

The extension of animal data to humans is fraught with difficulties, particularly where 'carcinogenic' chemicals are involved. Many animal carcinogens are not human carcinogens and vice versa. Nevertheless animal data, coupled with observations of human accidents (e.g. Seveso and Bhopal), combine to give an approximate base for comparison of risk and the likely effects of many substances on humans. 'LD' type data are no longer used extensively for hazard rating in the UK. Threshold limit values (TLVs) and the newer

Table 3. Acute health hazards of some solvents and corrosives. (c), Control Limits govern use; (sk), toxic by skin absorption.

Substance	TWA (8 hour)	TWA (STEL)	Risk ratio*/ factor	Main acute health risks
Acetic acid	10 ppm	15 ppm	Low risk	Skin and eye irritant at very high levels of vapour.
Formic acid	(sk) 5 ppm	-	Moderate risk	Skin, eye and respiratory irritant, causes skin burns.
Nitric acid	2 ppm	4 ppm	High risk	Severely corrosive to skin, eyes, teeth, moderate respiratory irritant.
Hydrochloric acid	5 ppm	5 ppm	High risk	Severely corrosive to skin, eyes, teeth, causes gastritis and bronchitis.
Hydrofluoric acid	3 ppm	6 ppm	High risk	Severely damages lungs, causes deep necrotic skin lesions.
Thioglycolic acid	1 ppm	-	Moderate risk	Liquid and vapour irritant to skin and eyes.
Acetone	1000 ppm	1250 ppm	1.55	Metabolized by body unchanged, very safe solvent.
Ethanol	1000 ppm	-	0.34	Vapour irritates eyes, and respiratory tract above 5000 ppm.
Phenol	(sk) 5 ppm	(sk) 10 ppm	High risk	Systemic toxin, rapidly adsorped through skin.
Propan-2-ol	(sk) 400 ppm	(sk) 500 ppm	1.25	Eye and respiratory irritant at 400 ppm and above.
Butan-2-one	200 ppm	300 ppm	2.86	Eye and respiratory irritant at 200 ppm.
Toluene	(sk) 100 ppm	(sk) 150 ppm	2.40	Hallucinogenic at high concentrations > 1000 ppm; vertigo, headache, coma, death.
Xylene	(sk) 100 ppm	(sk) 150 ppm		As for toluene plus eye irritant.
Carbon tetrachloride	10 ppm	20 ppm	256.00	Narcosis, liver/kidney failure, death.
Dichloromethane	200 ppm	250 ppm	13.75	Detectable by smell above TWA level, produces CO in body; causes severe burns.
White spirit	100 ppm	125 ppm	0.10	Deadens sense of smell, irritates eyes, induces tiredness.
Benzene	(sk) 10 ppm	-	63.00	Euphoria, headache, death.
Styrene	100 ppm$^{(c)}$	250 ppm$^{(c)}$		Narcotic effect, produces fatigue, eye, respiratory and skin irritant.

* The Risk Ratio was devised by Hammond (see Collins and Luxon 1982) to help select solvents for safe use in industry.

$$\text{Risk Ratio} = \frac{\text{The solvents evaporation rate}}{\text{The solvents TLV}}$$

The higher the RR the more dangerous, RR's > about 10 indicate a high risk solvent, RR's of 2-10 suggest moderate risk and RR < 2 indicates low risk.

eight hour Time Weighted Averages (TWAs) and Short Term Exposure Limits (STELs) are currently used to indicate potential toxicity to humans. The principal routes for chemicals to enter the body are via the eye, mouth, respiratory tract, through lacerations and by skin absorption. Large concentrations of solid, liquid or vapour phases of several chemicals cause severe, acute symptoms ranging from nausea, headache and vomiting (these are mainly flight reactions, i.e. warnings for the body to pull out and avoid the situation) to broncho-spasm, neuro-toxic effects, coma (generally when it is too late to take avoiding action, or where the chemical is very fast-acting) and death. Of concern to geologists have been reports of two deaths recently caused by acute exposure to hydrofluoric acid vapour and the dilute acid. The first, reported in the Houston Post (29 April, 1980), concerned a laboratory worker who spilled a small quantity of HF on himself and drove to hospital - where he later died, probably by inhaling fumes from his clothes. The second concerned a case where HF splashed on a refinery worker, covering 2.5% of his body; he died a few hours later by skin absorption of fluoride. Thankfully, such extreme cases are exceptional, but they do underline the degree of care required when handling hydrofluoric acid in the laboratory.

Precautions. Avoidance of acute injury by solvents or corrosive chemicals is simple enough: use protective clothing, goggles, face mask and gloves when handling acids (see Table 6), and always carry out operations with moderate or high risk chemicals in fume cupboards or under effective local exhaust ventilation systems. Clark et al. (1984) and Howie (1986) have reviewed the use of ventilation in conservation laboratories and workshops. Perhaps most importantly, ensure that new staff and volunteers are given extensive training, as soon as they arrive, in handling techniques for chemicals. Do not assume that technically qualified staff have received adequate grounding in laboratory safety. Last, but not least, do not consume food or drink near any chemicals or proprietary materials.

Chronic and allergenic effects of chemical exposure

Risks. Because of the uncertainties surrounding both the extent of exposure to low concentrations of highly toxic materials over long periods, and the difficulties of establishing clear links between exposure and the development of symptoms, this area is the one which causes most concern. Past history has demonstrated that moderate exposure to lead from cooking utensils etc., arsenic from dyes and pesticides and mercury in polluted fish has led to wide scale poisoning both in communities at large and in specific occupational groups.

Ziff (1985) claimed to demonstrate that mercury in dental fillings is responsible for a number of ill-defined and non-specific symptoms and adverse health effects in the general population, but no firm scientific evidence was produced in support of his theory. As the editorial of a recent issue of the British Journal of Industrial Medicine (anon. 1986) pointed out, the ills of today's society in general could be, and in some circles are, blamed vaguely on environmental pollutants such as pesticides, 'E' additives in food, etc., rather than on more specific causes such as poverty, over-indulgence in alcohol, poor working conditions, smoking, etc. The editorial defined a new 'specialist', the 'paratoxicologist', who, given a list of symptoms, is soon able to fit particular chemical exposures to them (and vice versa) and in doing so causes considerable worry and distress to others.

The extent of misinformation about the long-term effects of chemicals, which appears to be deeply ingrained in conservators throughout the UK and USA, is disturbing but the reasons are not too difficult to find. McCann (1979) pointed out that, in the USA, hazards in the arts received little attention until the mid 1970s, despite several cases of chronic poisoning and some fatalities among artists and restorers. McCann (1979) and Hunter (1978) described some of the dangerous habits and 'tricks of the trade' practised by craftsmen and the diseases named after various geologically based occupations, etc. ('masons' disease', 'potters' rot', 'rock tuberculosis' and 'stone cutters' asthma', all names for pneumoconiosis - the medical term for all occupational lung diseases caused by mineral dusts, including silicosis, asbestosis, siderosis, stannosis, berylliosis etc.) show how seriously the hazards were underestimated by the practitioners. It is worth noting that those at greatest risk in the mining industry have been the rock-drillers.

Myths and misunderstandings about the toxicity of common chemicals still abound. For several years rumours that xylene and toluene are human carcinogens have circulated in the museum profession and even gone into print. Neither of these substances when pure (i.e. benzene free) has shown any carcinogenic activity in animals or humans after several years research and observation. Benzene as a general solvent has been effectively banned for use outside a glove box or fume cupboard.

Table 4. Chronic and allergenic effects of commonly used solvents, resins and other materials encountered by conservators.

* including chrysotile, actinolite, anthophyllite, etc.

** for more information refer to the Asbestos Regulations 1970 *et seq.*

\+ The time weighted average (TWA) 8 hour limit is the limit for exposure below which it is considered safe to work for 8 hours per day, 5 days per week without harmful effects.

Substances or Material	Hazardous constituents	TWA (8 hour)$^+$	Chronic toxicity and allergenic effects
Acetone	-	1250 ppm	No known chronic effects, dermatitis after prolonged exposure to liquid.
Ethanol	-	1000 ppm	None from vapour.
Propan-2-ol	-	400 ppm	None from vapour.
Butan-2-one	-	200 ppm	None.
Toluene	-	100 ppm	Not carcinogenic, no long-term hazards known.
Xylene	-	100 ppm	Dermatitis, no evidence of carcinogenicity or neuro-toxicity.
Carbon Tetrachloride	-	10 ppm	Animal carcinogen, human kidney, liver and heart toxin.
Dichloromethane	-	200 ppm	Carcinogenic to mice at high levels, possibly neuro-toxic to man at high levels.
Chloroform	-	10 ppm	Systemic CNS poison, potential carcinogen.
Ether	-	1200 ppm	None.
White Spirit	Nonane, trimethyl benzene, decane.	100 ppm	Conjunctivitis, some reversible neuro-psychological effects.
Benzene	-	10 ppm	Aplastic anaemia, leukaemia.
Styrene	-	100 ppm	Dermatitis and conjunctivitis, no firm evidence of neurotoxic effects.
Epoxy resin	Organic peroxides	1 ppm	V. high risk of skin sensitization.
	Butyl glycidel ether	50 ppm	
	Maleic anhydride	0.25 ppm	
	Bisphenol polyamides	-	
Phenolic resins	Phosphoric acid formaldehyde	2 ppm	Mod. risk of dermatitis, conjunctivitis and respiratory irritation.
	Organic peroxides	1 ppm	
	Organic cobalt		
Polyester	Styrene, adipic acid polyesters	100 ppm	Dermatitis and conjunctivitis from styrene.
Polyurethane	Polyesters, amines	-	Dermatitis and respiratory effects from isocyanate.
	Isocyanate	0.02 mg/m^3	Hypersensitivity may develop in some to cured foam.
Asbestos**	Crocidolite/Amosite	0.2 fibres per ml per 4 hrs	May be present in specimens (UK & USA) conserved before c.1970, as resin filler or binder, as unspecified type, treat at crocidolite.**
	Other types*	0.5 fibres per ml per 4 hrs.	
Mica	May contain free silica	10 mg/m^3 Total dust 1 mg/m^3 Resp. dust	No firm evidence of lung disease.
Calcium carbonate	-)		No evidence of lung disease.
Plaster of Paris	Calcium sulphate)	10 mg/m^3 Total dust 5 mg/m^3 Resp. dust	No evidence of lung disease.
Glass fibre dust	-)		No evidence of lung disease.
Talc	Free silica, some asbestos	10 mg/m^3 Total 1 mg/m^3 Respirable	Fibrosis in lungs and calcified pleural plaques may develop over prolonged exposure.
Silica (fine sand)	Quartz	0.3 mg/m^3 Total 0.1 mg/m^3 Respirable	Silicosis.

Table 5. Causes and effects of mineral dust induced occupational lung disease (from Davidson and Macleod 1971).

Cause	Occupation	Description of Disease	Pathological Changes in Lungs
Coal dust	Coal mining	Coal-workers' pneumoconiosis	Focal and interstitial fibrosis Centrilobular emphysema Progressive massive fibrosis
Silica	Gold mining Iron and steel industries (metal casting) Metal grinding Stone dressing Pottery	Silicosis	
Asbestos	Manufacture of fireproof and insulating materials	Asbestosis	Asbestos bodies Interstitial fibrosis Bronchial carcinoma Pleural mesothelioma
Iron oxide	Arc welding	Siderosis	Mineral deposition only
Tin dioxide (cassiterite)	Tin ore mining	Stannosis	
Beryllium (? Beryl)	Aircraft and atomic energy industries	Berylliosis	Granulomata Interstitial fibrosis

Precautions. It is worrying to discover that some museum staff still use trichloroethylene, chloroform and even carbon tetrachloride as general purpose solvents without any safety precautions whatsoever. These chlorinated solvents have been known for many years to be highly toxic because they are readily metabolised to products which seriously damage the liver, kidneys and central nervous system. In addition, they are all potent experimental animal carcinogens, although there is no evidence of human carcinogenicity at present (Waldron 1986). Recent evidence on the toxicity of dichloromethane (Health and Safety Executive 1986b) indicates that, because of its acute effect at high concentrations due to the production of high blood levels of carbon monoxide and carboxy-haemoglobin and possible long term health effects, its general use should be carefully controlled and preferably confined to a fume cupboard. The safest chlorinated solvents recommended for general use at present are tetrachloroethylene and 1, 1, 1 - trichloroethane; neither are metabolised to any great extent by the body and long term health hazards are very minor, even at high levels of exposure. They are, of course, powerful narcotics and all, even trichloroethane, will decompose above 250°C (e.g. through a lit cigarette or pipe) to produce traces of highly toxic phosgene. One of the most toxic chlorinated solvents is tetrachloroethane (note the similarity in names to the last two) which, although not an experimental carcinogen, will cause severe CNS poisoning and gastro-intestinal and hepatic effects at very low levels of exposure.

Table 4 illustrates some of the chronic effects of exposure to a number of the chemicals used in geological laboratory work.

Toxic dusts

Risks. Areas of special concern at present, some of which are within the sphere of activities of geological conservators and preparators, include the development of occupational lung diseases through repeated exposure to fumes and dusts. Occupational

Table 6. Personal protective clothing for hazardous materials and processes. Y, highly resistant; S, may be affected; N, degrades, or permeable to chemical.

Chemical or process hazard	Gloves recommended						Eye protection △	Respiratory*** protection
	Natural* Rubber	Butyl Rubber	NBR Rubber	Neoprene	Nitrile	PVC** Disposable		
Acetic acid	Y	Y	Y	Y	Y	N	Yes	Use fume cupboard
Acetone	Y	Y	N	S	N	N	Advisable	No
Ammon. hydroxide	Y	Y	Y	Y	Y	N	Yes	Use fume cupboard
Butan-2-one	Y	Y	N	N	N	N	Advisable	Advisable
Dichloromethane	N	N	N	N	Y	N	Yes	Use fume cupboard
Diethyl ether	N	N	S	Y	S	N	Advisable	Advisable
Ethanol	Y	Y	Y	Y	Y	Y	Advisable	No
Ethyl acetate	Y	N	N	N	N	N	Yes	Yes
Formic acid	Y	Y	Y	Y	Y	Y	Yes	Use fume cupboard
Hydrochloric acid (conc)	N	Y	N	Y	N	N	Yes	Use fume cupboard
Hydrochloric acid (dil)	Y	Y	Y	Y	Y	Y	Yes	Yes
Hydrofluoric acid (conc)	N	S	S	Y	N	N	Yes	Use fume cupboard
Hydrofluoric acid (dil)	N	S	S	Y	N	N	Yes	Use fume cupboard
Hydrogen peroxide	Y	Y	Y	Y	Y	Y	Yes	No
MEK peroxide	Y	Y	N	N	N	N	Yes	Yes
Nitric acid (conc)	N	N	N	N	N	S	Yes	Use fume cupboard
Nitric acid (dil)	Y	N	N	Y	Y	N	Yes	Yes
Phenol	Y	Y	Y	Y	Y	N	Yes	Yes
Potassium & sodium **hydroxide** (50% ag.)	Y	Y	Y	Y	Y	Y	Yes	No
Propan-2-ol	Y	Y	Y	Y	S	N	Yes	No
Petroleum ether	S	S	Y	Y	Y	N	Yes	No
Styrene	N	N	N	N	Y	N	Yes	Use fume cupboard
Thioglycollic acid	S	Y	Y	Y	Y	N	Yes	Use fume cupboard
Toluene	N	N	Y	N	Y	N	Yes	Yes
Xylene	N	N	Y	N	Y	N	Yes	Yes
White Spirit	N	N	N	S	Y	N	Advisable	Advisable
Epoxy resin	N	N	N	N	Y	N	Yes	Use fume cupboard
Polyester resin	N	N	N	N	Y	N	Yes	Use fume cupboard
Polyurethane	N	N	N	N	Y	N	Yes	Use fume cupboard
Nuisance dusts, e.g. plaster, glass fibre	Avoid skin contact if sensitized to a specific dust.						Advisable	Advisable, see text.
Toxic dusts, e.g. talc, silica, asbestos	Avoid skin contact, use disposable gloves.						Advisable	Use fume cupboard or special respirator.
Ultra violet radiation	Use cotton, muslin, nylon or PVC gloves and arm protection.						Yes (see text)	-
Radioactive minerals	Use disposable gloves when handling most radioactive minerals (see text).							

△ Eye protection must conform with BS 2092 - 1967, with amendments (1970, 1972).

* NOT latex disposable gloves, these are not recommended.

** Polythene disposable gloves have better resistance to many organic solvents than PVC; check with supplier.

*** Where no protection is specified, steps must be taken to control exposure to levels below the recommended exposure limits.

asthma from exposure to colophony or rosin (present in soft-solder flux), hardwood dusts and formaldehyde are increasingly common. Asthma from di-isocyanates and epoxy resin curing agents is, at present, a compensatable occupational disease in the UK.

Several mineral dusts will cause lung disease (pneumoconiosis) where operators are regularly exposed to high levels. Waldron (1986) specifies siderosis (from processing iron ore), stannosis (from tin ore), chromite pneumoconiosis, silicosis and asbestosis (Tables 4 and 5).

Precautions. The likelihood of preparators developing any form of pneumoconiosis is exceedingly low, so long as effective means are used to control dust levels during rock cutting and mechanical preparation. The use of approved respiratory protection (to British Standard 2091 for toxic particulates) is the minimum requirement for occasional exposure. Puffer (1980) lists some of the minerals likely to give rise to dust hazards when being processed; few present any respiratory hazard to the casual examiner (see 'Toxic minerals' below). Where mechanical preparation, rock cutting and trimming are routine, it is essential to use some form of effective local exhaust ventilation (LEV) as many rock types contain free silica and other toxic minerals. Fig.1 shows dust removal using a mobile LEV hood during the preparation of a fossil vertebrate. Without an LEV system dust levels produced during this type of work would rapidly attain levels of 20-50 mg/m^3 in air. Respirable dust particles are, of course, not always visible in ordinary light; for further details see Chambers (1986) who gives useful guidance on choosing effective dust control systems.

For many dusty processes (including the use of plaster of paris, titanium dioxide fillers, corundum, chalk or limestone cutting, and vermiculite, no respiratory protection other than a basic disposable nuisance dust mask (to BS 2091) is necessary. Work with glass fibre and glass fibre reinforced plastics is more contentious. Man-made mineral fibres such as glass and rock wool are not at present classed as particularly hazardous, chiefly because they are composed of amorphous silicates. They do, however, have Control Limits for exposure (see below). Unlike asbestos mineral fibres, glass fibres when cut, ground or split into short fragments with a low length to diameter ratio, do not have the same tendency as crocidolite and split amosite fibres to implant themselves in lung cellular tissue. It is advisable however to grind GRP using LEV or suitable respiratory protection because the dust will often contain particles of sensitising polyester, epoxy or formaldehyde based plastics.

Allergenic effects

Risks. Amongst the commonest allergens or sensitisers met with in the geological laboratory are some epoxy resins, photographic developers (e.g. 'Metol'), formaldehyde and phenol-based compounds, cutting oils, polyesters, acrylics, di-isocyanates and some minerals (see below). Many sensitisers are also primary irritants which cause, more or less rapidly, dermatitis, eczema or various forms of acne. Some common primary irritants found in the geological laboratory might include potassium and sodium carbonates, ethanolamine compounds, most mineral and organic acids (dilute solutions), esters, ketones, chlorinated solvents, paraffin, cutting oils, glass fibre and cured polyurethane foam. There is some evidence that the last may also be a sensitiser in some individuals.

Precautions. The reactions to both primary irritants and sensitisers are similar except that in the case of sensitisers skin reactions may not occur for some time during exposure and may occur away from the area of contact. With primary irritants the use of protective clothing, gloves or barrier cream will reduce or eliminate the risk (Table 6). The only means of preventing sensitisation reactions, especially for individuals who have so-called 'hypersensitivity' is complete avoidance of exposure to the allergen, even change of occupation. With many individuals their sensitivity to, for example, many hard woods, disappears after a short time (they become 'desensitised'). Unfortunately desensitisation and hypersensitivity are not predictable either in terms of individuals or allergens. Desensitisation appears to develop to a greater extent with exposure to natural organic materials than to synthetic chemicals.

CHEMICALS AND LEGISLATION

Storage and use of flammable materials

Solvents with flash points of less than 32°C are rated as highly flammable and must be stored in accordance with the Highly Flammable Liquids and Liquified Petroleum Gasses Regulations (1972): the aggregate quantity of highly flammable liquids in any work room must not exceed 50 litres and it must be in suitable, closed vessels kept in suitably placed cupboards or bins of fire resisting material. These regulations do not apply to working/bench amounts of less than 500ml as long as they are kept in closable bottles, etc. This means that, as long as steps are taken to prevent the build up of flammable vapours to dangerous levels on the bench (e.g. by avoiding spillage or use of large open containers), and as long as no sources of ignition are present when solvents are present, most small-scale operations with solvent-based resins, glues, etc. are not subject to the HFL and LPG Regulations.

However, as soon as flammable vapour concentrations are allowed to build up to dangerous levels, the Regulations apply and the areas or room used will require flame-proof lighting, sockets, etc. The simple alternative is to confine the process to an effectively ventilated enclosure (e.g. fume cupboard). In practice this covers the use of solvent dipping tanks and large scale transfer (as from 25 litre drums to smaller vessels), etc., where additional means for earthing tanks and drums are required to prevent static initiated explosions - the act of pumping or even pouring solvent from a metal can through a metal pipe to another metal container can theoretically generate enough voltage to spark off an explosion. To prevent static build up, an electrical connection, an earth bond between containers or a conductor to ground with resistance not more than 10 ohms is required; the local fire officer will be able to advise.

In enclosed flammable stores all electrical equipment and wiring (including fire alarms and telephones) must be to specified explosion or flameproof standard (see Health and Safety Executive HS(G)22). Dispensing solvents in the open air is often an effective method which lessens both the risk of fire and inhalation of toxic vapours. Where large volumes of solvents are handled it is recommended that both gloves and eye protection are used (see Table 6 for the most suitable gloves for handling chemicals). Sax (1986), Bretherick (1981), Fuscaldo (1980), Steere (1976) and the Fire Protection Association's Information Sheets on Hazardous Materials (1974 to date) contain essential information on the hazards, precautions, fire-fighting procedure and the regulations applicable (Steere, Fuscaldo and Sax on the North American side) to the use of solvents and chemicals generally in laboratories and workshops.

Chemical labelling

Under new regulations governing the labelling of substances for use and transportation, manufacturers and suppliers are required (with effect from 1 January 1986) to label products supplied for home or work in accordance with standards laid down in an Authorised and Approved list (Health and Safety Commission 1984b). This document lists several hundred hazardous substances and the type of information required to be shown on labels attached to containers used to store or transport them. Two aspects are covered: first, the supplier must state on the label the name of the substance (chemical, proprietary or group identity) together with an indication of the general nature of risk, any particular risks, and the safety precautions required for storage, use and disposal; secondly, where substances are transported by road, rail or air, conveyance labels containing substance identification number, address of supplier and hazard warning sign must be attached to all packaging materials used.

The purpose of this cumbersome set of regulations (to the supplier and conveyor!) is to inform the user of a product, at home or at work, of its immediate and long term hazards and to advise on the safety precautions required. The labelling has to be shown on each separate layer of a supply package, which itself has to be adequate to contain the substance in case of accident and prevent risk to those handling and transporting it (Health and Safety Executive HS(R)22:1984). The 'crunch phrase' in these regulations, so far as conservators are concerned, is that supply of substances in the course of or use at work includes 'transfer from a place of work to another place of work whether or not in the same ownership, whether as principal or as an agent'. This includes quite clearly the supply by your laboratory or store of dispensed and broken down packages of solvents, resins and other chemicals for use in the field, at another museum or an out-station. Consequently, an amount of a substance which is sufficient to cause risk to health or safety during conveyance in the back of your (or your employer's) car, van etc., comes under the conveyance side of the regulations - and as such must be properly labelled and packaged. Until January 1987 quantities of less than 25 litres (or 25kgs for solids) are exempted from the conveyance aspect but not the labelling requirements. After that date the full force of the Regulations will apply to anyone conveying any chemical substance.

Finally, all hazardous waste chemicals must be properly labelled and packaged in accordance with the CPL Regulations by the user, not by the contractor employed to remove the waste. It is most important that the source laboratory clearly indicates the quantity and hazard of any waste chemical before it leaves the site. The whole subject of labelling is far too large to detail here. If you contemplate supplying others with chemicals or transporting them yourself, you should obtain the advice of your safety officer, environmental health officer or local factory inspector (see Health and Safety Executive Directory 1986).

Occupational exposure limits

At the present time the exposure of people at work to chemical hazards is controlled by reference to the limits advised by the Health and Safety Executive in Guidance Note EH40 - 1986. Two levels of control are stipulated:

1. Recommended limits are the exposure limits advised by the Health and Safety Commission's 'Advisory Body on Toxic Substances' whose remit is to establish standards of good practice and 'realistic criteria for the control of exposure, plant design, engineering controls and, if necessary, the selection and use of personal protective equipment'. Failure to observe these limits, whilst not automatically a breach of the Health and Safety at Work Act, could form part of a Health and Safety Executive inspector's criteria for assessing compliance with the law and would be taken into consideration in a tribunal or court of law. Some five hundred chemicals are listed in EH40 with their 8 hour TWA (time weighted average concentrations) and STEL (short term exposure limit = 10 minute TWA) values in ppm or mg/m^3.

2. Control limits which are based on Regulations, Approved Codes of Practices, European Community directives or Health and Safety Commission instruction, are limits which should not be exceeded. Failure to comply with a control limit may result in

Table 7. Substances subject to Control Limits, as of early 1986.

Substance	Name
Acrylonitrile	2 ppm (8 hour TWA)
Asbestos	See HSE Guidance Note EH 10
Cadmium and compounds (except CdO and CdS pigments, dust and fume)	0.05 mg m^3 (8 hour TWA)
Cadmium oxide, fume	0.0 mg m^3 (10 min. STEL)
Carbon disulphide	10 ppm (8 hour TWA)
Coal dust (in mines)	See Coal Mines (Resp. Dust) Regs 1975
Dichloromethane	250 ppm (10 min STEL)
MbOCA	0.005 mg m^3 (8 hour TWA)
Ethylene oxide	5 ppm (8 hour TWA)
Formaldehyde	2 ppm (10 min STEL)
Isocyanates	0.07 mg m^3 (10 min STEL)
Lead and compounds	0.1 mg m^3 (8 hour TWA) for tetraethyl lead 0.15 mg m^3 (8 hour TWA)
Man made mineral fibre (includes glass fibre)	5 mg m^3 (8 hour TWA)
2-Methyoxyethanol	5 ppm (8 hour TWA)
2-Methyoxyethyl acetate	5 ppm (8 hour TWA)
Styrene	100 ppm (8 hour TWA) 250 ppm (10 min STEL)
1,1,1 - Trichlorethane	350 ppm (8 hour TWA)
Trichlorethylene	100 ppm (8 hour TWA)
Vinyl chloride	3 ppm (mean annual concentration)
Wood dust (hardwood)	0.5 mg/m^3 (8 hour TWA)

enforcement action by a Health and Safety Executive inspector. With some controlled substances (i.e. those with no minimum threshold below which adverse effects do not occur, or where short exposures to high concentrations cause injury) exposures may need to be reduced to the lowest levels justifiable on a cost/risk basis.

The present strategy behind the application of Control Limits for exposure to relatively few substances, some of which are not highly toxic, is that these substances are very commonly used in industry. Until a few years ago, a great many were used without any real control of exposure (e.g. asbestos, vinyl chloride and lead compounds). Some, such as formaldehyde and styrene, have been shown recently to be potentially very harmful over both short and long term at levels of exposure just above the limits set, and they are included because of the dependence of large areas of commerce on their use. Substances subject to Control Limits, as of early 1986, are shown in Table 7.

Prolonged exposure to a number of the listed substances (and, of course, other toxic materials) may occur in the laboratory, workshop or elsewhere. Styrene, glass fibre dust, isocyanates and chlorinated solvents are amongst the most frequently used chemicals in geological technology. Exposures to levels above the control limit can occur where there is insufficient containment: in the laboratory or workshop the use of local extract ventilation or a fume cupboard will reduce the risk; outside the laboratory, however, the use of PU foam, epoxies, styrene and fibreglass may lead to problems.

Familiarity with the materials and/or lack of knowledge of the risks involved can lead to complacency. Fig.2 illustrates the use of portable extraction equipment for the removal of styrene fumes during work with polyester resins in a gallery situation. The operators are also using filtered-air supplied hoods for the removal of dust and nuisance odours (not styrene). The localized removal of

Fig.1. Mobile local exhaust ventilation system used for the removal of dust during mechanical preparation. Palaeontology Laboratory, British Museum (Natural History). (Courtesy of S. Rowles).

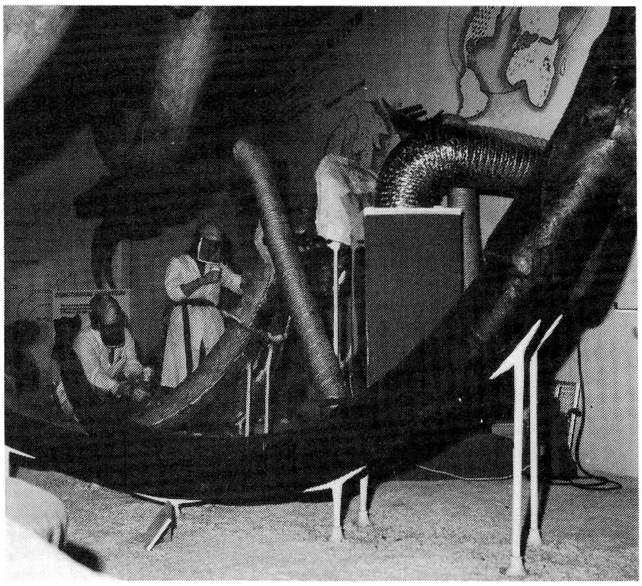

Fig.2. Portable fume extraction equipment used to exhaust styrene from gallery area during work with polyester resin. Fossil Mammal Gallery, British Museum (Natural History).

styrene is achieved by the use of a flexible ducting and hood system; the styrene fumes are collected and ducted to atmosphere via a nearby window. Using this type of approach it was possible to do the job without closing off more than a small part of the gallery to the public. Past experience in carrying out this type of work in public areas, without some form of containment, caused problems for staff and public alike through the build-up of fumes.

OCCUPATIONAL HYGIENE APPROACH TO HAZARD CONTROL

The reduction of risk of harm from exposure to hazardous agents is best approached systematically. The following criteria represent a basic work place hygiene strategy and, to a great extent, should be adopted in all aspects of laboratory or workshop work:

1, assess any hazards before commencing work
2, control exposure where necessary
3, ensure that control measures are used effectively
4, maintain the control measures adequately
5, monitor exposure regularly
6, adopt health surveillance where necessary
7, inform, instruct and train staff in safe systems of work

Assessing the hazards. This is usually straight forward unless a new substance is being used. Manufacturers or suppliers are now bound to give hazard data and other information both on the package and in the form of hazard data sheets. The latter vary considerably in standard at present, and it is prudent to obtain supplies from the most reputable dealers. In cases of doubt you can obtain guidance from the Health and Safety Executive, an occupational hygienist or, but not always, a chemist.

The control of exposure. This can be achieved by using protective clothing and personal protective equipment (see Figs.1 and 2: use of gloves, eye protection, respirators and laboratory coats) and by containment and extraction (Fig.2). Figs.3 and 4 show two types of local exhaust ventilation systems in use in an acid preparation laboratory. Fig.3 shows a 'push-pull' system used to remove acetic acid fumes from the top of a treatment tank. Air is directed across the top of the tank from the rising duct and lip at the front to the extract hood at the back. By maintaining a constant air velocity of 0.5m/s across the tank, acid fumes are removed effectively before they escape into the room. Fig.4 illustrates a less effective canopy hood arrangement. The principle involved here is that, theoretically, hot or warm fumes will rise from the bench to be collected and ducted away via the high level hood. In practice the acidic fumes, although of very low concentration, are cold and will not be pulled the distance from the bench to the hood and thus tend to escape into the working area.

The duty to ensure that control measures are used. This lies with both staff and management. Management has to provide the measures, whether mechanical systems or protective clothing, and the staff have to ensure that they are used effectively. The maintenance of mechanical protective equipment is a management responsibility. The maintenance of protective clothing is, however, the responsibility of the operator.

Monitoring of both atmospheric hazards and the efficiency of some control measures can be carried out on site by laboratory or work shop staff. Fig.5 illustrates a simple vapour detection system. The hand pump draws

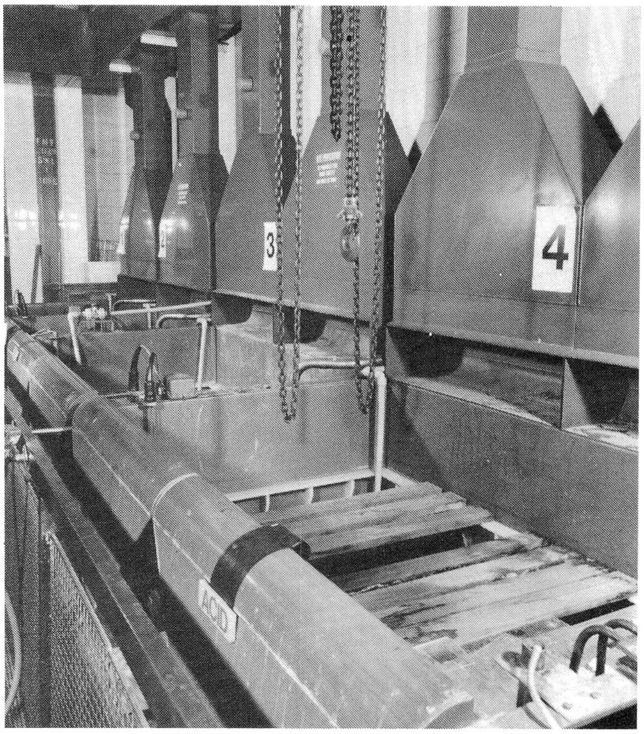

Fig.3. 'Push-pull' exhaust ventilation system for removal of acetic acid fumes from preparation tanks. Palaeontology Laboratory, British Museum (Natural History).

air through a colorimetric tube selected to react with the particular chemical contaminant present. This method is not accurate for a number of reasons but will often give an indication in a preliminary survey of whether or not a more serious problem exists. Fig.6 shows a basic personal or static air sampling pump and sampling head of the type used in a detailed survey by an occupational hygienist; very accurate exposure measurements can be carried out using this equipment but it is not suitable for use by untrained staff. Ventilation rates can be monitored using a variety of systems; it is not enough to use a piece of tissue or paper to gauge air flow across the face of a fume cupboard or hood. Figs.7 and 8 depict simple anemometers which give accurate air velocity measurements. For most extraction systems minimum air flow rates of 0.5 - 1.0m/s are essential to collect and entrain vapours. Fume cupboard face velocities when the sash is open should never fall below 0.5m/s (see Pal 1985 and Clark *et al*. 1984).

Health surveillance may be required for some work and it is usually sensible to consult an occupational health physician where exposure to highly toxic or controlled substances is concerned. There is also some merit in obtaining pre-employment screening for certain types of laboratory work (e.g. with epoxy resins and other sensitisers). It is generally recommended that pregnant women should avoid contact with laboratory chemicals, etc. Here again an occupational health specialist should be consulted.

Fig.4. Canopy hood arrangement. Palaeontology Laboratory, British Museum (Natural History).

In many cases the best people to undertake instruction and training are experienced laboratory or workshop staff. Consider asking a university or college chemistry department for assistance. Specialist areas like radiation safety require specialised training courses, e.g. those offered by the National Radiological Protection Board.

The total occupational hygiene approach to laboratory and workshop safety in the UK is likely to become standard with the introduction of new legislation in 1987-1988, i.e. the Control of Substances Hazardous to Health Regulations (Health and Safety Commission 1984a). The main thrust of these regulations will be to ensure that exposure of individuals to hazardous substances is reduced to the minimum and that such exposures are monitored and recorded. Some types of work will need to be closely monitored and it may be necessary to appoint an occupational hygienist to carry out some of the monitoring aspects required.

PHYSICAL HAZARDS

Conservators and preparators are likely to encounter a range of physical hazards; four main categories will be considered here:

1, noise and vibration
2, radiation
3, handling and lifting
4, machinery hazards

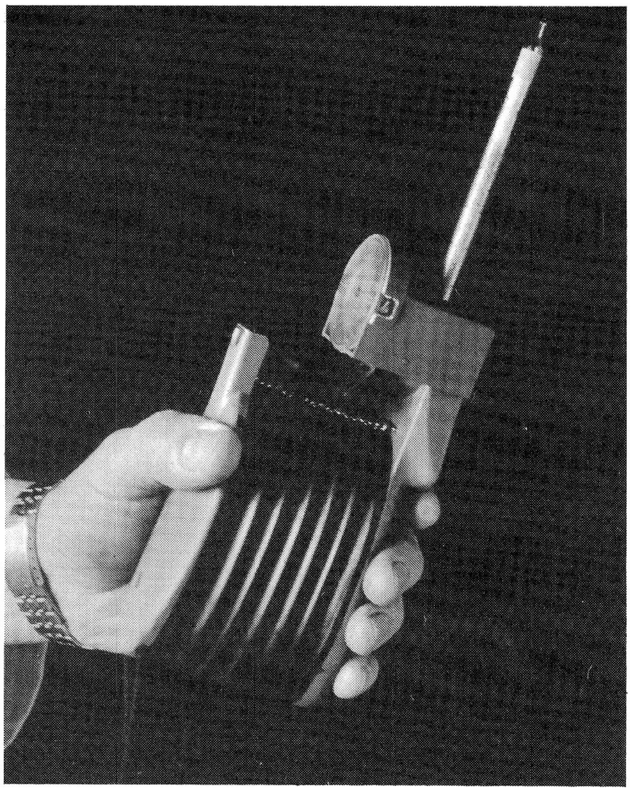

Fig.5. Combination Drager hand-operated bellows pump plus gas detector tube. Drager Safety, manufacturer.

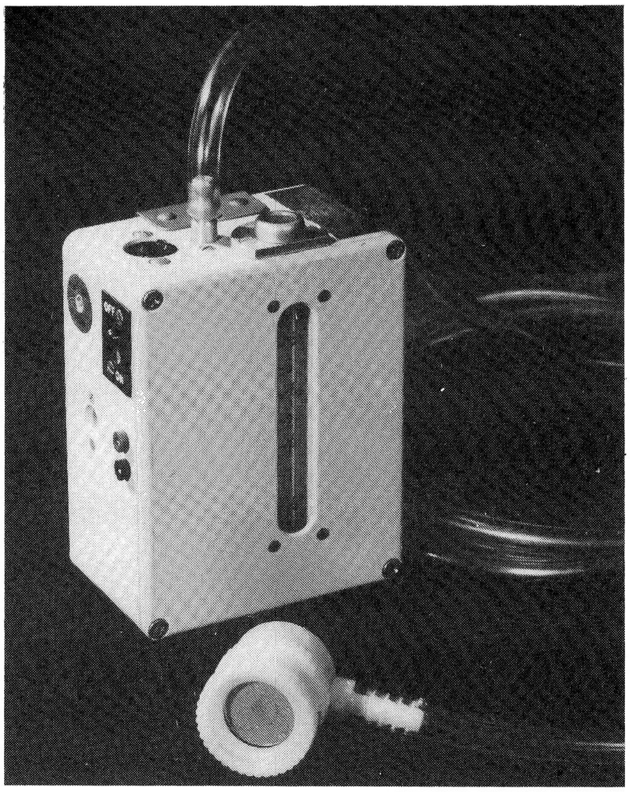

Fig.6. Sampling pump with sampling head. Ritheroe and Mitchell, manufacturer.

[Two further categories, construction and electrical safety, will not be dealt with here. For advice on these subjects readers are referred to Health and Safety Executive Guidance Notes: General Series and Plant and Machinery Booklets; in particular, GS 27: Protection against electrical shock (1984) and GS 28: pts.1-4, Safe erection of structures (1984-1986).]

Noise and vibration

A range of noise and vibration generating equipment is used during the preparation and conservation of geological specimens. The hazards presented by noisy work fall into two categories: impulse noise and sustained noise.

Impulse noise is the most hazardous type; exposure to repeated gunfire and drop forging without hearing protection will lead to rapid hearing loss. In these circumstances sound pressure levels of 150 dB(A) or greater will occur. [dB(A) are decibels measured on an 'A' weighted network sound meter which responds electronically to noise similarly to the human ear.]

Workshop and laboratory noise. The present limit for exposure to noise at work is 90 dB(A) on a sustained basis, i.e. averaged over an eight hour day. The dB(A) notation is a logarithmic scale, so for every 3 dB(A) rise, the noise level is effectively doubled. Table 9 indicates some of the noise levels expected during workshop and laboratory activities.

As can be seen there are many activities which, if prolonged, could potentially lead to hearing loss. Where noise levels from machinery and processes regularly rise to 90 dB(A) or more steps must be taken to protect both operators and others in the area. One possibility, used for rock saws and some band saws, is enclosure in an acoustic hood. Sporadic or infrequent exposure to noise levels above 90 dB(A) should be controlled by the use of adequate hearing protectors (wide frequency noise reduction or attenuation of 10-30 dB(A) should be attainable using good quality fluid filled ear muffs). Ear plugs give a much lower standard of protection, typically 5-10 dB(A) at best in the mid/higher frequency range. Cotton wool plugs are useless. Glass fibre plugs are effective but may cause a dermatitic reaction; they do, however, form a better seal in the ear canal than most of the shaped rubber plugs and foam inserts.

Noise monitoring and routine audometry (hearing loss monitoring for staff) are unlikely to be necessary in the normal conservation or preparation laboratory since it is unlikely that the 90 dB(A) limit will be exceeded for more than very short periods of time. High noise areas should, however, be clearly identified and warning posters and signs erected on any equipment or machinery requiring an acoustic enclosure or ear protection whilst in use.

Ultrasound. The hazards of exposure to ultrasound generated by sonic cleaning tanks, cavitation cleaners and ultrasonic beam or point source generators have been

Fig.7. Anemometer, rotating vane type with direct velocity readout. Airflow Development, manufacturer.

Fig.8. Thermal anemometer. Airflow Development, manufacturer.

investigated fairly intensively (see Williams 1983). The sensation of fullness or ringing in the ears after the use of ultrasonic equipment is common. This is caused through the re-radiation of white noise by the cavitation or cleaning process itself and the high peak level noise at a harmonic or sub harmonic of the ultrasonic generator frequency which may lie within or just above the range of hearing. These noise levels can be very high (>100 dB(A)) and are a hazard. Ultrasonic baths should therefore be enclosed in acoustic boxes or hoods. Some form of high quality hearing protection should always be worn during cavitation or the use of ultrasonic probes, etc.

Airborne ultrasound is effectively attenuated by the air and masked mechanically by the middle ear, so it should not present a hazard in the laboratory. Liquid-borne or solid-borne ultrasound, however, damages the skin and even the peripheral nervous system. Never place unprotected fingers in an operating ultrasonic tank or expose the skin to a cavitation cleaner or ultrasonic beam. Wear rubber gloves when using ultrasonic equipment.

An additional hazard is the production of aerosols above the liquid in the ultrasonic bath or at the tip of a cavitation cleaner. Bacterial contamination of cleaning agents have been known to cause respiratory problems. The water supply to cavitation cleaners should always be fresh; do not add antiseptic agents to the water. The best advice is either to remove the aerosol generated by a suction device near the probe tip, or wear a fine filter respirator. Enclosure of an ultrasonic tank in a perspex sound attenuation box or its use in a fume cupboard will remove the risk of aerosol contamination. Note, however, that the tank's ultrasound generator produces heat and must be adequately ventilated during operations when enclosed.

The final hazard in this section is vibration. Many of the hand held tools used for the preparation of fossil material produce varying levels of vibration. Two types of injury can occur with prolonged use of such equipment. The first is the harmless production of cysts in the bones of the wrists of those using pneumatic tools, drills and chain-saws etc.

The second, vibration induced white finger (VWF), is more serious and in extreme cases can lead to partial disablement. Instances of susceptibility to VWF in preparators and conservators have been discovered recently. The greatest hazard appears to occur where electro-vibratory and pneumatic tools are used without sufficient damping of the object being worked on or with inadequate damping of the handpiece itself. In many cases, VWF induced through repeated exposure to vibration is completely reversible, and passes off within an hour or so of removal from contact with the source of vibration.

The symptoms of VWF include, at the lowest level, occasional tingling or numbness during and immediately after use of equipment. More serious symptoms include development of blanching and numbness of the fingers away from work and interference with normal movements, including writing. Susceptibility to this condition may occur and in severe cases change of occupation may be necessary. An occupation health specialist should be consulted for advice on this problem.

Recommendations on time weighted exposures to vibration are being prepared in the UK at present, and there are now a number of accelerometers available for the determination of levels of exposure. The general recommendation is that the maximum daily duration of work with vibratory equipment should be 3-4 hours.

Compressed air. This is finding increasing use in workshops and laboratories nowadays. Compressed air equipment can cause serious noise and vibration problems. All equipment operated by compressed air, together with supply hoses, pipes and couplings should be inspected regularly and any defective components replaced immediately. Trailing and overhead air-hoses must be protected from damage by enclosure in channels or, over bridging spans of more than a few metres, by some form of supporting conduit. Codes of practice and specialized advice on safety aspects of work with compressed air are available from the British Compressed Air Society (London).

Radiation

Ionizing radiations. New regulations and codes of practice were introduced under the Ionizing Radiations Regulations 1985 which made some changes to existing guidance on aspects of using and storing sources of radiation. These include revision of dose limits, setting up controlled and supervised areas, hazard assessments and the appointment of Radiation Protection Advisers. Existing legislation included under the Radioactive Substances Act 1960 was not affected.. Certain types of work with apparatus used to generate ionizing radiation and sources of radiation required registration under the act and now this has to be notified to the Health and Safety Executive. The special provisions made in 1963 which dealt with the public exhibition of radioactive substances are unchanged except that the limits of exposure have been lowered to 5 msv/hour.

Storage of radioactive minerals

Brunton et al. (1985) and especially Dixon (1983) gave detailed descriptions of some of the main hazards likely to be encountered in storing, curating and exhibiting radioactive minerals. Exposure to levels above 7.5 pSv /hour, the present limit for non-designated areas, is unlikely to occur under normal circumstances; however, with large specimens and large collections it may be necessary to carry out measurements of radiation levels. As an overriding precept exposures to radiation levels should be as far below this figure as possible.

The dangers of storing radioactive minerals together in one area may outweigh the curatorial advantages. Firstly, radiation levels near or even above the dose limit may be present in the vicinity, and secondly, there has been concern about the build-up of highly toxic radon and its stable daughter isotopes in radioactive mineral stores to levels in excess of safety limits. It is generally recommended that enclosed stores should be extract ventilated to remove radon. As a matter of course monitoring of radiation levels (alpha, beta and gamma radiation) should be carried out; in addition, the activity due to radon decay should be measured.

The criteria for control and possibly designation of the store or an area in it as a controlled or supervised area are dependent upon three factors:

1, the total activity being handled
2, the activity in air in the area
3, the surface contamination level in the store

Expert advice on the above aspects should be obtained from an appointed Radiological Protection Adviser.

Handling radioactive minerals

Mainly theoretical considerations led Brunton et al. (1985) and Dixon (1983) to suggest that exposure to radiation during the routine handling of uraninite and other highly radioactive minerals is negligible in comparison with the notified dose limits. Puffer (1980) suggested that uranium minerals are toxic not so much through radioactivity but because of the chemical effect of uranium on the kidneys.

Prolonged exposure to uraninite and several other uranium minerals is hazardous and it is likely that the guidelines based upon those governing handling of unsealed radioactive substances (SI 1968 No.780) will apply to handling radioactive minerals in collections before too long. The basic rules for personal hygiene during the handling of radioactive minerals should include:

- use of protective clothing, i.e. gloves (PVC, latex or polythene, disposable type) plus toxic dust/high efficiency filter respirator (to BS 4555) for handling highly active species.
- obligation to wash hands after handling all other radioactive mineral specimens.
- monitor hands after washing and handling dusty or friable specimens.
- do not handle radioactive minerals when hands are cut or skin broken.
- do not eat, drink or smoke in areas where radioactive minerals are stored and handled.

Non-ionizing radiation

Included in this category are ultra violet (UV), infra red (IR) and radio frequency radiation. UV and IR generating equipment is used frequently in laboratory work.

Ultra violet radiation. UV (between 200-400nm) is divided into:

UV-A (near UV or 'black' light)	400-315 nm
UV-B (erythemal region)	315-280 nm
UV-C (far UV)	280-100 nm

UV below 250 nm will dissociate oxygen in air to ozone and below 160 nm will cause nitrogen to react with oxygen forming nitrogen oxides.

Lamps, including mercury, metal halide and inert gas, as well as flash and fluorescent tubes, all produce UV at varying wavelengths. High level UV illumination lamps may be fitted with double envelopes, the outer envelope being the UV filter; this outer case can be broken unnoticed and injuries have occurred in this way as the lamps do not fail to safety. No exposure to UV light is entirely safe: shorter wavelength UV affects the epidermis; at wavelengths above 300 nm deeper effects on the dermis are possible; with the eye, wavelengths of 300 nm affect the lens.

Acute effects of exposure (erythema or skin reddening and 'arc-eye') usually occur several hours after exposure. Chronic effects include loss of skin elasticity and cancer and, in the eye, cataracts and lens opacity. The limits for exposure to UV which apply to both skin and eye are based upon time-weighted irradiation levels at 270 nm. These range from 8 hours/day at 0.1 pW/cm^2 to 0.1 sec./day at 30,000 W/cm^2. For UV-A the level is set at 1 mW/cm^2 per day for duration of exposure of more than 16 mins./day.

Infra red radiation. IR (from 700 nm to microwave radiation at 300 GHz) has the most marked effect upon the eye; irradiation at 2000 nm causes a temperature rise of 45°C in the cornea in 2-3 milliseconds and thus causes intense pain and withdrawal. Cataracts may be an effect of repeated exposure to IR. The high intensity IR lamps used for drying purposes generally operate at wavelengths of 700 nm to 1500 nm and will not normally have any harmful effects. There are as yet no standards for exposure to IR sources (except IR lasers).

Visual Display Units and radiation. At the present time there is no evidence to suggest that any of the radiation emitted by VDUs is harmful. Ergonomic factors and prolonged working at VDUs can cause stress and strain problems. For more information see Health and Safety Executive (1986c) and Clarke *et al*. (1984).

Handling and lifting

Geological specimens present special problems in the context of manipulation as they are at one time often heavy, fragile and of irregular shape. Injuries through lifting and handling account for the absence of at least 100,000 people from work at any one time, and upwards of 100,000 people per year are seriously injured as a result. It is probable that the majority of museum geologists have suffered acute or chronic strains through handling their charges whether in the field or the collection. At the present time there are no guidelines to the limits for lifting except that the Factories Act (1961) and Construction Regulations (1961) contain the following rather alarming provision (*sic*):

'A person shall not be employed to lift, carry or move any load, as heavy as to cause injury to him' (!). Specific regulations do in fact cover some industries,e.g. Woolens and Worsteds (Lifting of heavy weights) Regulations (1926), The Pottery Regulations (1950), and both the Chartered Society of Physiotherapy and the TUC have published guidance:

Woolens (etc.) Regulations:

- men	120-150 lbs
- women and young males	60-65 lbs
- women less than 18 years	40-50 lbs

Pottery Regulations (women only!) 30-50 lbs

Chartered Society of Physiotherapy:

- men	120 lbs
- women	50 lbs
- young persons	35-40 lbs

TUC:

- men 16-18 : 20-35 : > 50yrs 44:55:35 lbs
- women 16-18 : 20-35 : > 50yrs 26:33:22 lbs

The situation is at present therefore somewhat confused, to say the least.

The approach to lifting large geological specimens requires three basic considerations:

1, conversion of an often irregular object into one which is more easily grasped and manipulated
2, adoption of strain-free lifting techniques
3, use of manual handling equipment

The first aspect will often require simply packing or mounting the specimen in a box or on a board so that it constitutes a rigid unit with its centre of gravity easily locatable within the confines of the package. Free lifting (i.e. without manual aids) should only be carried out by experienced staff; remember that training and instruction is a requirement under the Health and Safety at Work Act and that includes training and instruction in lifting. Several training courses, including the so-called 'Kinetic Methods', are available; the Chartered Society of Physiotherapists (Tavistock House (South), Tavistock Square, London SW1) and the Royal Society for the Prevention of Accidents (Birmingham) should be able to give further information on training courses. It is often preferable to use manual handling equipment, such as slings, simple cranes, hoists, pulleys and various types of lift-truck. All these pieces of equipment must, of course, be properly maintained and regularly inspected (Health and Safety Executive 1985) and, again, training in their use is a requirement.

Machinery hazards

Most geological laboratories and workshops house one or more pieces of equipment which require specialist training for their use, or basic safeguarding whilst in use. Abrasive wheels, band saws, bench mounted drills and wood- or metal-working machinery (including lathes, table saws, routers, honing and grinding machinery, rock saws, corers, etc.) all come under the category of dangerous machinery. The guarding arrangements for such equipment are not, as may be thought, solely the responsibility of the supplier or manufacturer. Training in their use is a matter for the employer and the use of guards is the responsibility of the operator. Neither the use of untrained operators nor the use of unguarded equipment should be tolerated.

Guidance on training in the use of abrasive wheels is a requirement of the Abrasive Wheels Regulations (1970) which also specified the type of guards required during operation. Guards and special requirements for the use of other workshop equipment are described in detail in a series of booklets published by the Machine Tools Trades Association, British Standards Institution publications (especially *BS 5304:1975, Code of Practice for Safeguarding of Machinery*), and the Health and Safety Executive's *Guidance Notes on Plant and Machinery*. The subject matter is large, but it is incumbent upon the employer and user under Sections 2, 7 and 8 of the Health and Safety at Work Act to ensure that all plant and equipment is safe for use, and this includes band saws, bench drills and abrasive wheels.

The generally accepted criteria for the identification of machinery dangers are as follows:

- traps : in-running 'nips' and wheels or 'scissors' (e.g. pulley belt on wheel or shearing machinery)
- impact : reciprocating table, automatic lathe
- contact : table saw, abrasive wheel
- entanglement : shaft of drill, or abrasive wheel
- ejection : abrasive wheel with wrongly positioned tool rest

For an excellent review of machinery hazards and control methods see Ridley (1983, Ch.26).

TOXIC MINERALS

The criteria available to the curator and conservator to help decide which minerals are toxic are at present in a confused state. Puffer (1980) listed two hundred toxic

Table 8. Some moderately to highly toxic minerals. O, not known to be toxic via this route; x, unlikely to be toxic via this route; *, likely to be highly toxic by this route; **, known skin sensitisers. Minerals potentially hazardous to handle are underlined.

Mineral Name	Toxic Element(s)	Ingestion	Inhalation	Skin
Adamite	As	*	*	*
Anglesite	Pb	*	*	0
Annabergite	Ni, As	*	*	*
Antimony (native)	Sb	*	*	0
Arsenic (native)	As	*	*	**
Arsenopyrite	As	*	0	*
Arsenolite	As	*	*	**
Asbestos minerals	-	*	*	0
Avicennite	Te	*	*	*
Bequerelite	U	x	*	x
Behoite	Be	*	*	x
Beryl	Be	0	*	0
Bieberite	Co	*	x	**
Boleite	Pb	*	*	0
Boracite	B	*	x	0
Borax (+ all sol borates)	B	*	x	0
Bournite	Pb, Sb	*	*	0

Mineral Name	Toxic Element(s)	Ingestion	Inhalation	Skin
Bromellite	Be	*	x	**
Bunsenite	Ni	*	*	**
Calomel	Hg	*	*	**
Carnotite	U, V	x	*	**
Carrobite	F	*	x	0
Cassiterite	Sn	0	*	0
Carlinite	Tl	*	*	*
Cerrantite	Sb	*	*	*
Cerrusite	Sb	*	*	0
Chromite	Cr	x	*	**
Cinnabar	Hg	*	*	0
Claudetite	As	*	*	*
Conichalcite	As	*	*	*
Crocoite	Pb	*	x	0
Curite	Pb, U	*	*	*
Cristobalite	Si	0	*	0
Descloizite	Pb, V	x	*	**
Emerald	Be	0	*	0
Erythrite	As	*	*	0
Eskolaite	Cr	*	*	*
Finnemanite	Pb, As	*	*	*
Fiedlerite	Pb	*	*	0
Frankdicksonite	Ba, F	*	x	0
Greenockite	Cd	*	*	poss
Goslarite	Zn	*	x	0
Georgiadesite	Pb, As	*	*	*
Hawleyite	Cd	*	*	poss
Heliophyllite	Pb, As	*	*	*
Jamesonite	Pb, Sb	*	*	0
Karelianite	V	x	*	**
Kermesite	Sb	*	x	0
Kasolite	Pb, U	*	*	0
Koettigite	Zn, As	*	*	**
Lead (native)	Pb	*	*	*
Legrandite	Zn, As	*	*	*
Linarite	Pb	*	*	0
Loellingite	As	*	*	x
Malachite	Cu	0	*	0
Melanterite	Fe	*	x	0

Mineral Name	Toxic Element(s)	Ingestion	Inhalation	Skin
Mimetite	Pb, As	*	*	*
Monteponite	Cd	*	*	*
Montroydite	Hg	*	*	**
Mercury (native)	Hg	*	*	**
Niccolite	As, Ni	*	*	x
Nickel (native)	Ni	*	x	**
Nitrobarite	Ba, Ni	*	*	0
Orpiment	As	*	*	**
Paratellurite	Te	*	*	x
Pentfieldite	Pb	*	*	x
Pharmacolite	As	*	*	*
Phenakite	Be	x	*	x
Phoenicochroite	Pb, Cr	*	*	**
Phosgenite	Pb	*	*	?
Pierrotite	Tl	*	*	*
Proustite	As	*	*	x
Pyragyrite	Sb	x	*	x
Pyromorphite	Pb	x	*	x
Quartz	Si	0	*	0
Realgar	As	*	*	**
Retgersite	Ni	*	*	**
Routherite	Tl	*	*	*
Schultenite	Pb, As	*	*	**
Selenium (native)	Se	*	*	**
Selenolite	Se	*	*	**
Senarmonite	Sb	*	*	x
Shcherbinaite	V	x	*	**
Siderite	Fe	0	*	0
Skutterudite	Co, As	*	*	**
Spherocobaltite	Co	x	x	**
Talc	Si	0	*	0
Tennantite	As	x	*	0
Tetrahedrite	Sb	x	*	0
Thorianite	U	*	*	x
Torbernite	U	*	*	x
Uraninite	U	*	*	x
Vanadinite	Pb, V	x	*	poss
Wulfenite	Pb	*	x	0

Table 9. Noise levels expected during workshop and laboratory activities.

			Effects	
dB(A)	Noise Intensity	Activity	Short term exposure	Long term exposure
30	very quiet	distant traffic through double glazing	none	none
60	quiet	normal conversation	none	none
75		balanced extract fan	none	none
80-85	loud	electric drill or airbrasive	none known at present	some evidence that exposure to sustained 85 dB(A) may cause gradual loss of hearing over many years.
90	present legal limit	compressed air equipment, woodworking machinery.	temporary deafness which may last from a few seconds to hours (may cause tinnitus) especially at levels of 95-105 dB(A)	sustained exposure to 90-105 dB(A) will lead to loss of hearing over even a few years (note addition of workplace noise and 'social' noise, i.e. discos, etc., may result in much enhanced risk of hearing damage). 8 hours of 90 dB(A) is equivalent to 15 minutes of 105 dB(A) noise.
90-100	very loud	band saw, vibro tool, etc.		
95-105	conversation difficult	grinding casts		
100-110	uncomfortably loud	rock saw	prolonged temporary deafness likely.	rapid loss of hearing likely.
135	painfully loud	hammering hard rock	repeated exposure causes severe damage, however pain causes withdrawal.	-
150-160			eardrum ruptures plus instant deafness caused by destruction of sensory mechanism of middle/inner ear likely.	

minerals, Lof (1985) gave about seventy in his world minerals chart and Brunton *et al.* (1985) outlined the toxic properties of about forty minerals. Each authority included many minerals the others did not, although the lists of Lof and Brunton *et al.* were not designed to be exhaustive. Table 8 is culled from these sources, together with data from Hunter (1978) and Waldron (1985), and lists those minerals considered to be moderately to highly toxic by ingestion, inhalation or skin contact. There are undoubtedly many other toxic minerals and some in this list are so rare or occur in such minute quantities that they really do not present a hazard at all. Those which could be potentially hazardous to handle are underlined.

Accidental acute poisoning by ingesting toxic material is unlikely except for arsenic and thallium compounds. The lethal dose for arsenic (as As_2O_3) has been reported to be as low as 20 mg for a child, 70 mg for an adult. Chronic effects are also a definite risk for curators and others who handle arsenic minerals regularly. The Health and Safety Excutive (1986a) considers that arsenic and its inorganic compounds should be regarded as human carcinogens. As a result, the present exposure limit of 0.2mg/m^3 will probably be lowered to 0.05mg/m^3. As an interim measure 0.2 mg/m^3 will become a Control Limit with effect from 1 January 1987. In addition, it is proposed that anyone exposed to arsenic compounds, other than very occasionally, should be subject to medical surveillance.

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Francis M.P. Howie
Safety Advisor
British Museum (Natural History)
Cromwell Road
London SW7 5BD

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ENVIRONMENTAL CONSIDERATIONS

BY J. ASHLEY SMITH

INTRODUCTION

Although I know very little about the conservation of geological material, the area of which I do have some knowledge, the decorative arts, is not too dissimilar. The collections at the Victoria and Albert Museum contain objects which are made from metals and their mineral alteration products, objects decorated with mineral pigments, gemstones, ceramics, and sculpture made from a multitude of different stones.

There are many people who know more about environmental control than I do but fortunately the subject is embarrassingly simple. If you think of the problem as that of a poor innocent object in danger from a wicked environment, then there are four ways of effecting a rescue.

1. Remove the object.
2. Remove the source of danger.
3. Create a barrier.
4. Control the source.

Removing the object. Certainly, as a short-term solution, removing the object to a better environment is a sensible course of action and may be very much cheaper than the alternatives.

Removing the source of danger. If the hazard is dampness in a basement, removing the source of humidity by suitable building construction seems obvious.

Creating a barrier. If there is too much light, put up shutters or a screen. If the pipes are too hot, lag them. If the atmosphere is dirty, put the objects under cover.

Controlling the source. If you want something more sophisticated, you may require closely measured and controlled levels of light, humidity and temperature. This requires a degree of mechanisation. The more the controls required, the more expensive the solution will be.

EFFECTS OF THE ENVIRONMENT

Light

It is widely assumed that inorganic materials are unaffected by light. This may be a dangerous assumption, partly because some inorganic compounds can be photosensitive but principally because inorganic objects that have been in museum collections will no longer be purely inorganic. Many will have been given (undocumented) treatments with a range of organic substances, many of which will discolour or embrittle on exposure to light. Many marble sculptures in the V&A show brown marks which are not metal stains but are organic in nature. There are obvious photosensitive compounds such as silver salts but there is also evidence that oxidation and sulphidation of metals is accelerated by light.

The four common sense courses of action can be applied to the hazard of light. The object can be moved out of direct sunlight. The source of light can be removed by blocking windows or turning off lights (making sure they turn off automatically if there is no one about). Using barriers to modify the nature of the light, Perspex VA will remove most of the ultraviolet component. Elegant control of natural and artificial light is possible, at some expense, by the use of blinds and dimmers activated by photocells.

Apart from damage caused by people, poor buildings and light, hazards of the environment really means hazards of the atmosphere. The principal factors are temperature, relative humidity and pollution; each of these can cause serious deterioration of museum objects.

Temperature

As temperature rises, the rate of any chemical reaction tends to increase. Many forms of deterioration are noticeably accelerated by relatively small rises in ambient temperature (direct radiation from sun or spotlamp can cause the temperature of the object to rise dramatically). It is theoretically possible for certain temperature changes to cause phase transitions, e.g. between α and β forms of tin at 13.2°C. There is a real danger to composite objects made from materials with differing coefficients of expansion, e.g. enamel (glass) has become detached from its metal support following a single excursion from 15°C to 0°C.

Humidity

Changes in temperature have direct effects on the moisture content of an object and its immediate environment. Humidity in a display or storage area is also affected by the weather outside or the presence of local sources of humidity (recently washed floors or people in wet raincoats).

High humidities lead to corrosion of metals and reactions of pyritic specimens. Low humidities can cause certain salts to lose water from their structure and thus change colour or crystalline form. Variable humidities tend to cause transport of soluble salts through porous matrices, resulting in staining or spalling of the surface or the eruption of salt crystals.

Both high and low humidities accelerate the exfoliation of laminar minerals such as mica. We have some Indian miniatures painted on mica from which the paint appears to be flaking, whereas in fact it is the upper sheets of the mineral that are coming away.

Pollution

There are chemical agents in the air which are deleterious but not technically pollutants. Water and oxygen cause a great many chemical changes, especially oxidation of metals. Carbon dioxide is involved in the corrosion of lead and in the transformation of copper corrosion products. Sulphur dioxide is produced in great quantities by natural sources such as the sea, but it is more widely known as an industrial pollutant. It has a serious effect on the surface of marble and limestone sculpture, converting calcium carbonate to a powdery layer of calcium sulphate.

Pollution can come from unexpected local sources. Acetic acid vapour from vinegar used in catering has been shown to cause corrosion of lead. Lead objects have also been corroded by acetic and formic acids from composite boards used in showcase and storage unit furniture. Acetates and formates have also been discovered as mineral alteration products of limestone stored in new cases. Perhaps the most surprising unwanted mineral reported is a nitrate salt produced by the degradation of cellulose nitrate adhesive on other objects in the showcase.

Sulphur-containing materials can cause deterioration, most obviously to photographs which contain finely divided silver. A number of paper and textile finishes and some adhesives contain sulphur. These should be avoided in showcase or storage box construction. Although the common sense answer to separating objects from atmospheric pollution is to create a barrier such as an airtight case, there is the danger that this barrier may seal pollutants and objects together. Since some sulphide minerals are potential sources of sulphur or hydrogen sulphide in a showcase, care should be taken to separate these from minerals which could be attacked. Studies of 'black spots' on copper alloys have shown that the black crystals of copper sulphide grow on the surface of other corrosion products such as sulphates, chlorides and carbonates.

CONTROLLING THE ENVIRONMENT

If you have done all the sensible things about removing obvious causes of damage, there may still be a need for close control of conditions, especially the level of humidity. Before rushing out to buy a dehumidifier or shovelling silica gel into showcases, there are five basic questions to ask:

1. What do I really need?
2. What can I afford?
3. Who is going to pay?
4. Who is going to maintain?
5. How hard do I want to work?

Monitoring

The continuous recorded measurement of conditions in the area of interest is necessary before any recommendations can be made. You cannot rely on the body's sensing facility to detect temperature and the body is not equipped to record any fluctuations in the atmosphere's water content. Judgement is necessary in interpreting the recorded data. Some small stores in the heart of a large building may have extremely stable conditions. The record may show that humidity is continuously on the dry side of normal specification. Recent research has shown that small rapid changes in humidity cause more strain than large longterm variations. It may cause less damage to keep objects dry but stable rather than subject them to the continuous oscillation that a humidifier operating in a small space would generate. This judgement will depend on the nature of the collections and may suggest separation of objects in store by the conditions they need, rather than any historic or taxonomic classification.
Methods of monitoring have been changing in the last ten years and the traditional whirling psychrometer and recording thermohygrograph are slowly being replaced by electronic instruments.

Humidification

There are three main ways of getting more moisture into the atmosphere: steam, spray and evaporation. Spraying has the disadvantage that any dissolved salts in the water are carried into the atmosphere and may be deposited as a fine white powder all over the exhibits. The evaporation techniques have come under suspicion with recent scares about 'Legionnaires disease', but current medical advice is that if the equipment is regularly cleaned there is no problem. The evaporative systems are the only ones that fail safe. If a steam or spray system decides to go wrong, then humidity can rise dramatically and uncontrollably. If humidity rises the process of evaporation is automatically slowed down and so the system is self regulating. Steam humidification is the one most commonly used in fully ducted systems. But what can you afford; a portable humidifier or an air-conditioning system? A large capital expense may come from a different vote and be easier to get than a small piece of equipment! How hard do you want to work? Will it be you carrying buckets of water to the humidifier every day? If it were plumbed in, who would be responsible for the maintenance? Can they be trusted? What are the effects if planned maintenance fails?

Since humidity can be controlled to some extent by controlling temperature, it may be possible to prevent some excursions into dryness in winter by fitting a humidistat to the heating system. If the relative humidity drops below a specific point, the heating is turned off and as the room cools the relative humidity will rise.

Dehumidification

There are two main ways of removing water from the atmosphere: by refrigeration or by use of a dessicant material. The refrigerant equipment heats the surrounding air which may not be wise if the temperature is already high. If the ambient temperature is low, the cooling coils may freeze up, seriously reducing efficiency. The water is usually collected in a reservoir which will need draining periodically. Dessicant systems work better at lower temperature, when the efficiency of absorption is greater. Whereas the refrigerant types can be free-standing, the dessicant dehumidifier needs some ducting to expel humid air from the room and may require air ducted in from outside.

Silica gel

Absorbent materials such as silica gel can be used not only as drying agents but as reservoirs of moisture to keep enclosed spaces such as showcases at constant humidity, despite local variations in temperature and humidity. The silica gel must be conditioned to the required humidity which requires a preparation area including equipment such as humidifiers and weighing scales. Again, how much physical work is involved? Twenty kilograms of silica gel is needed for each cubic metre of enclosed space. This needs to be moved from conditioning room to showcase and back at regular (if not frequent) intervals. Whose job is this?

CONCLUSION

The subject of environmental control is a matter of common sense. It is also the subject of an excellent book: The museum environment by Garry Thomson, a second edition of which is soon to be published. Other useful references include Berger and Russell (1986), Erhardt *et al*. (1982) and Howie (1978).

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J. Ashley-Smith
Conservation Department
Victoria and Albert Museum
South Kensington
London SW7 2RL

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CONSERVATION DOCUMENTATION

BY JOHN A. COOPER

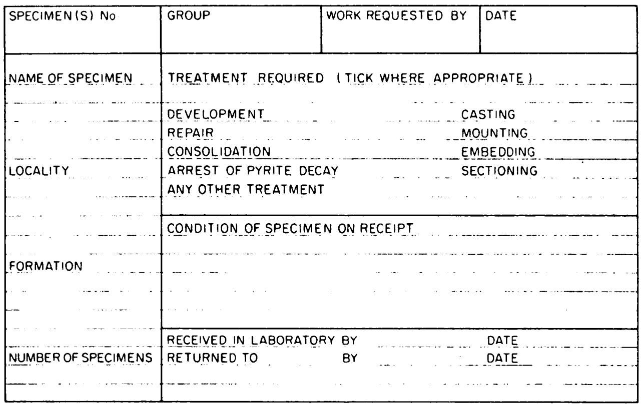
INTRODUCTION

There is a substantial body of text available to support the work of a museum geologist, in which one might look for guidance on both curatorial and technical matters. A few publications are worth noting as being significant in the development of this literature. Earliest in the field was probably the BM(NH) (1902) Handbook of instructions for collectors which contains chapters dealing briefly with methods for collecting geological specimens. This handbook went into many editions and in 1934 (5th edition) was split into component issues, No.11 being subtitled Fossils and minerals. The 6th edition (1956) is for Fossils, minerals and rocks, as is the current edition (1965). These handbooks were aimed at collectors, not curators, and never became common currency in the museum world.

Geology in the Museum by North, Davidson and Swinton (1941) is the earliest and perhaps the only attempt at an all-embracing account of museum practice in geology, not replaced until the recent arrival of GCG's Guidelines (see below). On the technical front, Mahoney (1966) included a chapter on 'Palaeontological Techniques' in his Laboratory techniques in zoology (not recorded by Sharpe 1983). This kindly treatment of palaeontology as a part of zoology and, more broadly, geology as natural history was continued by Wagstaffe and Fidler (1968) who introduced geology into the second volume of The preservation of natural history specimens; here, several authors contributed to over fifty pages of important though somewhat overlooked material. In the meantime, the growth and refinement of research procedures in university geology departments resulted in the authoritative Handbook of paleontological techniques by Kummel and Raup (1965) and later Geological laboratory techniques by Allman and Lawrence (1972). These publications, however, were not aimed at the museum laboratory where a substantially different set of procedures and ethics were in effect. For palaeontology at least, this situation was changed by Arthur Rixon's (1976) highly acclaimed and still appropriate Fossil animal remains: their preparation and conservation (sadly now out of print). The important collection of papers published under the title Curation of palaeontological collections (Bassett 1979) records the proceedings of the 1978 Cardiff colloquium, organised jointly by the Palaeontological Association and GCG; while not representing any concensus view, it remains an invaluable reference. Finally, the Museums Association's Manual of curatorship (Thompson 1984) must, by virtue of its two geological contributions and other relevant papers, be included in this list, even if it is not altogether useful.

The sum total of the literature available to the museum geologist lies not in these publications alone, however, important though they may be, but also amongst the many hundreds of articles that have appeared in journals all over the world; they have been admirably compiled by Sharpe (1983) in his bibliography Geology in museums. Perhaps the most significant publication of all is Guidelines for the curation of geological materials by Brunton, Besterman and Cooper (1985) which attempts to draw together the numerous threads of modern museum practice into a coherent statement for a principled profession (reviews appeared in Geol. Curator, 4, pp.357-360). As a first edition the profession must discover its weaknesses and false conclusions and work towards a universal consensus. Part of this process is the continued organisation of appropriate meetings by the Geological Curators' Group and the publication of proceedings such as this current edition.

The literature listed above provides us with a considerable resource concerning best working practices for museum based geology. It therefore came as something of a surprise to this author that, in even the most senior of the works cited, there is barely a mention of what may appear to some to be merely common sense, i.e. that if something is done to a specimen by way of repair or consolidation, then the job is recorded on the specimen's documentation. Rixon (1976, p.235) is the only exception: under 'Management' he described the 'request for work' system operated by the Palaeontological Laboratory of the BM(NH). This system utilised a laboratory record card (Fig.1) and a similar card is still in use today (Fig.2). In the Guidelines emphasis is placed on 'principles of documentation' and the fifth of these is that 'every significant event affecting a specimen must be recorded' (section B 1.2). In this context, laboratory processes are seen as particularly



SPECIMEN(S) No	GROUP	WORK REQUESTED BY	DATE

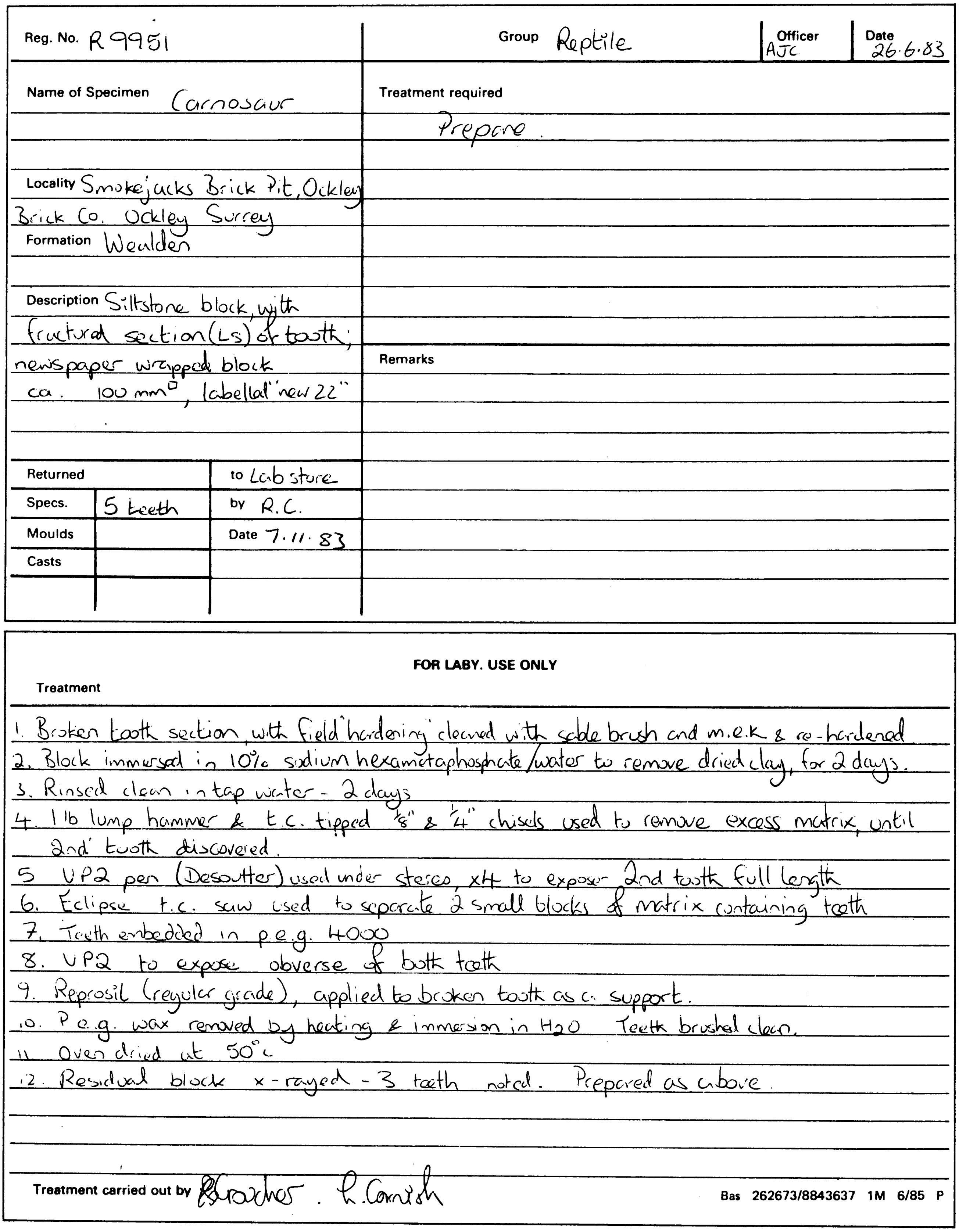
NAME OF SPECIMEN
LOCALITY
FORMATION
NUMBER OF SPECIMENS

TREATMENT REQUIRED (TICK WHERE APPROPRIATE)
DEVELOPMENT CASTING
REPAIR MOUNTING
CONSOLIDATION EMBEDDING
ARREST OF PYRITE DECAY SECTIONING
ANY OTHER TREATMENT

CONDITION OF SPECIMEN ON RECEIPT

RECEIVED IN LABORATORY BY DATE
RETURNED TO BY DATE

Fig.1. 'Request for work and laboratory record card', as devised by Rixon (1976, fig.26).



Reg. No. R 9951	Group Reptile	Officer AJC	Date 26.6.83

Name of Specimen Carnosaur

Treatment required Prepare.

Locality Smokejacks Brick Pit, Ockley Brick Co. Ockley Surrey

Formation Wealden

Description Siltstone block, with fractured section (LS) of tooth; newspaper wrapped block ca. 100 mm□, labelled "new 22"

Remarks

Returned		to Lab store
Specs.	5 teeth	by R.C.
Moulds		Date 7.11.83
Casts		

FOR LABY. USE ONLY

Treatment

1. Broken tooth section, with field 'hardening' cleaned with sable brush and m.e.k & re-hardened
2. Block immersed in 10% sodium hexametaphosphate/water to remove dried clay, for 2 days.
3. Rinsed clean in tap water - 2 days
4. 1 lb lump hammer & t.c. tipped 1/8" & 1/4" chisels used to remove excess matrix, until 2nd' tooth discovered.
5 VP2 pen (Desoutter) used under stereo, x4 to expose 2nd tooth full length
6. Eclipse t.c. saw used to separate 2 small blocks of matrix containing tooth
7. Teeth embedded in p.e.g. 4000
8. VP2 to expose obverse of both tooth
9. Reprosil (regular grade), applied to broken tooth as a support.
10. P.e.g. wax removed by heating & immersion in H_2O Teeth brushed clean.
11 Oven dried at 50°c
12. Residual block x-rayed - 3 teeth noted. Prepared as above

Treatment carried out by R.Croucher. R.Cornish

Bas 262673/8843637 1M 6/85 P

Fig.2. Completed example of current 'Request for work and laboratory record card' used in the Palaeontology Laboratory, British Museum (Natural History). Its development from Fig.1 is clear.

significant and the general rules for laboratory documentation are described in section B 5.4. Further guidance is given for the documentation of complex operations, such as the preparation of vertebrate remains from nodules (Fig.3).

In this account I want to elaborate on some of the thinking that underlies these sections of the Guidelines and try to establish a firmer philosophical basis for conservation documentation than space there allowed.

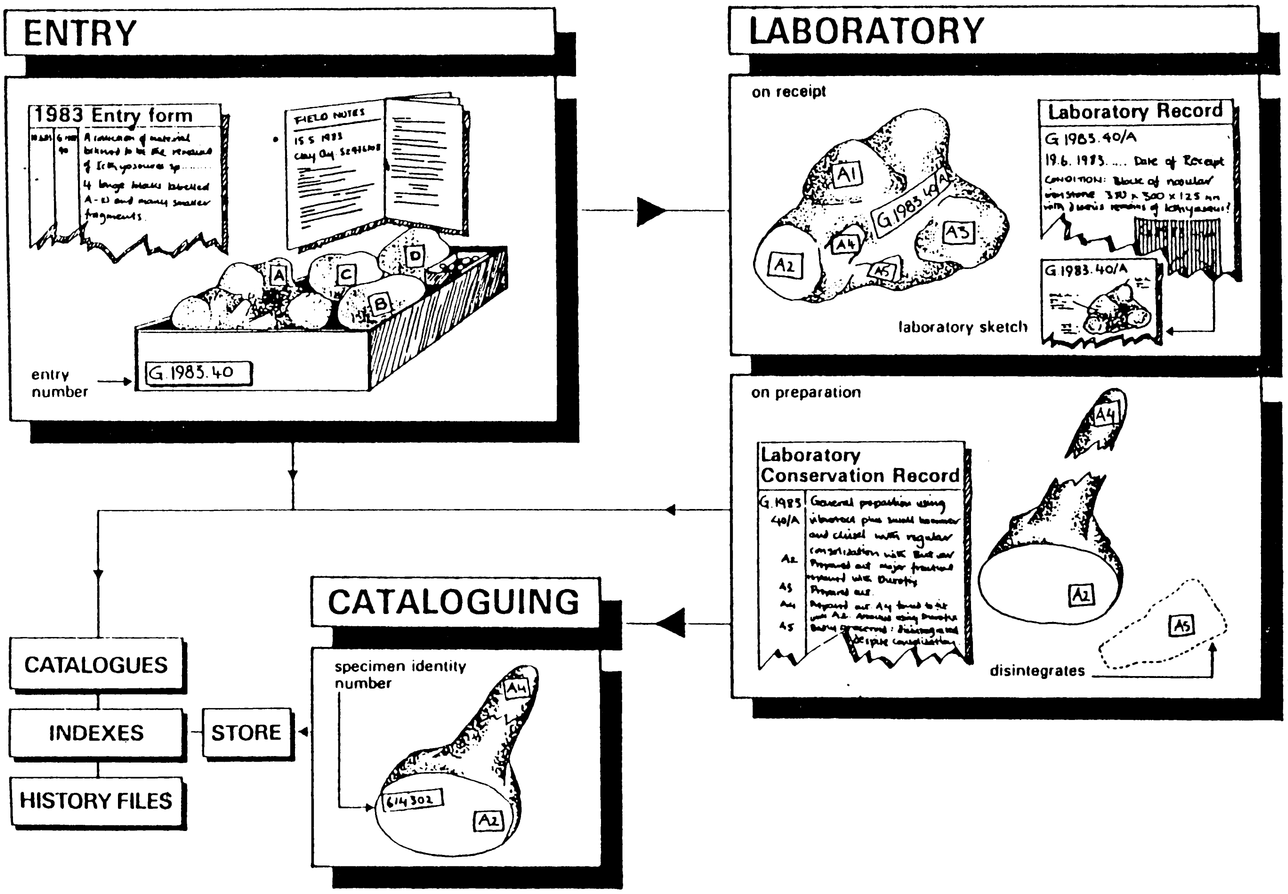


Fig.3. Schematic representation of the documentation of a complex laboratory operation. Reproduced with permission from Brunton et al. (1985, fig.9).

WHAT DO WE MEAN BY 'CONSERVATION'?

An interesting and instructive beginning is to consider the etymology of the word 'conservation'. The latin root of the word is servare, meaning 'to keep', and it is linked with the prefix con meaning 'together' or 'whole'. This gives us two shades of meaning to the word, both of which can be applied to situations in which the museum geologist has strong interests and which have led to many a semantic argument over titles and content of conferences, books, committees and jobs. In the sense of 'keeping together', conservation is the process by which we strive to maintain associations. From the locality to the museum and through to the laboratory, there sometimes seems to be a concerted effort to undo these associations: rock from landscape, stratum from stratigraphy, mineral from vein, specimen from matrix. Thus conservation measures are employed to reverse these situations and preserve ('before keeping') associations, thereby protecting information of potential value. We protect sites and control collecting using local and national powers, with the help of the Nature Conservancy Council, and document sites within the National Scheme for Geological Site Documentation. In the museum we continue this process by documenting all known associations of specimens in an unbroken thread from their arrival through to the laboratory. In a nutshell this is an application of the principle of reversibility which is normally reserved for the laboratory; in this case the principle should be that it must always be possible to reconstruct original associations by working backwards through the documentation.

Turning to the other shade of meaning of 'conservation', i.e. the 'keeping whole' of a specimen, here our concern is for its continued well-being or 'preservation'. In order to achieve a state of equilibrium between specimen and environment, we must consider not only its natural but also its artificial environment; the preservational requirements in the museum are therefore those of environmental documentation and control - temperature, relative humidity, pH, dust protection, etc. We must also understand and document fully the various processes that specimens are subjected to while in the museum. Not only might these affect the equilibrium of a specimen in any given environment, but they may also react adversely with the future process that may be deemed necessary. Thus we must record the glues, fillings, coatings, castings and consolidants as they are used.

It is this latter aspect of conservation through documentation that primarily concerns us here. I have tried to demonstrate above that, semantic arguments aside, the documentation process is a continuous one and that any artificial distinctions between documentation in the field, in the museum, or in the laboratory are meaningless. Further, it is essential that laboratory documentation is not considered exclusively to be the property of the specialised technician or conservator, since in essence the conservator and the curator are the same profession. The unfortunate semantic confusion between conservation to protect associations and conservation to retain integrity must remain.

WHY DOCUMENT CONSERVATION?

When considering the functions of documentation for laboratory processes, an important distinction arises between the work of a geological laboratory and that of, say, an archaeological conservation laboratory. In general, the techniques of archaeological conservation and those of allied disciplines are to a large extent investigative. They reveal evidence concerning compositions, methods of manufacture and decoration, functions, the nature of pigments, etc., and tell us a great deal about the people responsible for the artefact's production. In contrast, geological conservation is essentially concerned with specimen consolidation and stabilisation, apart that is from the obvious aims of specimen preparation - simply to reveal more of what is already apparent. There are of course many exceptions: archaeological and ethnographic objects may need to be 'preserved' just as much as fossils and minerals; brachiopods and corals may need to be serially sectioned in order to be identified. It is nevertheless true that what was discovered as a corroded lump of metal on the sea bed may by careful conservation often reveal a wealth of detail concerning its provenance, whereas a 'non-loc' ammonite will almost certainly remain just that. The implication of this distinction is that it provides a rationale for two styles of documentation. One, for the humanities, will frequently require very careful, continuous and detailed recording over a period of time, and in the end it may provide the substance of the entire documentation for the object and be regularly referred to. The other, for geological conservation, requires a relatively simple record of work done (though nonetheless careful and complete). This is the background against which the format of documentation should best be judged.

First, we must be quite unequivocal about the requirements of laboratory documentation: everything that happens to a geological specimen in the laboratory is a 'significant event' and must be recorded in full. The conservator and preparator must be particularly conscious of the inherent associations of specimen and matrix and, should these be at risk, then they too must be recorded. The standard list of items which require documentation is simple (Brunton et al. 1985, p.B53):

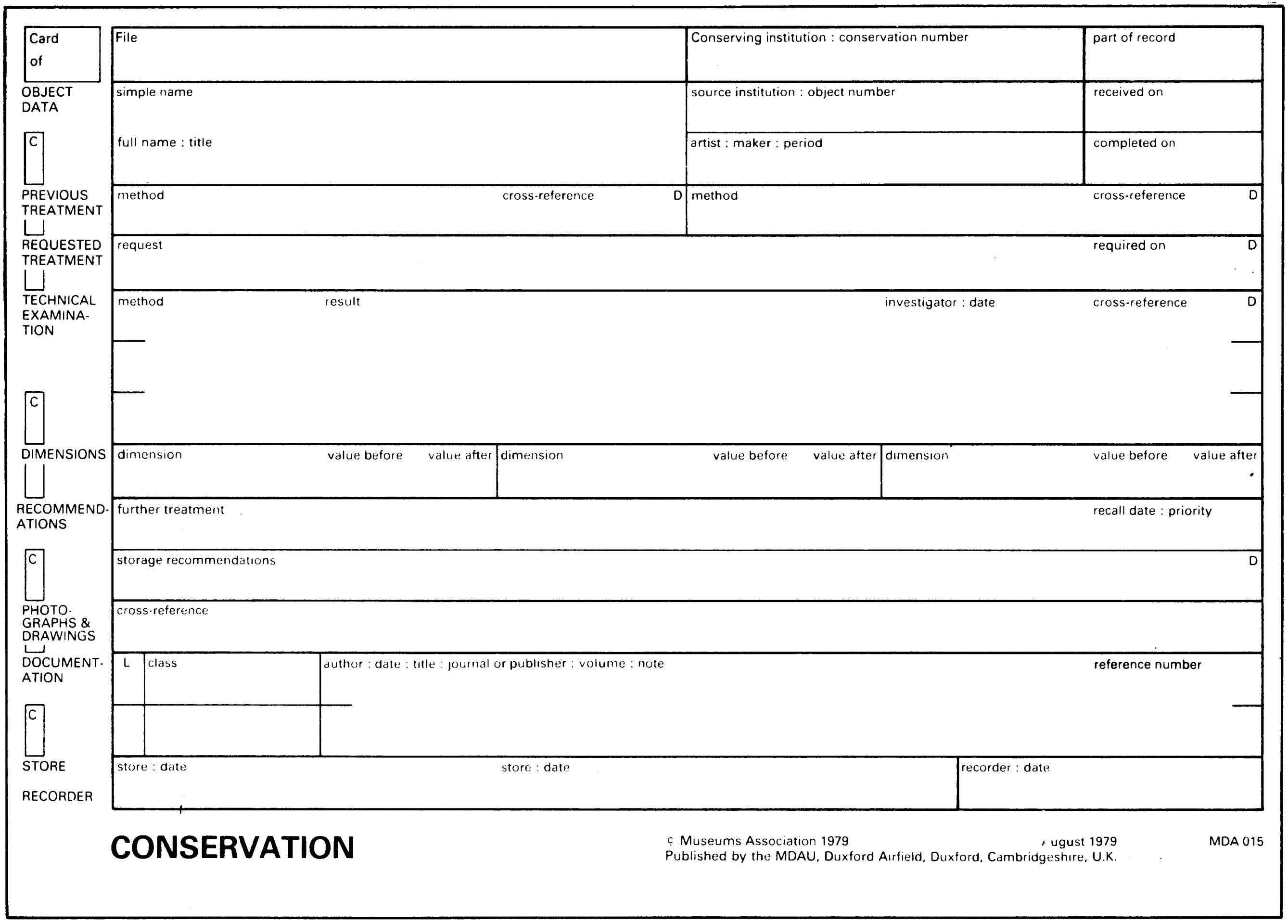
entry/specimen identity number
identification
condition on receipt
treatment given and techniques used
dates of receipt and return
name of conservator

The bulk of any record will consist of details of treatment and techniques, and the value of photographs, drawings and rough sketches to illustrate these details cannot be over-emphasised.

It may be an easy matter to agree on the list of items that should be recorded, but the format of recording them has engendered much discussion in other contexts. The Guidelines loosely recommends record cards for documenting laboratory processes, giving Rixon's version as an example but without discussing other available cards. Here then, further considerations are due.

THE FORMAT OF CONSERVATION DOCUMENTATION

In 1977 the Museum Documentation Association (MDA) published Proposals for the documentation of conservation in museums following the deliberations of a Conservation Working Party convened in 1974. Further products of these deliberations were the A5 (1979; Fig.4 herein) and A4 (1983) Conservation Record Cards and later (1984) the Instructions for their completion. These sophisticated cards, uniform with the keyword and detail approach of all other MDA record cards, contrast markedly with the kind of card exemplified by Rixon (1976). Their use requires considerable familiarity with the techniques of recording recommended by the MDA, whereas Rixon's card needs little more than common sense. Long recognising the deficiencies of common sense in the cataloguing of museum specimens, the MDA has rightly campaigned for the acceptance of its high standards of recording throughout the museum profession. Why then do the Guidelines not recommend the MDA card for geological laboratory documentation? In my view the crucial consideration is the use to which information is to be put; this in turn depends upon the nature of the institution, its collections and the conservator's job. I believe that this was also the view of the original working party for it is noticeable from the list of members (MDA 1977, p.36) that all were drawn from large or specialist institutions and all from the humanities. It comes as no surprise, therefore, that a card was developed suitable for large institutions, for the conservation of artefacts rather than natural history specimens, and for the use of full-time conservators. Against such a background the cards undoubtedly serve their dual purpose very well - on one hand they allow for the description of objects and treatments, on the other, like all the MDA cards, they allow for the preparation of indexes from these descriptions. I do not believe that the cards serve the purposes of technicians, or even curators, in geology or other natural history departments where the amount of conservation work carried out is relatively small. In provincial museums, for example, while it is undeniable that all conservation work should be thoroughly recorded, the place for such records is surely the Specimen History File (see Guidelines, Section B 4.4.7.3). Indexes are not generally required because few processes are repeated in



Card of

OBJECT DATA

File | Conserving institution : conservation number | part of record

simple name | source institution : object number | received on

C

full name : title | artist : maker : period | completed on

PREVIOUS TREATMENT

method | cross-reference | D | method | cross-reference | D

REQUESTED TREATMENT

request | required on | D

TECHNICAL EXAMINATION

method | result | investigator : date | cross-reference | D

C

DIMENSIONS

dimension | value before | value after | dimension | value before | value after | dimension | value before | value after

RECOMMENDATIONS

further treatment | recall date : priority

C

storage recommendations | D

PHOTOGRAPHS & DRAWINGS

cross-reference

DOCUMENTATION

L | class | author : date : title : journal or publisher : volume : note | reference number

C

STORE

RECORDER

store : date | store : date | recorder : date

CONSERVATION

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Published by the MDAU, Duxford Airfield, Duxford, Cambridgeshire, U.K.

Fig.4. The Museum Documentation Association's A5 'Conservation Record Card'. The reverse (not shown) allows for the description of object and treatment.

sufficient numbers to make them worthwhile or meaningful (although in the rare case of a curator embarking on a specific conservation research project, indexes may indeed become a necessity. [The MDA itself is conscious of a need to develop geological documentation practice throughout museums in the UK: continuing the long and fruitful association between MDA and GCG, a joint proposal has recently been submitted to the Museums and Galleries Commission requesting funds for a two year research programme. The documentation of geological conservation is, by definition, included in the proposed brief.]

It is interesting to note the fate of another recording format developed along similar lines to the MDA card. Some years ago, as part of a newly introduced computerised data handling system, the Palaeontology Laboratory of the BM(NH) developed a computer-compatible Laboratory Data Card, matching a Data Recording Format devised for the Palaeontology Department (Brunton 1979). The card 'is printed front to back on A5-sized card. It serves as a request by a Departmental Section to the Laboratory, and as a record of work carried out on a specimen. By using the same tagged data field system as the Departmental Form, information about work on specimens can be linked to data already in the system' (Brunton 1977, figs.3, 4). As a result of careful documentation, a wide selection of indexes and catalogues can be produced. For an institution as large as the BM(NH) and for a department as specialised as Palaeontology, with its large and full-time staff of conservators, the failure of this venture is significant. Although the system as a whole is not fully implemented throughout the department and the laboratory does not have its own computer or terminal, there appear to be other reasons which have led to the demise of the Laboratory Card. First, the Department does not think it necessary to alter the way treatments are manually documented and filed by laboratory staff. Secondly, while there is no objection to a computer based conservation documentation system, a shortage of manpower and training time means that the implementation and supervision of a new system would be very difficult. Conservators (like curators) probably prefer to get on with their jobs, rather than be sidetracked into administrative log-jams.

CONCLUSIONS

A documentary record of any conservation process is mandatory. The analysed documentation of the MDA-style record cards is most appropriate to specialists and full-time conservators who repeat methods and techniques on many specimens and who need access to the information they record for research. Provincial museum geologists are not in this position; their interests, as well as those of the profession, are best served by simplified methods of conservation documentation. Somehow a method which allows the curator to happily and properly conserve as he curates, and the conservator to curate as he conserves, must be established.

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John A. Cooper
Booth Museum of Natural History
194 Dyke Road
Brighton BN1 5AA

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A STRATEGY TO SAFEGUARD THE GEOLOGICAL COLLECTIONS OF THE SMALLER MUSEUM

BY MICHAEL A. TAYLOR

INTRODUCTION

The geological collections of small museums are a significant part of the British geological heritage. Doughty (1981) recorded 121 museums with geological collections of up to 1,000 specimens, and 105 with between 1,000 and 10,000 specimens, of which only fourteen had curatorial geological staff. Yet many of these museums contain significant geological material of importance for research, display and education, as exemplified by two recent case studies: the Fraser Collection at Wolverhampton (Roden 1985) and the Lyme Regis (Philpot) Museum (Taylor 1986). Virtually all these collections are in urgent need of a greater or lesser degree of curation and conservation work to halt continuing deterioration and disorder, and to restore them to a fit state for use (Figs.1-3).

I am concerned here with two major questions. Firstly, what can the non-specialist curator do to obtain specialist advice on and help with the management of geological material? Secondly, since the Geological Curators' Group rightly perceives the welfare of collections as a major priority, what should we do to 'establish our priorities quickly and formalise them into an intelligible scheme' (Doughty 1985, p.7)?

PRIORITIES FOR THE SMALLER MUSEUM

Assessment: surveys and advisory reports

Before taking any action or making any decisions about a collection, the curator who is not a geologist must have the collection surveyed by a specialist museum geologist (or more than one if the range and importance of the collection warrant it). The ensuing report should assess the content and nature of the collection, its importance, the state of its documentation and storage, and the physical condition of the specimens and their environment. The report should also assess the remedial work needed in documentation, storage, specimen conservation, and any necessary environmental control; it should outline the actual and potential value and use of the collection to the community, whether local, tourist, or academic. The appropriate level of staffing should be indicated if the collection is sufficiently large and important. Only then can the museum authorities make a rational decision

Fig.1. Basement store, Bath Geological Museum.

about priorities for its inevitably limited resources, and take the courage to commit its funds for a substantial period.

Such surveys should be arranged through the local Area Museum Council (AMC), which should either deploy a suitable member of its own staff or else approach a suitable person, possibly through the GCG. AMC participation ensures that the AMC is made aware of the problems from the start, and becomes involved in such a way that it can best assess the problem and draw upon its existing contacts, resources and expertise. It can also consider the problems in the context of other, neighbouring museums (with a view, for example, to obtaining curatorial help). The survey, moreover, gains from the independent but nevertheless familiar authority of the AMC, and is better received than if it were written solely by an 'outsider'. Not all geological curators are prepared to give advice or produce such reports, which can take several days or even weeks when survey, travel, research and writing up are included. Guidelines for the reports should be drawn up to ensure evenness in procedure, assessment and coverage. These surveys should not be entrusted to non-geological curators, and here I particularly have in mind biological curators and Collections Research Units where they do not have the expertise or the specific task of producing a full report of the type outlined above.

The experience of such surveys by the Area Museum Council for the South West (AMCSW) and the Area Museum Service for South East England (AMSSEE) indicates that geologically inexperienced curators tend to vastly underestimate their collections' value, importance, potential use, and even number of specimens (by a factor of ten in some cases). Questionnaire-based surveys thus cannot show all the problems and potentials of geological collections; the real situation is even more catastrophic than the picture drawn by Doughty (1981).

Remedial action

The priorities for remedial action will depend on the relative composition, importance and condition of the collection. In most cases of any degree of neglect, both curation and conservation will be needed. There is little point in removing deteriorated material and conserving it at great cost if it is then replaced in the same dirty, damaging conditions, and if the removal has dissociated it from its documentation. Nor is there much point in curating a collection which is continuing to disintegrate. It cannot be too strongly emphasised that small museums must be given curatorial and conservatorial cover. Anyone in doubt of this should read a case study such as that of the Fraser Collection (Roden 1985).

I will not outline the techniques and proper standards of curation, remedial conservation and environmental control since they have been reviewed by Doughty (1984), Howie (1984) and Brunton et al.(1985). Every museum with a geological collection should have at least these three key references.

Both curator and conservator have a vital role in even the smallest museum. Geological conservators should not be confined to their laboratories, because conservation extends to every store and display. Cleaning of neglected collections, documentation and storage in an appropriate environment are all major elements of working on neglected collections, whether carried out by a curator as 'physical curation' or conservator as 'conservation'. Laboratory conservation work needs special equipment, chemicals and expertise, and even physical curation needs a full understanding of the basics of cleaning and repairing different geological materials, and properties of storage furniture and environment (e.g. Howie 1979; Brunton et al. 1985). Indeed, even 'cleaning' the dust off some neglected specimens needs quite sophisticated techniques, equipment, materials and skills. The organisation of any geological service must recognise that conservation is not just a laboratory job.

Commonly a collection will need a check and overhaul (or even complete renewal) of the documentation, sorting and storage. Conservation needs vary greatly according to the content of the collection and its previous storage. In many cases dirt is the major conservation problem in terms of the numbers of specimens affected, while a smaller proportion need repair or consolidation. Collections with high proportions of delicate but grossly soiled or broken specimens, subfossil bone, pyritiferous material and other environmentally sensitive material will present correspondingly high demands for specialist laboratory work in remedial conservation and repair.

The museum should be advised (and if need be supplied with copies) of the books and articles it needs to cover the history, curation and present usage of the collections. Very few small museums have access to the specialist geological literature.

Preventative action: environmental control

It is essential to minimise further deterioration, and the consequent need for remedial action, by instituting proper environmental control. In far too many museums the first step in 'environmental control' still remains the provision of proper storage furniture (such as card trays in well-made wooden cabinets), thus eliminating the two most common storage problems: dirt and mechanical abrasion. The relative size of the problem posed by humidity-sensitive material such as subfossil bone and pyritiferous material depends very much on the amount of material, and the particular behaviour of the museum's environment. Full airconditioning, or even humidity control alone, is too costly and technically difficult to monitor and maintain in many of the museums in question. A far more appropriate method is to enclose

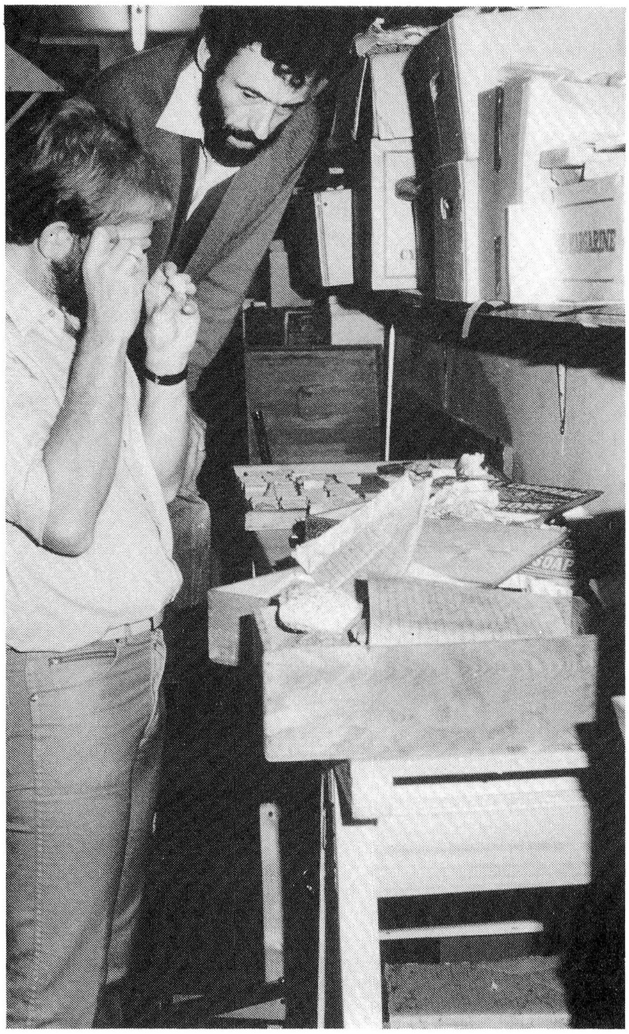

Fig.2. Charles Moore Collection, Taunton Museum, being examined by Charles Copp (City of Bristol Museum and Art Gallery) and Mark Davis (Taunton Museum).

specimens in their own microclimate, mainly by storing them in the same well-built wooden cabinets, which at least buffer short-term variation in humidity. Even then, it may be necessary to monitor the relative humidity inside the case and to alter it by the use of conditioned silica gel, itself needing periodic replacement. Here we come up against the general problem that small museums tend to lack the staff time, expertise and equipment to monitor their internal environment with any precision, let alone control it.

Displays and other activities

Display work is important; it is basic to the museum's public service and arouses public interest and support for collections which otherwise remain out of public sight and mind. It is a matter for joint work by the local curator and the geological specialist (Denford et al. 1984; Taylor 1986): typically, the specialist selects and prepares material for display and provides information, scripts and illustrations, while the local curator ideally has the energy, enthusiasm and local knowledge and contacts to establish the overall theme and level. Where possible, the local production of display materials (such as labels) ensures consistency and ease of replacement and alteration.

Acquisition, enquiry services, fieldwork, education and perhaps environmental recording are tasks best carried out by locally based specialist museum geologists: a point reflected by the GCG 'Thumbs Up' scheme's twofold division of geological museums and their services into those with and without specialist curators (Besterman 1985).

PROVISION OF CURATORIAL STAFF

The small museum without a geological curator or conservator can pursue several possible options when considering how best to fulfil the priorities set out earlier. The 'small museum' has been defined as having less than four professional curatorial staff, and many museums have one or none (Denford et al. 1984). The vast majority of District Council and independent local museums, such as Woodspring, Portland, Bridport and Lyme, are staffed on this sort of level and cannot possibly provide permanent specialist curatorial posts for each of the disciplines represented in the museum's displays and services. This situation will persist as long as the museums remain in their present form (i.e. they are not enlarged or combined into a county museum service) and each museum must therefore seek external help.

At the larger end of the scale many museums, such as Dorchester, Taunton and Exeter, have posts for 'natural sciences' curators. In many of these museums, the large natural history and geological collections have been lumped into large, unmanageable departments staffed by a single natural scientist who is often (at least in the south west) a biologist. Moreover, some counties and districts, such as Cheltenham and (until recently) Wiltshire, have always lacked professional natural sciences curators despite the presence of substantial collections. In many, perhaps most of these museums, the governing bodies and directors have never really appreciated the value and potential use of their own natural sciences collections, even when there is clearly no service being provided by any more 'local' museum. These circumstances arise through previous staffing and management policies not being fully informed; so a major aim of each survey report must be to make it clear what level and type of staffing is needed to safeguard the collections and, beyond that, to establish various levels of public service. I am speaking from direct experience of the deep ignorance or uncertainty of many museum staff about their geological collections, and their delighted goodwill and enthusiasm following enlightenment!

Clearly some collections - Bath being an excellent example - are so large, complex and important that they need at least one permanent specialist member of staff (and, if possible, two to provide continuous cover). How large is 'large'? Doughty (1981) suggested that collections with 10,000 specimens should have in-house staff. Even much smaller collections can justify the presence of full-time curators who will be supplementing collections management with display, education, field work, site recording and perhaps even pastoral services to other museums in the area.

Therefore, three main types of small and not-so-small museums need external curatorial cover:

small museums, with few or no permanent staff.
museums with 'natural sciences curator' posts presently held by biologists.
museums which should be establishing their own natural science or geological curatorial posts, but meanwhile need advice and guidance on recruitment, and temporary cover.

Each museum has a number of options depending on its nature and situation, even if it cannot obtain in-house staff either within the establishment or through incorporation within a county museum service with a specialist geologist: four options are considered below.

1. Curatorial cover by staff working in nearby museums

If a nearby museum has a specialist geologist it may be possible to obtain formal or informal advice and even help. For example, Bristol City Museum staff curated much of the Lyme Regis (Philpot) Museum's collection, and the Royal Albert Memorial Museum, Exeter, and provided facilities for temporary staff conserving Pleistocene mammal material belonging to the Torquay Natural History Society Museum.

There are, however, fundamental problems with this approach. Formal or even informal reallocation of curators' time is easily misinterpreted as indicating that looking after their own collections and services is less than a full-time job, Moreover, employing authorities are strongly territorial and unlikely to countenance 'their' geologist working in the service of another authority's ratepayers when they are after all increasingly and correctly publicly accountable to their own.

This option is probably more likely to be successful in the long term sense of continuing support when the client museum is within the geographical boundary of the larger museum's local authority. This highlights the importance of county museum services employing specialist geologists and giving assistance to independent museums, even when they have not been formally incorporated into the county museum service. Some district museums, particularly in rural districts, could also provide such help. This help might be free or paid for on an agency basis, possibly supported by the local Area Museum Council.

2. Consortia

Small museums can combine into a consortium to provide funds and a large enough collection in toto to recruit a specialist geologist. Area Museum Council advice and funds, even if only pump priming, are valuable. Wiltshire's museums are currently served by a natural sciences curator (on a three year contract) by AMCSW, Wiltshire County Museums Service and Devizes Museum (Wiltshire Archaeological and Natural History Society). Such consortia are sometimes slow to get off the ground and at least initially tend to run on a short-term basis since the contributors are naturally unlikely to commit themselves at once to funding a permanent post. However, a temporary post can be an important step in arousing sufficient interest and demand to justify a permanent service.

3. Area Museum Council geological services

Several AMCs have set up short-term experimental geological schemes to provide advice and help in curation and conservation (AMCSW, AMSSEE, West Midlands Area Museum Service and formerly East Midlands Area Museum Service). They differ in their operation, funding and practices, and their long-term funding and direction remain to be resolved. Major questions are:

- the overall balance of work between surveys and advice, curation and specialist conservation.

- the degree to which the services are subsidised, and therefore their availability to the small and poor museum (surveys are perhaps the most important service to provide free or at low cost).

- the degree to which larger museums attempt to rely on these services rather than provide their own specialist staff, thereby excluding smaller museums.

- the problem of providing conservation services when there are no trained conservators or properly equipped laboratories in provincial museums.

These questions are at present being discussed within the GCG and the results will, it is hoped, be presented as a set of Guidelines for AMC geological services. A consensus seems to be emerging that curatorial services should where possible be provided by locally based specialists at county or district level. The AMC has a most important role to play in carrying out the initial collection surveys, advising on staffing and recruitment, and perhaps even providing pump-priming. Wiltshire, Bath, Taunton and North Devon District have received this type of advice from the AMCSW. The AMC should also provide a specialist conservation service (see below) although again this must not allow larger museums to abdicate responsibility for their own collections. It will also have to provide curatorial services for those museums which slip through the net - such as it is - of county and district museum services. This means a long-term goal of a curatorial officer and a specialist conservator working for each AMC. Meanwhile the demand for services is far in excess of the present

Fig.3. Basement store, Swindon Museum, 1984.

provision, and the current schemes cannot be seen as final solutions. Yet even these schemes are a great improvement on the situation of five years ago (Doughty 1981) and have given us a mass of experience and data on which to build.

4. Workers who are not geological curators

The small museum can provide from its own resources a certain amount of work which need not be obtained from the above sources or other grant-awarding bodies. This is, however, dependent on advice from and liaison with a specialist geological curator. An unsupervised 'non-geologist' - whether curator or volunteer - cannot be expected to restore a neglected collection to order since curation and conservation, even at the most basic level, demands some familiarity with the material. For example, the decision to dust or wash a specimen depends in part on its susceptibility to moisture, and therefore on an accurate identification of the specimen and any consolidants. Nor is geological experience alone sufficient without an understanding of curation and conservation. For these reasons, unsupervised workers, including permanent staff, volunteers, and MSC personnel, should never work on a geological collection without advice from and continuing contact with a specialist museum geologist - if possible one who is experienced in helping smaller museums.

The non-specialist can do immensely valuable work in collaboration with a specialist. At its simplest this can mean saving the time and costs of the specialist by doing the more straightforward, routine work. To take the Lyme Regis (Philpot) Museum as an example, the 300-odd uncatalogued but labelled specimens could be catalogued by a non-geologist who had been instructed how to number specimens and record their data in the museum's relatively simple register, as long as a geologist checked over the work afterwards to weed out inadvertent errors. However, if the collection had been in such disorder that specimens needed matching to strayed labels, or if the documentation system was more complex, using MDA conventions and a thesaurus of terms, then the specialist would have had to do a larger proportion of the work. I have already noted the need for local curator and visiting specialist to collaborate in, for example, display work. A small museum will invariably need assistance from or, at the very least, close supervision by a geological curator to carry out major tasks, such as restoring order to its collection.

Some amateur and professional collectors have practical skills and equipment for preparing fossils. One museum, the Museum of Isle of Wight Geology, depends heavily upon volunteers to collect and prepare material. This source of help, whether free or paid, is not often exploited but can be very useful as long as the work is carried out to the appropriate standards.

CONTINUING MAINTENANCE OF THE COLLECTION

Once a collection is in order, the museum staff remain responsible for its general integrity and security (in the broadest sense), for example by controlling access to the specimens and maintaining the week-to-week changes in documentation arising from loans and the return of specimens from conservation. Indeed, there is little point in providing assistance to a museum whose staff are unwilling to take specific responsibility for this basic level of security.

The museum needs to maintain contact with a specialist curator and conservator and draw upon their advice and help if necessary. Doughty (in Morgan 1981) has warned that the very act of putting a collection into order increases its usage, and may lead to more damage and abuse than if the collection had never been disturbed. Other problems include the inevitable enquiries brought into the museum, and the general need to keep documentation up to date and check over the condition of the collection.

The question of what type of documentation system to use needs careful thought. I favour a simple 'number/label/register/file' system if it has to be maintained by a non-geologist. In my experience systems as sophisticated and complex as MDA cards or their equivalent are in practice unworkable unless they are filled in by specialist museum geologists. An idea, not implemented, from AMCSW experience is to prepare a standard set of geological specimen labels, including determinative slips, 'specimens removed' labels, labels indicating past conservation treatments, and so forth, together with a documentation guide containing just one set of the various options offered by the GCG's Guidelines. These labels, together with tags, could be printed to order for each client museum. Is there, indeed, a case for producing this as a joint GCG/AMC effort complete with a simplified version of the Guidelines, for the non-geologist (cf Locke 1986)?

UNIVERSITY, POLYTECHNIC AND COLLEGE COLLECTIONS

The museums of institutions of higher and furher education, such as universities, polytechnics and colleges, are typically staffed by 'curators' selected on the basis of academic excellence rather than curatorial skills, let alone any knowledge of preventative and remedial conservation. The need for these curators and technicians to engage in research means that many such collections (museums) are effectively staffed on the level of small museums with the equivalent of few or no staff, even though the staff list may indicate several curatorial and technical staff. Moreover, these staff will not always have specialist museum curatorial expertise. Such collections are by their nature heavily used (and often abused) and must be considered potential clients for external curatorial and conservatorial expertise and services.

SPECIALIST CONSERVATION

British museums have held outstanding collections of geological material for the last two centuries, and it has long been known that many types of geological material need conservation for repair, stabilisation, and preparation. Nevertheless, the absence of specialist conservation of geological material is a major failing of British museums. There is no career structure nor provision of adequately equipped laboratories, comparable to those in archaeological conservation, outside the British Museum (Natural History). There is little or no useful research under way into materials and techniques outside the BM(NH). This means that there is no supply of trained conservators to work in provincial museums and, as a result, geological curators are forced to carry out their own conservation work - even though they have to pick it up by reading, word of mouth and trial and error. The standards of conservation practice and methods are therefore very uneven, unsophisticated (indeed archaic) and static. There is a massive backlog of deteriorated material, much of it in museums with specialist curators.

For the small museum this means an almost complete lack of specialist geological conservation services, yet museum staff should never try to carry out any cleaning or repair work without consultation with a geological conservator, or a curator with the necessary experience and knowledge.

Most specialist curators (but by no means all) are able to handle the cleaning and minor repair of most specimens (although again the quality of their experience, knowledge and skills is unreliable). But the conservation of material needing special equipment and skills (for example, decayed pyritiferous material) must be carried out by trained staff in a properly equipped laboratory, on the grounds of health, safety, and the need to have the work done competently. The museum will be fortunate, however, if it can find a specialist laboratory to do this. Most 'labs' in provincial museums are in fact partly-equipped workrooms used part-time by the museum's own curator. Present AMC services have no permanent laboratories, and it can be argued that they cannot justify the cost of fitting out and equipping specialist laboratories until their projects last for more than the present two or three years, and the lab is occupied by a full-time specialist conservator. This would demand that AMCs either drop the survey, curation and documentation aspects of their services - which I have already argued are indispensable - or expand their services to include at least one curator and one conservator, and employ them both on a longer term basis. Nevertheless, at least two AMCs do presently attempt to provide a limited laboratory conservation service within the restrictions of equipment and skills. A major problem with further progress is that the normal AMC practice of placing conservators in existing museum facilities is frustrated by the lack of geological conservation laboratories.

Where only a few specimens need remedial conservation or preparation, a superficially attractive solution is for an archaeological conservator to carry out the work. For example, the consolidation of subfossil bone is a standard technique of archaeological conservation. Other types of specimen are treated by techniques and equipment superficially similar to those used in archaeology. As a result, some directors and curators (even geological curators) assume that if a conservator can treat a coin with air abrasive then he or she can also clean a dirty Chalk echinoid, or treat oxidised pyrite on an ammonite. However, the conservator is still unfamiliar with the nature of the object and the implications of treatments (for example, how much and what to remove, or the implications of removing labels or residual matrix, with their evidence for the age and source of the specimen). Such an attitude also impugns the training and professionalism of conservators, implying that it is satisfactory for them to carry out work without being trained for it; this is unethical, unfair to conservators and puts the specimens at risk. Thus archaeological conservation laboratories offer little or no scope for geological conservation, except when the staff are supervised and trained by a geological specialist. Moreover, most and probably all such laboratories are already overworked and it is difficult to justify diversion to a subject area for which the staff are not trained.

So the small museum requiring specialist conservation is now in an impossible position. It cannot remotely justify the cost of its own laboratory or staff specifically devoted to geological conservation. It must therefore wait on its larger neighbour museums, county services or AMCs to provide one. All it can, and must, do is to ask for such a service - if the need is not known to exist locally then it will never be satisfied.

The Group should consider it a major priority to press for the establishment of geological conservation services with properly trained staff and equipment, serving museums at all levels. Guidelines for these are in preparation.

TRANSFER OF COLLECTION

In some cases it is appropriate to transfer a collection to a museum which has the staff and facilities to care for it, e.g. when the original museum closes, when several collections in an area are amalgamated to justify a specialist curator (as has happened in some county museum services), or when the original museum decides to give up its collection on the grounds that it cannot be looked after. Transfer, however, is not necessarily an easy solution; it needs careful preparation and execution. The collection and its documentation will be in disorder and only a thorough search of the entire museum and its files - and sometimes the local library, which often started as part of the museum - will be needed to find all the specimens and details. Sometimes some curation and conservation work will be needed before the collection can safely be moved without mixing up specimens and data, or damaging fragile material. (These points also apply to internal moves of collections, which should only be done under specialist supervision.)

The most important material (typically the type and figured specimens) has sometimes been removed 'for safety' to a large institution, such as a university or the British Museum (Natural History). This is difficult to do without missing specimens, especially if they are not clearly labelled. It can also be argued that this process damages the integrity of a collection which may contain many other fine specimens from the same locality.

Museums should be aware of the implications of internal and external transfers of their collections.

CONCLUSIONS: THE PLIGHT OF SMALL MUSEUMS

Many museum services are too small to appoint their own specialist geologists even when they possess significant geological collections. This is a major problem for anyone concerned with the care and use of geological material. The 1974-1975 reorganisation of local government missed a major opportunity to alleviate this problem, and museums remain a non-statutory, concurrent function of districts and counties or Regions. The result is that many museums remain within the care of tiny district museum services, while there are many independent museums (as well as some district museums) in counties without county museum services. Their only formal assistance comes from those Area Museum Councils with geological schemes, and even these schemes are as yet only temporary, pending conclusions about their future aims and funding.

I am forced to agree with Doughty (1981) that the only systematic solution is to enact legislation which sets out basic standards for the curation and conservation of collections as an integral part of legal powers to run museums. 'There will be no significant improvement ... without legislation placing well-defined responsibilities on the authorities.. To do nothing would not maintain a status quo since the existing situation is one of rapid deterioration on a grand scale.' I am also compelled to agree that only a fully professional, statutory national museum service - or at least its equivalent in terms of systematic coverage - can halt and then reverse this decline.

The one bright spot is the initiative of those Area Museum Councils which have set up geological services. Their short-term, experimental nature, and their diversity, have already allowed us to accumulate a pool of experience of work and advice in many different situations. The services are, of course, on such a scale that they can do little more than inform, advise, catalyse and lubricate; something will only be done if the museum itself has the will or resources. Even this is a vast improvement and if AMCs can continue to provide such a service, to develop properly professional geological conservation services, and to provide miscellaneous curatorial and display services, then they will be doing as much as one can possibly expect given their limited scale and resources.

RECOMMENDATIONS

Like Doughty, I finish with a group of 'temporary expediencies awaiting a fully considered policy':

For the non-geological curator faced with a geological collection:

1. Obtain a survey and report by a specialist geologist and conservator, if possible through the local Area Museum Council, before taking any decision or action over the collection.

2. Where appropriate, review the need and availability of specialist staff, either in-house or externally through a consortium, pastoral museum service or Area Museum Council.

3. Arrange for an overhaul of the entire collection as needed, including curation, documentation, minor repair, storage and environmental control.

4. Identify material needing specialist laboratory conservation and if possible have this work done.

5. Thereafter maintain the collection in good order, allocating this specific duty to a staff member and obtaining continuing specialist advice.

6. During all work on the collection, ensure that everyone involved - governing body, management, professional and volunteer staff, and visitors - accept their responsibility to carry out as much work and no more than their expertise, skills and resources permit, and to remain under the supervision of specialist museum geologists.

7. If none of the specialist advice or help needed is forthcoming, make the needs known specifically and loudly to the local AMC and to neighbouring museums.

For the Geological Curators' Group:

8. Actively encourage small museums to ask for help, and direct their requests via the local AMC in the first instance.

9. Draw up guidelines to procedures, coverage, standards expected and reports for such surveys.

10. Consider establishing liaisons with AMCs to ensure that they are put in touch with the most suitably experienced and willing specialists, in cases where the AMCs do not have their own geological expertise; also consider the possible benefits of close liaison over other matters (e.g. 'rescue' efforts), to ensure the most acceptable and persuasive presentation to the museum governing body involved.

11. Actively encourage and advise AMCs, county museum services and similar bodies on pastoral care of museums in their areas (guidelines in preparation).

12. Consider how we can best make progress on the general problem of the lack of training, staff and facilities for fully professional geological specimen conservation (guidelines in preparation on establishing such services).

13. Bear in mind that the GCG is, by its very nature, biased towards a minority of museums with geological collections - those with specialist geological curators - and always remember the problems of museums without.

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Michael A. Taylor
Area Museum Council for the South West
City of Bristol Museum and Art Gallery
Queen's Road, Bristol BS8 1RL

(present address)
Leicestershire Museums Service
96 New Walk, Leicester LE1 6TD

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SOME ADHESIVES AND CONSOLIDANTS USED IN CONSERVATION

BY SUZANNE KEENE

INTRODUCTION

A vast range of adhesives and resins is available today, and the manufacturers of many of them make extravagant claims for their suitability in any application. There is a great deal of detailed information available on the chemical make-up of these substances, yet a look into any museum store will soon convince you that the wrong adhesive or consolidant is second only to poor environmental conditions in its destructive power. How do conservators, who often have no more than a basic grounding in chemistry, make sense of this jungle of opportunity and information? To be suitable for use in conservation, adhesives and consolidants should have characteristics not often found in commercially formulated adhesives. In practice, if these criteria are applied, the choice is drastically reduced.

REQUIREMENTS FOR ADHESIVES AND CONSOLIDANTS

Before discussing the required characteristics, I shall examine very briefly what conservation aims to do. Is it possible to generalise at all about this when such an enormous variety of objects is conserved?

From a Henry Moore sculpture to a fossil to an historic costume, everyone carrying out conservation work would probably have certain aims in common. First, they would want to preserve the real object, and neither to make a replica nor to carry out work which would alter its original state in such a way that its value as a piece of evidence is destroyed. Conservators would also be concerned to avoid using methods, techniques or materials which would damage the object. At least some would feel it important that their work should be removable or reversible at a future date, when perhaps someone realised that a mistake had been made in reconstruction, or that the materials used had aged in an unexpected way, or because fashions in restoration had changed. All would hope that the object looked good when finished, that the work was completed as quickly and conveniently as possible, and that the results lasted a long time without deteriorating.

So a list of what is required from resins to be used as adhesives or consolidants might include these features:

> harmless to the object: not giving off harmful vapours at any stage, nor likely to expand or contract during setting or ageing.
>
> strong enough to hold the join or to consolidate effectively; but weak enough that, if subjected to too much stress, the adhesive gives way before the object.
>
> chemically stable and not likely to break down, discolour, or otherwise deteriorate over time.
>
> chemically compatible with the object (e.g. some adhesives are not suitable for sticking glass or rubber, because of their chemical nature).
>
> have been in use over a long enough period for the effects of natural ageing to be assessed.

It is also desirable that the resin should be:

> easy to use (goes and stays where you want it, sets quickly or slowly as required, is the right consistency, is easy to clean up).
>
> non-toxic to the user.

THE NATURE OF ADHESIVES AND CONSOLIDANTS

I do not distinguish here between adhesives and consolidants, since the same material can often be used as either, depending on the viscosity of the solution made up. Most adhesives and consolidants consist of polymers - long chain molecules mixed up like spaghetti. Chemical bonds may form between adjacent chains (known as cross-linking), either intentionally or as a result of ageing or breakdown, in which case it is difficult or impossible to dissolve the polymer. Many of these materials are resins - glassy solids. Two main types of resin are used in conservation: ones which set due to the evaporation of the solvent (it is usually the intention that these will redissolve), and ones which set due to a chemical reaction (these can sometimes be broken down but they cannot be dissolved). Resins are supplied in various forms: as the pure substance in pearl or granule form, in solution in water or an organic solvent, as emulsions (droplets of resin/solvent suspended in a watery matrix), or as two- or three-part systems which set when mixed.

MANUFACTURERS' FORMULATIONS

Commercial manufacturers are usually (though not always) most concerned with the handling characteristics and short-term durability of their products. The pH of the resin and the emission of vapours harmful to objects are not always of importance to them. Resins in emulsion rather than in solution are

Table 1. Properties of resins which affect choice.

Properties of resins which affect choice

1, viscosity

2, Tg (glass transition temperature : a temperature range within which a resin changes from a hard glassy substance to a soft sticky one)

3, tack (= 'stickiness' when unset), slip (= ability of the adhesive to allow the position of parts to be adjusted), etc.

4, mechanical strength when set/cured

5, bond strength when set/cured

6, speed of setting/curing

7, flexibility/brittleness when set/cured

8, dimensional changes on setting/curing

9, reversibility (= ability of the resin to be re-dissolved at any time after setting)

10, resin/solvent ratio

11, chemical compatibility with materials to be adhered/consolidated

notorious for the latter problem: most emulsions are quite acid to prevent the components separating; for example, quite a strong smell of acetic acid can often be detected from a bottle of polyvinyl acetate emulsion; acetic acid causes corrosion in metals such as lead and copper. Rubber-based adhesives tend to give off sulphide fumes on setting and ageing, which affect silver. The emission of harmful vapours by adhesives is a very real problem, in both the storage and display of objects.

Another problem arises when manufacturers change the composition of their product. This is not usually publicised, and it can happen to resins supplied in the pure form, not just to made-up products. The composition of one of the most widely used resins, Paraloid B-72, was changed a few years ago; this was only detected because an analytical laboratory was carrying out some tests and found anomalous results between two batches of resin.

There are often quite a number of additives in commercially prepared resins. Up to 20% of the product may consist of different resins to modify the properties, plasticizers to prevent the resin becoming brittle, and so on; sometimes, although the main resin has quite good properties, the additives may cause the system to deteriorate on ageing. Plasticizers, for instance, often migrate out of the resin, either into the object or as vapour into the air. Manufacturers supply data sheets on request for all their products. These describe most of the main characteristics of the product, such pH, shelf life, setting time, viscosity and strength, and usually give the main chemical composition - but they do not usually give details of additives.

Therefore, on the whole it is sensible to be rather conservative in the choice of adhesive or consolidant. This is not to say that new products should never be used. One problem is the general dearth of conservation scientists; there may be many suitable resins not in use for conservation yet simply because they have not been sufficiently tested.

When these various factors are taken into account the list of resins to choose from is considerably shortened. Of course, it is often necessary to compromise - to decide that one factor is more important than another for a particular job. Sometimes it may be possible to use one resin as a 'separator' - for example, to coat a surface with a resin that will easily dissolve before using a much stronger but irreversible resin as a backing or support.

Although the additives in commercially prepared adhesives make their ageing characteristics suspect, they are often included to make the product easy to use, and some products are temptingly convenient. It is possible, however, for the conservator to modify the properties of pure resins; ingenious ways of making adhesives thicker, thinner, quicker or slower setting are quite often published in the conservation literature. The solvent in which the resin is dissolved, for example, can make a considerable difference to its handling properties. For Paraloid B-72, a higher resin/solvent ratio can be achieved using toluene or xylene than acetone, and the former evaporate more slowly, so that a matt finish is more easily obtained. Inert fillers such as phenolic microspheres or aerogel silica (both of which must be handled with care, with precautions against their inhalation) can be added as thickeners or fillers. The tack of pure resins can be improved by applying them, allowing them to dry, and then reactivating the surface to be joined by spraying with solvent. These are

Table 2. Some ways of modifying the properties of resins.

Modification	Properties affected
1, choice of solvent used to carry resin	- modifies viscosity, drying/setting time, sometimes gloss
2, chemical plasticizers (usually added by manufacturer)	- modify flexibility when set
3, thickening agents (inert fillers, aerogel silica, microballoons)	- modify handling characteristics, dimensional stability when setting, and final strength
4, fibres (glass fibre, carbon fibre, etc.)	- modify mechanical properties when set (rigidity and strength)

just some of the ways in which the properties of resins can be modified using known and tested materials.

EXAMPLES OF ADHESIVES AND CONSOLIDANTS USED IN CONSERVATION

The adhesives and consolidants more commonly used in archaeological conservation are the ones that are most familiar to me, but this includes quite a variety of resins because such a range of materials is involved. Those listed below have all been in use for a number of years and have been fairly thoroughly tested. Starting with the weakest and most easily reversible:

Cellulose derivatives: methyl cellulose, carboxymethyl cellulose, etc: Klucel, Tylose, etc. There are quite a few variations, having slightly different handling characteristics.
Supplied: powder, flakes, or granules.
Desirable properties: soluble in water and (some of them) in organic solvents, when they form a gel; form flexible or semi-flexible films on setting; seem to be stable and highly reversible.
Undesirable properties: adhesive power not great, too weak for many applications; fairly recently developed so relatively untested in use.
Uses: coming into wide use for consolidation and adhesion of organic materials (e.g. basketry, leather) and in paper conservation; can also be used to modify other adhesives and for the local application of solvents or reagents such as acids, which can be carried in the gel.

Cellulose nitrate: HMG, clear UHU etc.
Supplied: in tubes as resin in solvent system.
Desirable properties: easy and convenient to use, easily reversible, and not too strong; good joins if used for appropriate purpose.
Undesirable properties: not very stable, embrittles with age; in sheet form (e.g. movie film) may self-ignite.
Uses: widely used in archaeology and decorative arts conservtion for making small joins.

Waxes: natural (beeswax, carnauba wax, etc.) and synthetic (microcrystalline, polyethylene, etc. - a wide variety).
Supplied: as solids in pure form.
Desirable properties: easily removed, weak and flexible, so not likely to damage object.
Undesirable properties: soften in warm conditions and pick up dirt; deform.
Uses: worth considering as a filler for objects likely to expand and contract (e.g. wood, bone, ivory).

Polyethylene glycol waxes: not strictly speaking consolidants - water soluble waxes, ranging from liquid to lardy to hard brittle solid, depending on molecular weight.
Desirable properties: miscible in all proportions with water; are thought to form some sort of weak bond with deteriorated cellulose, preventing shrinkage on drying; seem to be reversible.
Undesirable properties: lower grades are hygroscopic, higher grades do not penetrate well due to size of molecules; no adhesive power.
Uses: high grades (up to 4000) used to replace water in waterlogged wood; low grades used as stabiliser/plasticiser in freeze drying; will not hold together fragmentary objects (adhesive must be used).

Polyvinyl acetate (PVA or PVAc): Mowilith, Vinamul. A different resin from polyvinyl alcohol and polyvinyl chloride, both of which have considerable disadvantages.
Supplied: as solid resin or made up as solution or as emulsion; available in various grades (depending on the size of the resin molecule and the additives) from hard and glassy to soft and flexible.
Desirable properties: stable, have been used for many years, easy to use, mostly easily reversible though emulsions are suspect; not too strong.
Undesirable properties: rather low Tg means they are likely to pick up dirt; emulsions are acid and may give off acid vapours.

Uses: useful consolidants, emulsions useful because of high resin/liquid ratio and where water miscibility is necessary; used in archaeology and decorative arts, also (flexible grades) in textile conservation; to a large extent superseded by acrylics.

Acrylics: Paraloid, Acryloid (resins); Primal, Texacryl (emulsions or dispersions). A class of resins with numerous members, often formulated as copolymers (a hybrid of two resins. e.g. methacrylate/acrylate, methyl methacrylate/methacrylate), each with rather different properties.
Supplied: as solid resins, in solution, or as water-miscible emulsions/ dispersions.
Properties: in general, acrylics are water-white clear resins; some hard and glassy, others soft and flexible; soluble in a variety of solvents; stability varies.
Paraloid B-72, in particular, is one of the most stable synthetic resins known: fairly strong, hard resin inclined to give glossy finish if solvent chosen unwisely; soluble in several solvents giving high resin/solvent ratio; easily reversible; penetrates well if used as consolidant; high Tg so no problems with surface softening.
Texacryl and Primal dispersions: very high resin/solvent ratio; penetrate well due to extremely small size of emulsion droplets; varying flexibility of set film; reversibility not as good as Paraloid B-72.
Uses: Paraloid B-72 is possibly the most widely used resin in conservation at present, its applications ranging from picture varnishes to consolidants for stone, wall paintings, mortar and corroded metal.

Polyesters: made by a large number of manufacturers; not all identical.
Supplied: as two- or three-part kits; resin needs hardener and/or catalyst to set.
Desirable properties: good long-term stability; hard and more or less glass-clear; appearance, strength and handling characteristics can be modified by the addition of fillers (matting or bulking agents) and fibres (glass fibre).
Undesirable properties: surface may remain sticky after setting; can only be reversed by using 'resin disintegrators' or methylene chloride (paint strippers), in which case swells and breaks down, does not dissolve.
Uses: most commonly used in casting (replicas, mounts, etc.) but some brands sold as adhesives for stone, tile, etc. (do not penetrate and stain), and even as consolidants, for paint or stone.

Epoxies: Araldite, Ablebond, Devcon etc. Another large family of resins; all two- or three-part systems in which the resin sets on mixing.
Desirable properties: very strong, the least likely resins to expand or contract on setting; stable and resistant to chemicals, etc.; very wide range of handling and physical characteristics (e.g. fast/slow setting, water white clear/opaque, very liquid for casting/paste like for adhesion); very good adhesion.
Undesirable properties: too strong for many applications; essentially irreversible ('resin disintegrators' will cause swelling and disintegration); certainly irreversible if used on porous material.
Uses: where very stong joins are required; in some glass repair where refractive index is close to that of the object; where strong, rigid, dimensionally stable resin is needed; for mounts or supports (object can be coated with separating resin if necessary); even available as foaming system, good for supports and mounts.

Silanes: these products are described by Susan Bradley (herein).

Note: cyanoacrylates ('super glues') generally fail in the short term and, in archaeological conservation, are mostly used only for temporary repairs.

CONCLUSION

In this brief review it has only been possible to explore the edges of this vast and complex jungle and note some of the paths into it. My aim has been to draw attention to the most important considerations for the practical conservator. Fortunately there are some excellent publications which give a useful background to the science of adhesion: for example,the Crafts Council series, Science for conservators (especially Book 3 on adhesives and coatings) and two collections of conference papers, Resins in Conservation (Tate et al. 1982) (which includes an excellent review by Susan Bradley of tests for resins, describing the factors to test for and how this can be undertaken) and Adhesives and Consolidants (Brommelle 1984) (which has useful appendices of adhesive terminology and of specific materials).

A NOTE ON HEALTH AND SAFETY

Many people are affected by exposure to resins and solvents: dermatitis and allergic reactions may occur when using some of them. It is most important always to use them in a place with good ventilation, and fume extraction is essential for many. Good hygiene, a proper means of cleaning yourself and the workplace, and of disposing of unused products and waste are essential. Safety data sheets for resins should always be obtained from the manufacturers or suppliers, who are obliged to supply them on request. See Howie (herein).

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Suzanne Keene
The Museum of London
London Wall
London EC2Y 5HN

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AN INTRODUCTION TO THE USE OF SILANES IN STONE CONSERVATION

BY SUSAN M. BRADLEY

INTRODUCTION

Silanes have been used in the conservation of stone for about twenty years (Lewin 1966, 1972; Hemple and Moncrieff, 1972, 1976; Bosch 1972; Rossi-Manerasi 1976; Weber 1976; Anon 1980; Grissom 1981). Their use is regarded as controversial by some of those who work in this area of conservation because they are irreversible. The main reason, however, why silanes are so widely used is their versatility. The surface of very deteriorated stone can be supported with facing-up tissue paper prior to consolidation and the consolidant solution applied through the tissue. This allows powdery surfaces and flakes to be secured without loss. Desalination and cleaning can be carried out following consolidation without damage to the surface of the stone (Hanna 1984). These techniques can be applied to both deteriorating stone specimens and mineralised fossil remains. An understanding of the chemistry and properties of silanes will allow them to be used in appropriate circumstances and avoid the type of disaster which can occur if irreversible materials are used inappropriately.

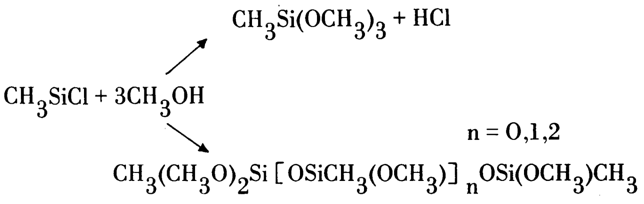
THE CHEMISTRY OF SILANES USED IN STONE CONSERVATION

The silanes used in stone conservation are alkoxy silanes and silicone esters (Table 1). They are all derivatives of silane, SiH_4, where one or more of the Si-H bonds have been replaced by Si-O bonds (Eaborn 1960). Alkoxy silanes polymerise to form polymers with water repellent properties, i.e. although water droplets cannot penetrate stone treated with these materials, water vapour still can. Silicone esters polymerise to form polymers based on a silica lattice which are not water repellent.

Other silanes can be used in stone consolidation, but the presence of larger groups such as butyl or phenyl can inhibit polymerisation due to steric effects. However, dibutyl dibutoxysilane has been used successfully for stone consolidation in Czechoslovakia, (Sameck 1985).

Manufacture

Alkoxy silanes are made by the reaction of an organosilicon chloride with an alcohol. For example, for the production of methyltrimethoxysilane (MTMOS) which is commonly used as a stone consolidant:



$$CH_3SiCl + 3CH_3OH \rightarrow CH_3Si(OCH_3)_3 + HCl$$

$$CH_3SiCl + 3CH_3OH \rightarrow CH_3(CH_3O)_2Si\,[OSiCH_3(OCH_3)]_n OSi(OCH_3)CH_3 \qquad n = 0,1,2$$

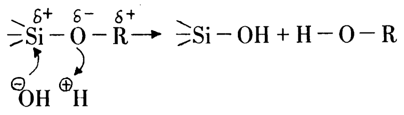
The second product is in fact the major one of this reaction. To prevent acid hydrolysis of the MTMOS or the organosilicon chloride, the hydrochloric acid must be removed from the reaction mixture either by using an acid acceptor or by adding a high boiling hydrocarbon to limit the solubility of the acid. If hydrolysis is not prevented the reactants and products will polymerise in the reaction vessel.

Table 1. Silanes commonly used for stone conservation in the UK.

Silane Type	Chemical Constituent	Commercial Product
Silicone ester	Tetraethoxysilane(TEOS): $Si(OC_2H_5)_4$	Stone Strengthener OH - Wacker Chemie GMBH
Alkoxy Silane	Methyltrimethoxysilane(MTMOS): $CH_3Si(OCH_3)_3$	T40140, Dow-Corning Ltd. Dynasylan MTMS - Dynamit Nobel (UK) Ltd. Brethane, Colebrand Limited
	Ethyltriethoxysilane(ETEOS): $C_2H_5Si(OC_2H_5)_3$	Stone Strengthener H - Wacker Chemie GMBH

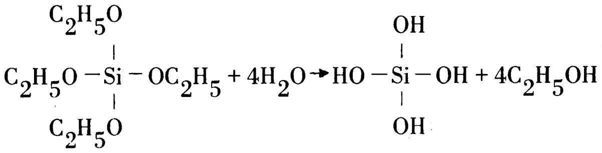
Curing

The first step in the curing mechanism of alkoxy silanes and silicone esters is hydrolysis; this occurs under acid or alkaline conditions by nucleophilic attack (i.e. attack by a negatively charged species on one which is more positively charged):

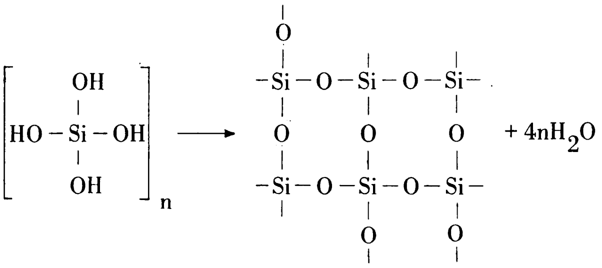


$$\geq\overset{\delta+}{Si}-\overset{\delta-}{O}-\overset{\delta+}{R} \rightarrow \geq Si-OH+H-O-R \qquad \overset{\ominus}{O}H \; \overset{\oplus}{H}$$

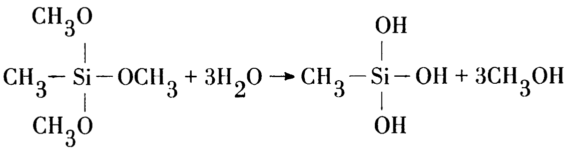
The reaction continues via a condensation reaction (i.e. one in which water is produced to form a three dimensional polymer lattice *in situ*). For a silicone ester such as tetraethoxysilane (TEOS), the polymer produced has a silica lattice structure:



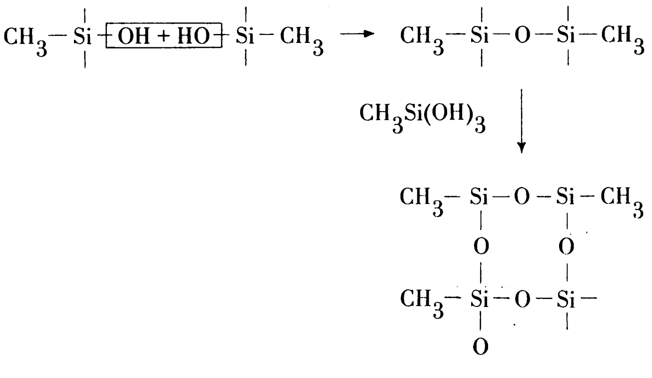
$$C_2H_5O-\underset{C_2H_5O}{\overset{C_2H_5O}{Si}}-OC_2H_5+4H_2O \rightarrow HO-\underset{OH}{\overset{OH}{Si}}-OH+4C_2H_5OH$$



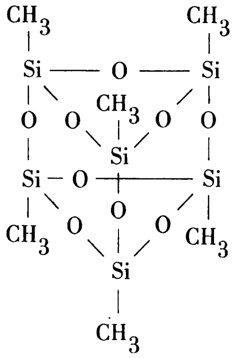
For MTMOS the equivalent reaction is:



$$CH_3-\underset{CH_3O}{\overset{CH_3O}{Si}}-OCH_3+3H_2O \rightarrow CH_3-\underset{OH}{\overset{OH}{Si}}-OH+3CH_3OH$$

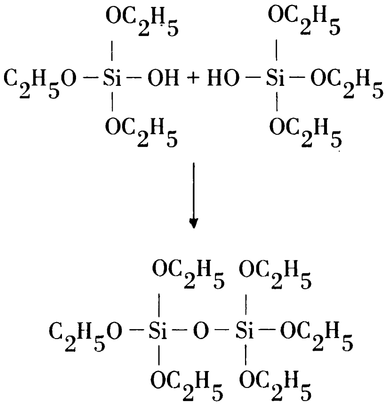


A modified silica lattice, or an oligomer such as that shown below may be formed.



The presence of the alkyl groups (in this case methyl - CH_3) in the polymer imparts water repellency. If the methyl groups are replaced by larger groups (such as ethyl - C_2H_5) the degree of water repellency decreases. The water repellent effect is therefore dependent on the alkyl group attached to silicon in the polymer; butyl groups impart very little water repellency.

These reactions may not happen exactly as shown above if the condensation reaction occurs before hydrolysis is complete. If two molecules, each with one hydrolysed group, come together, then polymers can form step by step:



$$C_2H_5O-\underset{OC_2H_5}{\overset{OC_2H_5}{Si}}-OH+HO-\underset{OC_2H_5}{\overset{OC_2H_5}{Si}}-OC_2H_5$$

$$\downarrow$$

$$C_2H_5O-\underset{OC_2H_5}{\overset{OC_2H_5}{Si}}-O-\underset{OC_2H_5}{\overset{OC_2H_5}{Si}}-OC_2H_5$$

The mechanism of polymerisation is being studied at New York University (Lewin et al. 1985); here the tri and tetra silanols have not been observed, suggesting that condensation does indeed occur before hydrolysis is complete. As polymerisation is initiated by hydrolysis, the amount of moisture present will affect the rate of reaction, as will the addition of a catalyst (e.g. an acid, alkali or metal salt such as a titinate). The three components must be dissolved in a suitable solvent such as ethanol since water and silane are not miscible.

Methyltrimethoxysilane (MTMOS)

MTMOS is supplied as a pure monomer. It will polymerise slowly without the addition of a catalyst or water, but can be used with a catalyst. If MTMOS is weighed into sample tubes and allowed to cure under ambient conditions, the effect of relative humidity and temperature on curing can be observed. Charola et al. (1984) have shown that at 30-50% relative humidity a coherent polymer is formed which does not shrink excessively, but at higher values polymerisation occurs quickly, causing stress which cracks the polymer. Unreacted methoxy (OCH_3) and silanol (-Si-OH) groups remain in the polymer following curing, and their presence can be explained by considering the interface between MTMOS in the sample tube and moisture in the air,i.e. the liquid meniscus. Some moisture vapour must penetrate the meniscus but an intimate mixing of MTMOS and moisture vapour throughout the solution is unlikely. Hence,despite water being produced by the condensation reaction,there is probably not enough in the bulk solution to ensure complete reaction. This situation also exists in porous stone where, in the case of stone objects being consolidated at the British Museum, MTMOS is dispersed in pores of less than 150 µm diameter. Even though there is some bound water in stone, it is not enough to ensure complete polymerisation. The effect of the residual groups has not been evaluated, although no adverse effects have been noted through the natural ageing of objects stored in museums. Complete polymerisation is said to occur at 100% humidity (Charola et al. 1984).

At ambient relative humidity levels loss of MTMOS occurs due to evaporation. When uncatalysed MTMOS is allowed to cure in sample tubes exposed to the atmosphere, weight losses of up to 99% occurs (Bradley 1985). Such weight losses are considerably reduced when MTMOS is applied to stone samples.

When MTMOS is used with a catalyst,the polymer yield approaches the theoretical maximum of 49%. So why use MTMOS without a catalyst? The answer is that MTMOS starts to gel very rapidly if used with the existing catalysts, and does not penetrate deeply into the stone; this results in the formation of a hard glassy layer of polymer on the surface of the stone which is aesthetically obtrusive. MTMOS on its own is a poor consolidant; for instance, if it is mixed with stone powder to form a tablet, coherency is introduced but the tablet is weak and easily broken. As a result, MTMOS is usually used with 5-20% by volume of Raccanello Acrylic Silane (a mixture of two acrylic resins and a silicone polymer dissolved in a mixture of trichloroethane and toluene) or 2-5% of Paraloid B72 (an ethylmethacrylate copolymer) dissolved in it. Scanning electron microscope examination of cross sections through oolitic limestones treated with such a system show that the acrylic resin forms a layer towards the outer edge of the sample. Penetration with MTMOS appears to be deep since a high degree of water repellency is achieved throughout the samples, with the silane acting mainly as a deep penetrating solvent. Similar results may be obtained by using 111 trichloroethane as a solvent for the acrylic resin as it is probable that the resin produces the outstanding consolidation observed when this system is used on both limestone and sandstone.

Another material based on MTMOS and designed specifically for stone consolidation is Brethane (Price 1981). Brethane was developed at the Building Research Establishment as a consolidant for buildings; it is a three pack system (MTMOS, a catalyst and solvents) and cures rapidly. Old stone buildings often have very thick walls and their penetration during treatment requires a large amount of consolidant. In practice total penetration is not necessary but enough consolidant must be taken up to ensure that at least the outer 10cm is consolidated. Brethane starts to gel before too deep a penetration has occurred, thereby securing the deteriorated outer layers of stone. The application of an uncatalysed silane to a wall would result in unchecked penetration and it would be difficult to obtain good consolidation at the surface of the stone in these circumstances. Brethane can be used on small specimens but its rapid curing means that the working time available to the conservator is short. Generally a long working time is needed to obtain the best results when treating a complex object.

Ethyltriethoxysilane (ETEOS)

Although ETEOS monomer could be used for stone consolidation, it is not exploited in this manner. ETEOS is the main constituent of Wacker Stone Strengthener H, a one pack stone consolidant containing ETEOS, a catalyst and solvents. Curing starts when the product is applied to a stone surface; it penetrates deeply, is a good consolidant and is easy to apply (Weber 1976). The polymer produced is of the modified silica lattice type which introduces water repellency. The final hardness of the stone surface is not as great as that achieved when acrylic resins in MTMOS are used, but if a harder finish is required acrylic resin can be dissolved in the material for a final application.

Tetraethoxysilane (TEOS)

TEOS has been used for various purposes in conservation, including the treatment of waterlogged wood. Again, although the monomer alone could be used for stone conservation, the problem with silanes containing ethoxy groups is that the curing reaction proceeds more slowly than that for MTMOS, so their use in an uncatalysed form is not favoured. TEOS is the main component in Wacker Stone Strengthener OH, a one pack stone consolidant containing TEOS, a catalyst and solvents. The polymer produced is of the silica lattice type and does not impart water repellency. Stone Strengthener OH penetrates deeply and gives good consolidation but, like Stone Strengthener H, the surface finish is not as hard as that for MTMOS containing

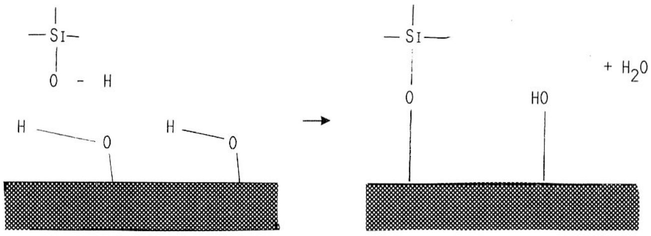


Fig.1. Silane based consolidants bond to hydroxyl groups present on the surface of many materials.

acrylic resin. If a harder finish is required acrylic resin can be dissolved in the material for a final application.

PROPERTIES

The silane based consolidants described above have several properties which are exploited when they are used as stone consolidants. Probably the most important is that they bond to hydroxyl groups; these are present on the surface of many materials (Fig.1) but are particularly associated with those containing silicon and aluminium i.e. silica (quartz and sand) and clays (Anon 1983; Lewin et al. 1985). Silanes therefore bond to the surface of pores in a siliceous stone, creating a strong network. Silanes have also been used with considerable success to treat deteriorated limestone sculptures. Although some hydroxyl groups adhere to the alkaline surface of calcite, there are generally considered to be fewer sites for silanes to react with than is the case for sandstone, and poorer consolidation would be the expected result. In practice good consolidation has been obtained, and natural weathering tests carried out at the Victoria and Albert Museum and the Building Research Establishment have shown that limestones impregnated with silanes are more durable than unimpregnated controls (Hempal et al. 1976; Price 1975, 1981). The limestone sculptures treated with silanes at the British Museum prove to contain 5-21% clay and/or quartz, while in SEM examination the silane is observed to prefer the clay or quartz matrix to the surface of calcite crystals.

All silanes (except uncatalysed MTMOS) form hard, strong tablets when mixed with powdered stone, and increase the compression strength of treated stone. They also increase the resistance of stone to chemical attack: during immersion in 20% HCl for 24 hours, the loss in weight of treated specimens was minimal compared to the 70% lost by an untreated control; the consolidated specimens retained their structure whereas the control disintegrated.

The treatment of stone with alkoxy silanes results in the formation of a water repellent polymer in the stone. This polymer inhibits only the passage of liquid water into the stone, not the passage of moisture vapour. While it is not strictly necessary to employ a water repellent silane such as MTMOS on specimens displayed or stored indoors, it has been applied extensively to stone objects in museums simply because it is an excellent consolidant when used in conjunction with acrylic resins.

Because the so called water repellent silanes do not prevent the migration of water vapour into stone, after treatment with MTMOS and ETEOS soluble salts can still be dissolved or move about in specimens when changes in the relative humidy of the surroundings occur. The polymers formed by silicone esters allow both moisture and water vapour to penetrate stone, so to prevent damage which would be caused by salt movements, desalination should be carried out. Salts can be removed from treated stone using a poultice technique. Suitable poulticing materials are sepiolite (a natural magnesium silicate) or pulped blotting paper. Several successive poultices should be applied to salt contaminated specimens, each being tested for the presence of soluble salts when it is removed. Desalination should continue until the poultice is salt free. This treatment does not remove all the soluble salts from the stone but it can reduce the salt content by as much as 80%.

If specimens need cleaning this can also be carried out following consolidation by using a suitable solvent: distilled water, a dilute solution of 'Symperonic N' in distilled water, acetone and yellow label 'Nitromors' have all been used for cleaning sculpture. Cleaning is normally carried out using cotton wool swabs wetted with the solution. Detergent or 'Nitromors' residues are removed with distilled water and acetone respectively. Particularly stubborn dirt may be softened by applying a poultice of the type used for desalination. Consolidation with silanes does not prevent the reaction of atmospheric pollutants at the surface of the stone, as an impermeable layer is not formed; it should, however, reduce reaction rates since they involve water and the contact between the surface and water is reduced.

The colour of stone can darken following treatment with silanes. The extent of darkening will depend on the type of stone being treated. Sometimes a patchy effect occurs on the surface of a treated stone if silane systems containing acrylic resins are used. Before embarking on treatment, the effect of the material on the stone should be investigated on an inconspicuous part of the object. Ageing tests carried out by the author in 1983 (unpublished) showed that both stone samples consolidated with silanes and the polymers produced by silanes are unaffected by heat, while light causes some lightening of treated stone.

PRACTICAL APPLICATION

Silanes are hazardous materials and should only be used if the health and safety advice given below and by Howie (herein) can be adhered to.

As with all deep penetrating consolidants, silanes can only be used successfully on

A

B

Fig.2. Egyptian limestone block statue (British Museum EA 172). A, before conservation; B, after conservation.

porous stone. Silane is applied to the object using a dropping pipette (when powder on the surface of the object will not be disturbed) or a brush, continuing until it no longer penetrates the stone. After a short period the application may be resumed and the treatment continued until the stone accepts no more consolidant. Any pools of silane which build up on the surface must be removed as they produce a glassy appearance if allowed to cure.

If the surface of an object is very badly deteriorated, facing up tissue may be applied using polyvinyl alcohol as an adhesive. The consolidant can then be applied through the tissue. The tissue can be removed after curing by using water or acetone as a solvent. Curing of the consolidant takes up to six weeks. This period should elapse before any other treatments, such as desalination or cleaning, are carried out, after which a further application of consolidant should be made. Normally very little extra consolidant is taken up but the application ensures that freshly exposed surfaces and pores are treated (Hanna 1984).

The techniques outlined above have been described more fully by Hanna (1984) and were used in the conservation of the Egyptian limestone block statue shown in Fig.2. Its surface had suffered considerable damage from flaking and powdering and was also very dirty. In order to consolidate the sculpture the badly damaged areas were first secured with tissue paper adhered with polyvinyl alcohol; blisters were supported with a mixture of acrylic resin, silane and stone powder. The sculpture was then consolidated with MTMOS containing 5-20% of 'Raccanello' acrylic silane. After consolidation, surface cleaning and desalination were carried out using poultices prepared from sepiolite and distilled water. Fig.2B shows the sculpture after conservation.

CONCLUSIONS

Highly deteriorated porous specimens in geological collections could be consolidated using silanes. The advantage of treatment with these materials is that desalination, cleaning and repair can be carried out after consolidation, thus minimising damage to the friable surface of the specimen. The technique has ben applied with considerable success to limestone and sandstone sculptures in the British Museum collections. The addition of silanes to the list of consolidants used in geological conservation would increase the range of work which could be carried out. However, as silanes form an irreversible polymer in the stone they should not be thought of as consolidants for routine use but only as 'last resort' treatments for very deteriorated samples. The health and safety aspects associated with the use of silanes will also tend to restrict their use to well equipped laboratories.

HEALTH AND SAFETY

Silanes are skin and eye irritants and can affect breathing. Full face masks with the correct organic filter, or air fed masks, should be worn by the user; other workers should be excluded from the consolidation area or provided with the same type of mask.

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Susan M. Bradley
Department of Conservation
British Museum
Great Russell Street
London WC1B 3DG

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APPENDIX

Suppliers

Methyltrimethoxysilane (MTMOS):
Dow-Corning Ltd., Bridge House, Reading, UK; Dynamit Nobel (UK) Ltd., Gateway House, 302-308 High Street, Slough SL1 1MF, UK.

Brethane: Colebrand Ltd., Colebrand House, 20 Warwick Street, Regent Street, London W1R 6BE, UK.

Wacker Stone Strengtheners H and OH:
Wacker Chemie GMBH, Postfach, D-8000 Munich 22, West Germany [UK suppliers: Bio-Kil Laboratories Ltd., Brickyard Industrial Estate, New Road, Gillingham, Dorset SP8 4BR, UK.

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A VIEW OF ETHICAL CONSERVATION AND MINERAL SPECIMEN FALSIFICATION

BY ROBERT WALLER

INTRODUCTION

The purposes of this paper are: 1, to show that many of the conservation treatments applied to mineral specimens differ little from those employed to produce mineral fakes; and 2, to discuss the implications of this fact for conservators and curators who wish to ensure that all mineral specimen conservation is ethical conservation, not mineral specimen falsification. Certainly there will be conservators and curators who disagree with the ideas presented here, and I hope that they will present their arguments in future papers, to encourage an open debate. For background and for specific examples of mineral fakes this paper draws heavily on Dunn et al.(1981) and Nassau (1984), which those interested in a more thorough treatment of fakes and the methods of their production and detection should consult.

There exists a very active market for collectable mineral specimens. While it is difficult to put a dollar figure on this, the North American market (excluding gemstones) would certainly be in the hundreds of millions of dollars per year. Depending on the definition of 'falsification' adopted, 10-50% of this figure will be the result of falsification or unethical enhancement of specimens - itself therefore a multi-million dollar industry. Why this should be the case is not hard to understand - great gains in specimen value can be achieved with little cost in time and materials, and in some cases with little skill. A quick dip in concentrated hydrochloric acid, which is inexpensive and readily available, can change a virtually unsaleable calcite crystal into one that might easily be sold for ten or twenty dollars.

What does this have to do with ethical conservation? Surely conservators would never dream of dipping a calcite into concentrated hydrochloric acid to improve its appearance, would they? Hopefully not, but any chemical treatment - even just rinsing in deionized water - will have some effect on the surface of most minerals. What constitutes an acceptable degree of alteration, and consequently an acceptable conservation treatment, must be an arbitrary decision.

HISTORICAL CONSIDERATIONS

The earliest literature reference to specimen falsification is in a codex called Papyrus Holmiensis. This fourteen page papyrus is a third or fourth century Greek transcription of part of a multivolume work by an Egyptian chemist, Bolus of Mendes. The original work dates back to about 200 BC (Nassau and Hanson 1985). The Papyrus Holmiensis contains seventy recipes dealing with the falsification of stones, including one entitled 'Cleaning of Crystal' (Nassau 1984, p.10): 'Cleaning of smoky crystal. Put it into a willow basket, place the basket into the cauldron of the baths and leave the crystal there seven days. Then, when it is clean, take and mix warm lime with vinegar. Place the stone in this and let it be mordanted. Finally: colour it as you wish.' Things have not changed very much in the last two millenia.

In his Natural History, Pliny (c. 70AD) states: 'it is possible, they say, to heighten the brilliancy of dull stones, by steeping them for fourteen days in vinegar, this adventitious lustre being retained by them as many months', and that 'all precious stones in general are improved in brilliancy by being boiled in honey.' Other references to mineral falsification dealing primarily with gemstone enhancement, but having some relevance to specimen falsification, have been discussed by Nassau (1984). Dunn et al. (1981) reviewed specimen falsification from the 1890s to 1976.

One of the oldest known faked mineral specimens forms part of a statuette entitled 'Moor with tray of emeralds' (Dunn et al. 1981). It was constructed around 1724 by Dinglinger and Permoser. Many of the sixteen emerald crystals carried by the figurine were implanted into crude holes carved in a matrix which is older than the artwork itself, possibly dating from the early sixteenth century.

Several examples of specimen falsification are known from the seventeenth to the nineteenth centuries and, unfortunately, fakes have become increasingly common during the last hundred years.

TYPES OF FALSIFICATION

There are eight general types of mineral specimen falsification:

1, mechanical fabrication
2, chemical synthesis
3, alteration of composition
4, alteration of form
5, alteration of colour
6, alteration of lustre
7, alteration of clarity
8, misrepresentation of locality

Provided conservators are careful to maintain documentation with specimens and do not complete 'gaps' in specimen labels, then they are not apt to be implicated in no.8. It is possible, however, that even the best

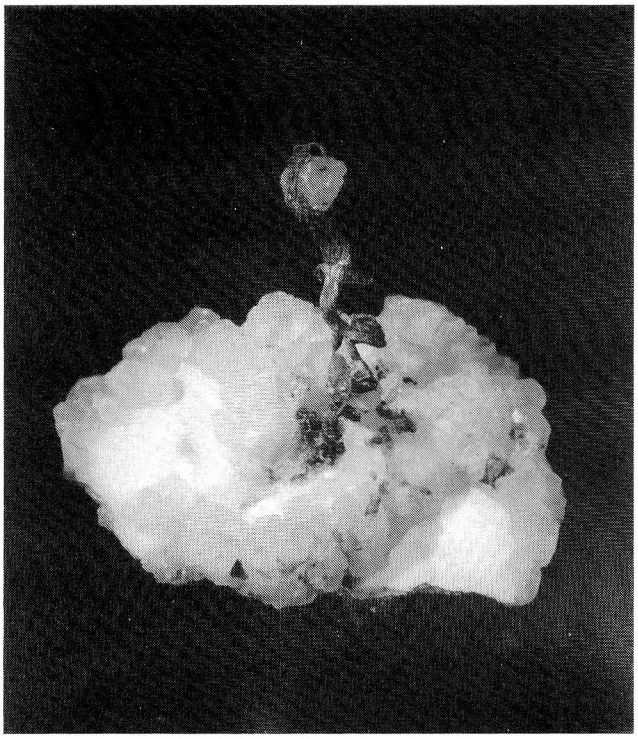

Fig.1. Silver. NMNS #32030, from Beaverdell, British Columbia. This specimen could be a fake involving attachment of unrelated parts, or it could be the result of a very poorly conceived and executed conservation treatment. Width as viewed, 5cm.

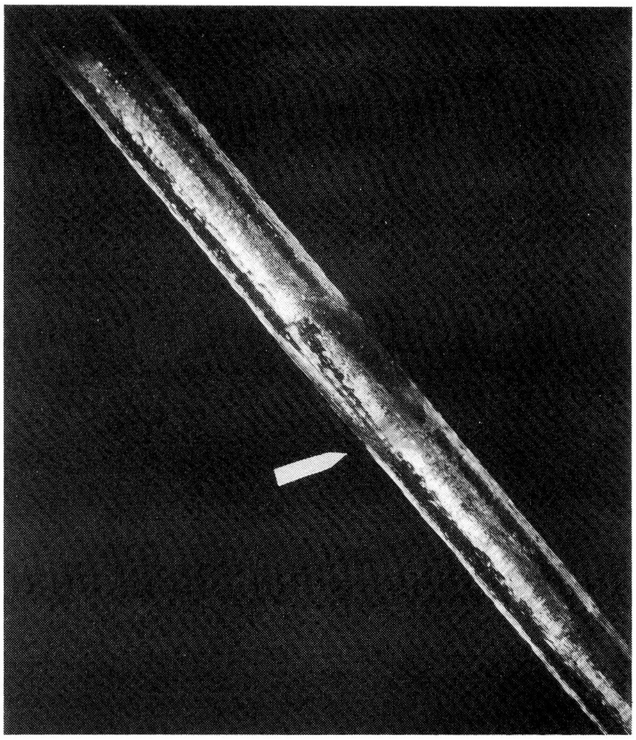

Fig.2. Beryl (var. aquamarine). NMNS #43084, from Minas Gerais, Brazil. The arrow indicates the location of a repair along a break nearly perpendicular to the length. Width as viewed, 1cm.

intentioned conservator could be accused of any or all of nos.1-7.

1. Mechanical fabrication

Mechanical fabrication is without doubt the most common form of falsification. The emerald specimen discussed above was an example of fabrication.

Fig. 1 shows a fabricated specimen of wire silver on calcite. At first glance it might appear to be the small calcite crystal set into the silver wires that is the falsified part of the specimen. In fact that is not the constructed part of the specimen; the silver actually penetrates into the calcite crystal. Examination under ultra violet light shows clearly that all of the silver has been attached to the matrix. On close examination the calcite crystals in the attached part exhibit etching of the crystal faces unlike the rest of the matrix, hence this may be a faked specimen. On the other hand, the etching may be a result of a chemical treatment of the silver while it was detached from the matrix, in which case it may just be an extremely poorly repaired specimen. There is sometimes a grey area between repair and falsification.

Fig.2 shows an aquamarine crystal that has been repaired with an epoxy resin selected to match the refractive index of the crystal as closely as possible, so as to render the repair unnoticeable. Some mineralogy curators and collectors would consider this unethical falsification, although I suspect the majority would not. Dunn et al. (1981, p.208) illustrated a tourmaline crystal composed entirely of plastic. I suspect virtually all mineralogy curators and collectors would consider that to be outright unethical falsification. Somewhere between the aquamarine crystal, which is less than one part per thousand plastic, and the tourmaline, which is 100% plastic, an arbitrary division between ethical conservation and unethical falsification must be drawn.

2. Chemical synthesis

Synthetic bismuth crystals (Fig.3) are among the most attractive of synthetic crystals. Fortunately, they have been sold as synthetics for so long that all but the most inexperienced collector would not be fooled into thinking such a crystal attached to matrix was a natural specimen. Yet many other highly soluble minerals that occur naturally in a variety of forms are frequently grown synthetically, then sold as natural specimens.

How could a conservator be accused of falsification through synthesis? Any time that chemical treatment of a specimen is undertaken there will inevitably be at least traces of the chemical left on and/or within the specimen. Hence, any chemical treatment will result in the addition of synthetic chemicals to the specimen. Often these chemicals have naturally occurring mineral

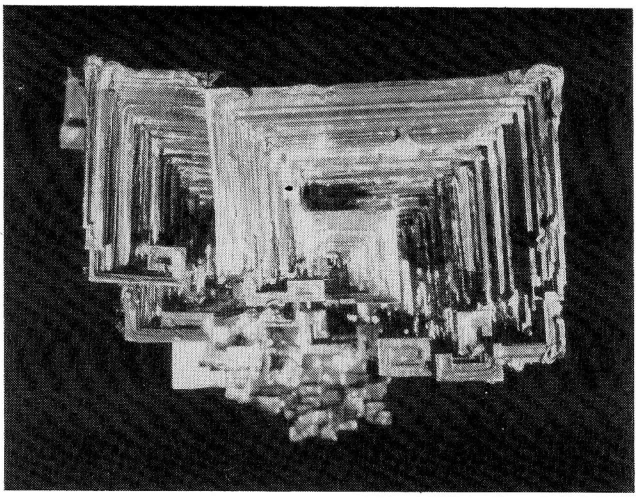

Fig.3. Bismuth (synthetic). NMNS #46059. Width as viewed, 5cm.

equivalents, in which case a mineral species has been added to the specimen. Where the chemical deposited has no known natural equivalent, the result is potentially even more frightening, since there is then a possibility that the chemical might be thought of and described as a new, naturally occurring mineral.

As well as this sort of 'accidental' addition of chemicals to specimens, there are cases where intentional additions are made. The treatment of severely oxidised pyritic specimens falls into this category. Complete removal or neutralization of any free sulphuric acid is essential for the preservation of specimens suffering from sulphide oxidation. As complete removal is often not possible, the acid must be neutralized <u>in situ</u>, which generates new chemicals or mineral species within the specimen. Given the necessity of treatment, there is still a choice of agents for neutralization - and hence a choice of which chemicals are left in the specimen after treatment. It is probably more ethical to produce a chemical easily recognisable as an artifact of treatment, such as ammonium sulphate, rather than one likely to be thought of as occurring naturally in such specimens, such as barium sulphate.

Whatever is produced, it will be a synthetic growth within the specimen. Whether the benefit of the treatment in terms of prolonged specimen life is worth the contamination induced is a curatorial decision that will depend largely on the intended use for the specimen.

3. Alteration of composition

As the motivation for falsification is generally monetary, it is not surprising that silver and gold are often faked. This is commonly done by electroplating gold or silver on to copper nuggets.

Many conservation treatments are capable of altering surface composition, e.g. the removal of calcite from scapolite crystals using hydrochloric acid. Dr G. Robinson (pers. comm. 1985) related a case of a graduate student who spent a little over a year studying chemical zonation in scapolites and found that many of them were chloride-rich near the crystal surfaces. Needless to say, he was not too impressed when someone pointed out to him that those specimens which exhibited this zoning were those that had been exposed using hydrochloric acid. This is just one of many possible examples that lead to a preference for the use of organic rather than inorganic chemicals for mineral specimen conservation treatments whenever a choice is possible.

4. Alteration of form

Several minerals, particularly silver and gold, are so malleable that many collectors cannot resist the temptation to 'improve' their form. They often feel added licence to do this since many such specimens would have been distorted by natural forces before collection, or inadvertently distorted while being collected.

The silver specimen shown in Fig.4 is an example of this, and it is clear that something other than natural distortion has occurred here. Some curators consider any distortion beyond that which is truly accidental to be unethical falsification. But there has been at least one curator of a major North American mineral collection who would delight in bending his gold specimens to make them look like animals, people, angels or anything else that might catch his fancy; he took immense pride in his work, and never for a moment thought it might be unethical.

Could a conservator ever get mixed up in this kind of business? Certainly the practice of removing bruised corners of a crystal by cleaving them away could be construed as fabricating faces. Another example arose when the possibility of removing unattractive late generation siderite from rhombohedral siderite crystals from Mont-Saint-Hilaire was investigated. It was found that a pulsed ruby laser was capable of spalling away the late generation siderite and producing a lustrous rhombohedral form. Is this ethical, or is it simply a way of carving crystal faces? Siderite has an excellent cleavage parallel to those rhombohedral faces, so it is likely that the surface exposed was not in fact a contiguous crystal face, but simply a collection of cleavage surfaces approximating to a previous form.

It can be argued that such treatment attempts to make the crystal resemble as nearly as possible a previous known state. It is too easy to get caught up with new technology and forget what is basically occurring. In fact, from the ethical standpoint, this sort of treatment equates with a 'treatment' that involves breaking the crystal from the matrix, cleaving six new faces, then cementing the crystal back in place; many would consider that treatment highly unethical. Yet many others would consider the analogous treatment with a laser an

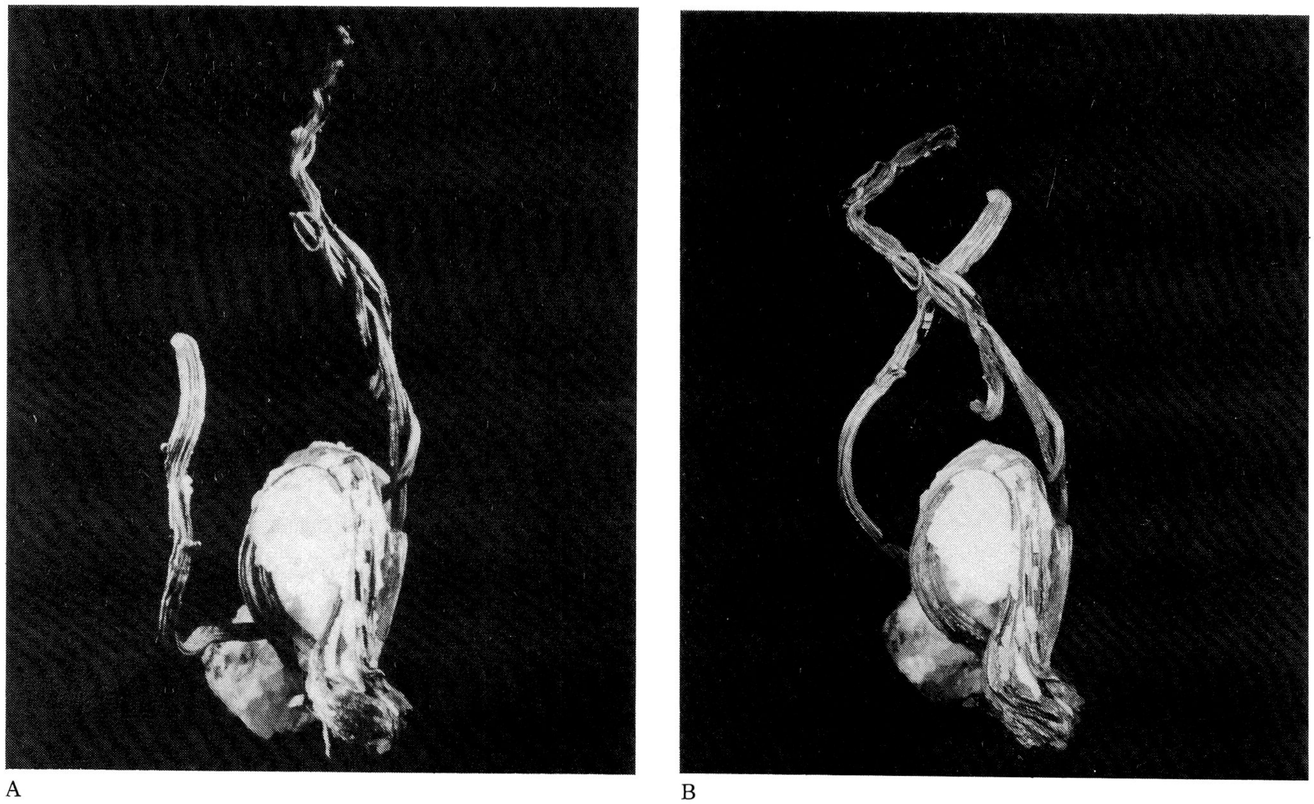

Fig.4. Silver. NMNS #39443, from Silver Islet, Thunder Bay District, Ontario. A, photograph taken prior to 1980; height as viewed, 7cm. B, photograph taken in 1986; height as viewed, 5.5cm.

acceptable procedure - one that might euphemistically be called 'cleaning'.

5. Alteration of colour

Dyeing of specimens is something that conservators should not have to worry about being accused of. The nearest a conservator normally comes to this sort of activity is the repatination of specimens. Alteration of colour, however, is very commonly done - each time a natural pigmentation of iron or manganese oxyhydroxides is removed from a specimen.

6. Alteration of lustre

The hematite (kidney ore) in Fig.5 shows a small area on its left side where the specimen has broken. This area exhibits the true lustre of the material. Very many specimens of this type have been rubbed with black shoe polish then polished on a buffing wheel. This practice is so common that it has gained a quasi-acceptance. Lustre is, however, an important intrinsic property of a mineral in a particular mode of formation and hence must be preserved if a specimen is to remain a mineral specimen and not become an artifact of lapidary art.

While it is nice to think that a conservator could never be accused of doing anything like this, it is not certainly so. In the mineral conservation laboratory of the National Museum of Natural Sciences, Ottawa, organic powders are replacing inorganic powders as media for air abrasives since they are less aggressive towards crystal faces. Cork is particularly gentle, but when mineral collectors and dealers have been told that cork is being used in air abrasive machines, as often as not they will say, 'Oh, so you are polishing the crystals; that sounds good.' While this is certainly not the intention, any mechanical development of this type will have some effect on the surface of specimens.

7. Alteration of clarity

For thousands of years emeralds have been oiled to fill fractures, thereby improving their clarity. Today, some mineral dealers are known to spray penetrating oil on many of their specimens to improve their clarity. Is this unethical? Surely the clarity of a specimen is an aspect of its true nature and, as such, should not be altered by a conservation treatment. So is it always unethical for a conservator to enhance the clarity of a specimen? Museum specimens are sometimes used solely to show colour or even colour zonation in crystals. The colour of these specimens often becomes more apparent if the specimens are impregnated to improve their clarity; in effect, the value of the specimen for its intended purpose is improved. The intended purpose for the specimen, to educate the public about colour in minerals, is in itself ethical. If it is clear that the specimen has no unique scientific value, then it could well be argued that failing to maximize the educational value of the specimen is unethical. In this case the conservator who fails to alter the clarity of the specimen could be accused of behaving unethically.

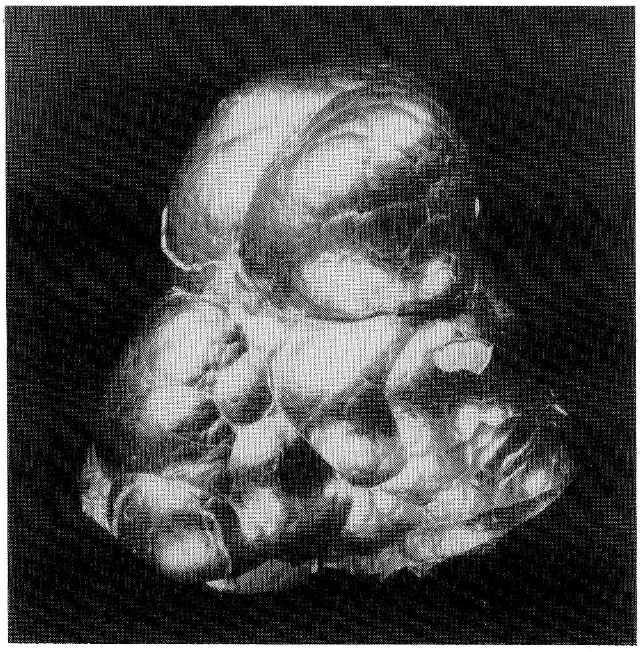

Fig.5. Hematite. NMNS #34142, from Cleator Moor, Cumbria, England. Buffing of this type of specimen to improve its lustre involves abrading away many thousands of crystal terminations. Width as viewed, 12cm.

CONCLUDING REMARKS

Why should anyone be concerned with ethics? People are concerned basically because they want to be 'good'. Most people would like to think that their efforts in life result in something that is 'good'. But good to or for what? While few people concern themselves directly with the good of all mankind, I believe that most people still consider the overall effect of an action on all of mankind to be the best measure of that action's 'goodness'. Most definitions of conservation that I have read run along the lines: 'conservation is the means by which preservation is achieved', implying that the ultimate goal of conservation is to attain the best possible state of preservation for objects. But practically all objects are best preserved in sealed containers, never dissected for study or illuminated for display. Such ideal 'conservation' would provide no benefit to mankind and hence cannot be judged as ethical. Objects in themselves are not important; it is the scientific and aesthetic enrichment that they can provide to people that is important.

That the goal of conservation implied by many definitions of conservation is not necessarily a worthy goal for humanity presents a problem for conservators who wish to avoid involvement in unethical conservation practices. Conservators must certainly abide by a code of ethics for conservation practice (e.g. <u>Code of ethics and guidance for practice for those involved in the conservation of cultural property in Canada</u>; as approved by the membership of the International Institute for Conservation - Canadian Group, at their 18 May AGM). Such a code, however, can only deal with the question of whether or not the means of conservation are ethical. The question of whether or not the ends of conservation are ethical can only be answered after consideration of the intended use for the conserved objects. In museums it is curators who determine what is the best way in which an object can serve society (i.e. for research, reference or display) and it is they who are best qualified to dictate what degree of alteration is acceptable, considering the intended use of the object. The problem now is that curators have not reached a consensus on the question of what degree of alteration is acceptable, and hence what constitutes ethical conservation. A conservator interested in ensuring that all conservation is ethical must, in addition to following a code of ethics for conservators, encourage and support curators in reaching a consensus on what applications of conservation are ethical in any given situation.

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Robert Waller
National Museum of Natural Sciences
National Museums of Canada
Ottawa K1A OM8
Canada

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SPECIAL PROBLEMS IN THE CONSERVATION OF PALAEOBOTANICAL MATERIAL

BY MARGARET E. COLLINSON

INTRODUCTION

Palaeobotanical material encompasses the fossil remains from an entire kingdom (Plantae) of our classification of living organisms. However, by comparison with the attention devoted to fossil remains of the Kingdom Animalia, particularly vertebrates, published guidelines for the conservation of plant fossils are meagre. This may be due to a combination of the specialist conservation requirements of plant fossils, the very few (if any) trained personnel working in this area, and the general lack of endeavour channelled into conservation matters by palaeobotanists themselves. The situation is emphasised by the guidelines for conservation given by Brunton et al. (1985). Only one problem peculiar to plant fossils merits passing mention, the hygroscopic and unstable nature of some lignitic material (ibid. pp. C4, C11), and the classification of palaeobotanical material is considered difficult (p.B24) and best left to a specialist. Whilst this is true, it must also tend to deter conservation and curatorial work on plant fossils.

I hope to provide here some guidelines for plant fossil conservation. I wholeheartedly endorse the concept of Brunton et al. (1985) that conservation begins in the field and cover these aspects elsewhere (Collinson, in press). Some plant fossils are suited to outdoor conservation (e.g. in situ tree stumps, as at Yellowstone National Park, USA: Dorf 1965) or to outdoor display after removal from site (e.g. the trunk in the grounds of the British Museum (Natural History), London). However, this paper covers only those problems specific to plant fossils in indoor collections. It assumes the existence of full documentation, labelling, cataloguing, registration etc. and suitable storage organisation, conditions and cabinets (e.g. following the guidelines of Brunton et al. 1985). A fuller account of palaeobotanical conservation is to be published elsewhere (Collinson, in press).

NATURE OF PALAEOBOTANICAL MATERIAL

Plant fossils are usually isolated organs or small parts of the original plant. They range from pollen grains, calcareous nannofossils (only a few µm in size) through spores, seeds, leaves, leafy and fruiting shoots, up to tree trunks and stumps (several metres in height or circumference, perhaps with ramifying, anchoring structures at their bases). These diverse plant parts occur in a variety of preservational states, ranging from those composed largely of original organic matter through to those with partial or total mineralisation. They may be found enclosed within indurated or non-indurated sediments. Frequently parts of fossils are removed for study (e.g. cuticles from leaves and thin sections from mineralised tissues). Material may be prepared and mounted on slides for light microscopy, on stubs for scanning electron microscopy (SEM) or on grids for transmission electron microscopy (TEM). Those interested in the plant fossils themselves, their study and significance should consult Thomas (1981) for an introductory account and Stewart (1983) and Taylor (1981) for more advanced treatments.

Palaeobotanists use an extensive range of preparative and illustrative techniques to investigate plant fossil material. Lacey (1968), Wagstaffe and Fidler (1968, pp.284-286, 376-381) and Kummel and Raup (1965, pp.224-232, 471-481, 530-598, 699-706) provide suitable references for standard palaeobotanical techniques. Techniques for working with microfossils (and some smaller macrofossils) were reviewed recently by Batten and Morrison (1983), Chapman (1985) and Phipps and Playford (1984). A variety of techniques may be used in any one investigation (e.g. Mapes and Rothwell 1984; Schaarschmidt 1985; Walker and Walker 1985). It is essential that curators and conservators maximise the potential application of all techniques to material in their care; any treatment likely to restrict investigative work should be avoided. Maximum scientific and educational value and specimen longevity should be aimed for.

Preservational state (see Scott and Collinson 1983; Stewart 1983, ch. 2), especially variation in organic content, is the main influence over conservation methods. The following sections therefore cover each major group of preservational states. Preparations made for microscopy are dealt with in a separate section. [For a detailed account of plant fossil preservation consult Schopf (1975).] A macrofossil is defined here as a fossil which can be clearly seen (though not necessarily identified) without the aid of a high power microscope.

MACROFOSSIL COMPRESSIONS

Macrofossil compressions encompass any compressed or partially compressed plant or plant part composed of original organic material (variously modified due to 'coalification' processes). The softest plant tissues will have decomposed to leave only the more resistant materials. Examples are: a leaf represented by upper and lower cuticles (sometimes with coalified tissues between); an empty seed coat; and a branch represented by the compressed secondary water conducting tissues of the wood. Every possible intermediate exists between a compression fossil and an impression fossil (see below), i.e. some, but not all, of the more resistant organic tissues may remain.

Fossils in matrix

Many compression fossils must be conserved on the matrix in order to retain their integrity (for exceptions see below); many, especially from older strata, present few special conservation problems.

When rock is split, a fossil is usually fractured, often leaving unequal portions in each piece of matrix. Complex form may only be revealed after detailed examination of both part and counterpart (Rex 1983), so both should be conserved (together, but never one on top of the other). They may be labelled 'pt.' and 'cpt.', given the same number and a. and b. suffixes and, like all such fossils, should be stored in cardboard trays packed to prevent movement within drawers.

These fossils are cleaned using standard techniques of soft brushes and dust extraction (but always check first to see that no organic material or matrix portions are loose; see below). Breaks may be repaired with polyvinyl acetate (PVA) emulsion which may also be used as a support to seal the reverse of blocks with friable matrix (C.R. Hill pers. comm. 1985). Always take care not to impinge upon areas of interest and to retain all broken fragments.

Never discard specimens without specialist advice. Whilst some 'scrappy' specimens are really of little value, others may reveal a critical organic connection between two organs. Also, the reproductive parts of the plant are often harder to recognise than the leaves (e.g. some fern material and flowering plant flower and fruit parts).

Exfoliation. Major conservation problems arise when organic material is only loosely attached to the supporting matrix. Differential drying of the matrix and organic material causes exfoliation of the organic fossil. [Comparable problems occur with some fossil bone (Howie 1979a, b; Brunton et al. 1985, pp.C4, C11).]

Specimens with loose organic material, or in friable matrix, or released from matrix (see below), should never be cleaned without specialist advice. Meanwhile remove with minimum handling to a clean area and never blow on such a fossil or invert it. Label the upper surface if this is possible without obscuring areas of interest; if not, label the lower surface by placing glue on the label and lowering the specimen onto it (when the label should be read by carefully peering underneath the specimen, not by turning it over). Never store these fossils in trays or containers whose lids have electrostatic properties (e.g. cellulose acetate), and always ensure that a non-specialist is made aware of the risks by so labelling the outside of drawers or cabinets.

Newly collected specimens in these risk categories should arrive wrapped in damp paper enclosed in polythene. They should be dried out slowly, either through the polythene or under a polythene tent (as described by Howie 1979b for fossil bone), where a relative humidity of 45-50% is the final minimum level. Precise analyses have not been undertaken for plant fossils and circumstances probably vary according to the material. Care should be taken to avoid fungal and algal growth. Material can be kept dark and cold (e.g. in cold store) and fungicide should be added. [Collectors should use water with fungicide to initially moisten their wrapping papers.]

Fossils with loose organic material should be stored finally in sealed cabinets, with conditioned silica gel to buffer humidity fluctuations (cf. Howie 1979a, p.121). In practice, however, no large scale storage system is likely to maintain the required humidity levels and all dry stored specimens within the risk categories can be expected to show exfoliation.

Spraying specimens with artists' pastel fixative, artists' finishing varnish or an acetone soluble clear acrylic spray such as 'Krylon' (Dilcher 1974, p.124) will prevent exfoliation, but careful timing is needed to prevent the coating clouding or peeling away if the specimen was too moist; if too dry, exfoliation may have already begun. Such spray coatings have unfortunate drawbacks: they are difficult (sometimes impossible) to remove completely, thus posing problems for future study such as cuticle preparations, electron microscope examination, film pulls, latex peels etc.; they are often shiny, which hinders light microscopy and photography; and they may prevent further preparation of incompletely exposed fossils. Spray coatings therefore are not recommended.

An alternative, for specimens on coherent matrix which have never been allowed to dry out, is fluid storage. [It is imperative to test unwanted matrix before using this method.] Material may be stored during the early stages of observation in water containing a fungicide such as phenol or thymol (or in water changed daily, in flowing water, or in slightly acidified water if suitable for the matrix: see also Oddy and Lane 1976; Clarke 1985). After initial study, material may be stored permanently either in a mixture of glycerol and water or glycerol and alcohol, or in polyethylene glycol (PEG) 200-600, each with a fungicide such as thymol or phenol (Dettman 1965; Schaarschmidt 1985; Tiffney 1981). This method has been used for slabs of oil-shales from the Eocene of Messel, West Germany, which bear leaves, fruits and seeds (conserved in the Senckenberg Museum, Frankfurt, West Germany). 15% glycerine with phenol, or PEG 400, has also been used for Kimmeridge shale fossils (Plenderleith and Werner 1971, pp.331-332).

A difficulty is that all alcohol based media cause some dissolution of organic material, usually indicated by discoloration of the fluids to orange or brown. Long term effects of this on plant structure have not yet been investigated. Schaarschmidt (pers. comm.

1985) and personal observations suggest that glycerol based media cause less dissolution than PEG. Care must also be taken to ensure that labelling inks are alcohol resistant. Silicon oil is an inert alternative, although it has not been tested on this material. Transfer requires an alcohol and toluene series as the fluid is not water miscible. The expense involved for a large number of specimens on slabs makes its viable use unlikely, even if it were known to be preferable.

Another alternative approach is to impregnate material gradually with water miscible fluids which can subsequently be polymerised after total replacement of water. This method is used widely in archaeological work to conserve waterlogged material (e.g. wooden structures using PEG 4000-6000, often termed 'carbowax'). A voluminous literature exists and summaries have been given by Oddy and Lane (1976), Grattan (1982) and Grattan and McCawley (1982). The method was formerly used for Messel material and has also been used for Kimmeridge shale fossils from the surface of which polymerised PEG was removed using acetone or methylene chloride (Oddy and Lane 1976). The method has also been used for specimens isolated from matrix (e.g. for Miocene fruits: Gregor 1978).

With palaeobotanical material the aim is not only to conserve the overall integrity but also to allow for detailed study of surface and internal features. Experimentation is needed, however; the removal of PEG from the surface after embedding would expose the often delicate, thin surface layer (e.g. leaf cuticle, outer fruit wall) to as much risk as it would have experienced before embedding. Critical control of removal would be essential to protect this layer. Furthermore, the likely need for frequent removal of PEG for study (and subsequent replacement) would also prove a greater risk to the specimen than fluid storage. Fluid storage is therefore recommended where possible.

Unfortunately, there is as yet no method either for preventing the exfoliation of specimens where the matrix is unsuitable for fluid storage, or for adequate treatment of specimens where exfoliation has already taken place. Advice is as follows: handle specimens with special care and do not subject them to any airflow (including breath); ensure that specimens never get dusty (as cleaning will probably also remove the organic material) and do not attempt to clean old collections without specialist advice; let new specimens dry out slowly over several months; try to avoid relative humidity fluctuations and falls below 50% in storage areas; attempt re-humidification of specimens which have seriously deteriorated (handling with great care) by using a polythene tent and gradually increasing relative humidity (see Howie 1979a, b); photograph specimens at risk as soon as possible, but keep them humid and use cold light sources; always study specimens in these conditions; in dry conditions keep drawers closed; support the reverse of friable matrix blocks using PVA.

Some of the materials described by Keene (herein) should be tested for their potential role in conservation of these problematic palaeobotanical specimens. Any material must combine the facility to prevent exfoliation with a finish that does not impair photography or microscopic examination, and it must be easily and totally removable so that no residues are observed under the testing conditions of high magnification electron microscopy.

Specimens released from matrix

Some specimens may be released from matrix for study by means of the transfer technique (Lacey 1968; Dilcher 1974, p.127) and its modifications (Crepet et al. 1975; Daghlian et al. 1980). The technique involves covering the outside of the fossil with cellulose acetate or nitrate; once set, the matrix is then removed by an appropriate acid to leave the fossil supported by the cellulose film. It cannot be recommended as a routine conservation method for the following reasons: 1, the upper surface of the fossil is irretrievably embedded; 2, specialised experience is necessary; 3, the technique is time consuming and often requires special laboratory conditions.

Rarely, relatively thin or delicate plant parts, such as leaves, form coherent compression fossils (e.g. in paper shales: Dilcher 1974, p.65; Dimichele et al. 1984). Entire leaves may be lifted from the matrix or released by simple maceration techniques; they may be cleared and mounted between large glass slides or stored dry in envelopes. Such material is ideal for display purposes, especially when slide mounted. Usually, however, only the more durable, integral plant organs form coherent compression fossils which can easily be released from the enclosing matrix (e.g. fruits, seeds, megaspores, wood pieces). Release can be accomplished by various techniques (see References) and any residual matrix removed using hydrofluoric acid, after which they should be stored in fluid as described above.

If drying is essential (e.g. for SEM study), specimens should be dried slowly and it is my experience that they survive this one drying episode. However, subsequent rewetting (with expansion) and redrying (with contraction) greatly increases the risks of specimen fragmentation, so specimens should not be dried unless it is essential. Critical point and freeze drying techniques have not proved helpful.

Handling of these fossils must be kept to a minimum and should employ sable hair paint brushes of 00,000 or 0000 sizes. If handling dry material, the brushes may be lightly moistened with distilled water then wiped almost dry in order to pick up the specimens. Very small objects may be handled with an eyelash mounted on a toothpick. Tweezers and needles should never be used.

Securely sealed, yet easily openable containers are required for fluid storage. Glass or plastics (providing they do not react with fluids) are suitable. Screw on or clip on plastic caps (not corks) may be used but always check a sample of any proposed container before use. Tubes sold for postal transport of sterile blood samples are very suitable, as are glass vials of various forms. For all fossils isolated from matrix the greatest risk is in movement within the container, either physical shock or stranding above the fluid level. Vials which narrow at their base, with this narrowed portion surrounded by a collar of tube width, stand upright but allow specimens to sink into the restricting space of the narrowed base.

All specimen containers should be stored upright and prevented from falling. This can best be achieved by lining drawers with foam padding (e.g. 'Plastazote') into which holes can be cut appropriate to the containers using a cork borer for circular forms (C.H. Shute and C.R. Hill pers. comm. 1985). 'Freelite' (McGavin 1985) may be a preferable alternative to 'Plastazote'. Cavity slides, boxes and gelatin capsules are sometimes used for small, isolated, dry fossils. Again movement within the containers is a hazard. Gelatin capsules are not impact resistant and also have undesirable electrostatic properties, as do any plastic cavity slides (especially if the coverslip is plastic). Plastic tubes are also inappropriate for dry specimens for this reason. As a general rule, adhesives and consolidants should not be used to hold specimens in place in containers. Permanent adhesives should never be used.

MACROFOSSIL PETRIFACTIONS, CASTS, MOULDS AND IMPRESSIONS

These fossils contain no original organic material but are composed either of sediments bearing an impression of the organic material (e.g. a leaf impression), or of sediments which have infilled a once hollow cavity (e.g. a hollow stem, to form an internal mould) or a space once occupied by now decayed plant tissues (e.g. stem casts), or of minerals such as silica or calcite acting in the same manner. Petrified wood is a result of complex infill, crystallisation, decay and further infill of original wood cells, but no organic cell walls survive.

Impressions, moulds and casts are often examined using replication with various compounds (e.g. latex or silicon rubber: Crankshaw 1984; Hamilton Waters 1983; Hill, in press). It is imperative therefore that no consolidant is applied to such fossils, even though no organic material would be obsured in the process.

Some fossils are the result of production of hard mineralised parts during the life of the plant (e.g. diatoms, calcareous algae, etc.). Small examples may be stored as described above for isolated, dry compression fossils.

All of these fossils require no special conservation methods and should be treated as appropriate for their component minerals or sediments.

MACROFOSSIL PERMINERALISATIONS

These (e.g. coal balls) result from infiltration of mineral rich fluids and subsequent crystallisation within plant material. Decomposition is thus prevented and the support conferred resists compression. Much of the original organic material remains in the fossil, often including very delicate plant tissues. Conservation problems relate to the combination of organic material and minerals which sometimes require conflicting treatments.

Permineralisations are usually studied by acid etching of the mineral and incorporating the protruding plant material into a cellulose acetate film, using the peel technique (Lacey 1953; Joy et al. 1956; Stewart and Taylor 1965; Matten 1973, pp.169-170; Chitaley 1985; Basinger 1981). Portions of, or entire peels may be stored loose in labelled envelopes (e.g. in a card index system), or mounted on microscope slides using Canada balsam in xylene (see below for comments on slide storage). Peels shrink over time so their original dimensions should be noted (Joy et al. 1956).

Labels with peels or slides must cross reference to the original block. This block may be in one or several pieces, each of which might have yielded one to many peels from a number of surfaces (e.g. various planes of section required for study of wood anatomy). A complex system of accurate cross referencing is therefore called for. Sometimes an original specimen is entirely reduced to peel sections.

Siliceous and calcareous permineralisations usually require no special conservation techniques. The latter, however, may sometimes incorporate pyrite. Particular problems occur when mineralisation is largely or entirely due to pyrite. These have been dealt with by Howie (1979a, b), Cornish and Doyle (1984) and Cornish (herein). I summarise here only those aspects peculiar to fossil plants.

Whereas organic material is best stored in humid conditions, pyrite requires dry conditions. This conflict may be solved by precise control of humidity (e.g. over conditioned silica gel) or by storage in a fluid which is incapable of absorbing water vapour from the environment (e.g. silicon oil). Specimens stored in silicon oil must first be dehydrated as silicon oil is obviously not water miscible. If, as is the case with many London Clay fruits and seeds (Collinson 1983), pyrite permineralised fossils have an outer organic layer (e.g. the seed coat), this will exfoliate if the fossil is removed from the fluid. However. drying can be accomplished by transfer through a series of water/alcohol, alcohol/toluene, toluene/silicon oil mixtures, thus never leaving the fluid phase. Such specimens should be kept wet from the moment of collection, washed thoroughly in changes of water (with fungicide unless changed daily) and transferred through such a series. Photography of this material at the earliest possible stage is essential (Collinson 1983).

Pyrite reacts very variably once exposed to humid air. An apparently stable plant fossil can suffer rapidly after being fractured for examination of internal detail. [Knowledge of such details is usually essential for determination, so the problem cannot be avoided.] Again photographic documentation is an immediate essential. Wilkinson (1984 and references cited) documented exceptionally well preserved fine details within pyritised plant axes, yet these are lost very soon after fracturing (Wilkinson pers. comm. 1985) and no means of conserving them has yet been found. The negatives are therefore a vital record which should be conserved with care. Where possible, duplicate material should be conserved for fracture on future occasions.

In contrast to problems with London Clay pyrite permineralised plants, neither Matten (1973) nor Edwards et al. (in press) found any problems with Devonian material. Carboniferous coal balls, though mainly calcareous, often include veins of pyrite; their size and usual application of the peel technique precludes the use of silicon oil. Leaving a peel on all cut surfaces of the coal ball has been found helpful (J. Galtier, J. Holmes, G. Rex, pers. comm. 1984). Coating other surfaces with materials previously used in 'preventing' pyrite decay (Howie 1979a) may also help. There is no entirely suitable answer at present for these or other large plant fossils composed of risk category pyrite. Relative humidity must be controlled but even then insufficient studies have been undertaken to guarantee results. If possible, representative portions of material should be conserved in silicon oil. As yet, no experimentation has been undertaken on the ease of removing silicon oil from specimens to be examined under the testing conditions of high power electron microscopy.

MICROFOSSILS AND MICROSCOPY PREPARATIONS

This topic is dealt with in more detail elsewhere (Collinson, in press) and only the major relevant points are mentioned here. A very wide range of palaeobotanical material may be conserved on microscope slides. Samples are prepared for palynomorph studies and for palaeoenvironmental analyses. These include pollen, spores, dinoflagellates and other algal resting cysts, fungal spores etc., fragmentary plant material (e.g. cuticles, wood, etc.), and calcareous nannofossils, silicoflagellates and other mineralised plant parts. Preparations are also made from the whole range of macrofossils described above, such as spores from compressed sporangia, cuticles from leaf compressions, thin sections from compressed wood, thin sections from petrified and permineralised tissues and peels from permineralised tissues. These latter sections may be much larger than the 'standard' microscope slide and consideration should be given to them when preparing slide storage areas. All slides prepared from larger material must be cross-referenced to their source but they are best stored in separate slide storage areas rather than with their source specimens (see also Brunton et al. 1985).

Mounting media and mounting techniques have varied enormously. Conservation problems relate largely to non-permanent mounting media which have dried out or flowed during storage, or to broken slides; both require the rescue of material and its remounting. Rescue of glycerine jelly slides has been covered by Hill (1983) and Sincock (1984) (see also Chapman 1985; Collinson, in press).

Slides must be stored horizontally, coverslip uppermost, and preferably in trays within a purpose built cabinet. Trays should have stops to prevent them from being pulled out in one movement.

The choice of a slide mounting medium for its maximum durability (perhaps a criterion favoured for conservation) may be at odds with the possibility of future removal of material from slides (e.g. for electron microscope study). Thus a high quality glycerine jelly preparation (see Hill 1983) may be preferable to one made from an irreversible mounting medium.

When palynomorph strew-mounts are incorporated into a collection, a primary role for the conservator is to ensure that type, figured or noted specimens can be located by future workers. Coordinates should be established for all such fossils using an England or Halton Finder available from microscopy suppliers.

Residues from which palynomorphs have been prepared should be fluid stored as for compression fossils, in small air-tight vials in glycerol to which thymol or phenol has been added (Batten and Morrison 1983; Chapman 1985). Residues stored by other means have proved hard to rescue if dehydrated (Chapman 1985; Doher 1980; Shane and Clark 1981). Permanent fluid storage of residues from which calcareous nannofossils have been prepared has proved impossible due to growth and dissolution of the constituent minerals (Taylor and Hamilton 1982).

Special problems

In the case of very small, strew-mounted fossils, requiring specialised microscopy and suffering from growth and dissolution of mineral constituents with time, it may be impossible to create a permanently conserved specimen collection. Lord (1982 and pers. comm. 1985) considered that, for nannofossils, the photographic negatives are the specimen type equivalents.

SEM stubs and TEM grids have an as yet unknown shelf life and photographs may represent the best or only source of information if they do deteriorate. Chapman (1985) suggested use of a standard set of illustrations for all pollen observed under

SEM. This seems an excellent idea which should be followed by other workers in this and related problem areas. Photographic negatives should be conserved with the same care afforded to specimens in these cases, as in others referred to in this paper. Duplicate specimens, matrix samples, or duplicates of prepared residues should also be conserved wherever possible.

Expansion and shrinkage, acting differentially on the portion of the specimen attached to the stub, may cause fragmentation of material on SEM stubs. Mounting media are also susceptible (Chapman 1985) but non-permanent ones are preferable if specimens are to be removed for other means of study. Removal of specimens from SEM stubs should never be attempted without specialist advice. SEM stubs are best stored in sealed cabinets under controlled desiccation (Collinson, in press).

TEM grids may be stored in purpose built specimen grid holders. However, I am unaware of any study assessing their shelf life or preferential storage environment.

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Margaret E. Collinson
Department of Biology
King's College London (KQC)
Kensington Campus
Campden Hill Road
Kensington, London W8 7AH

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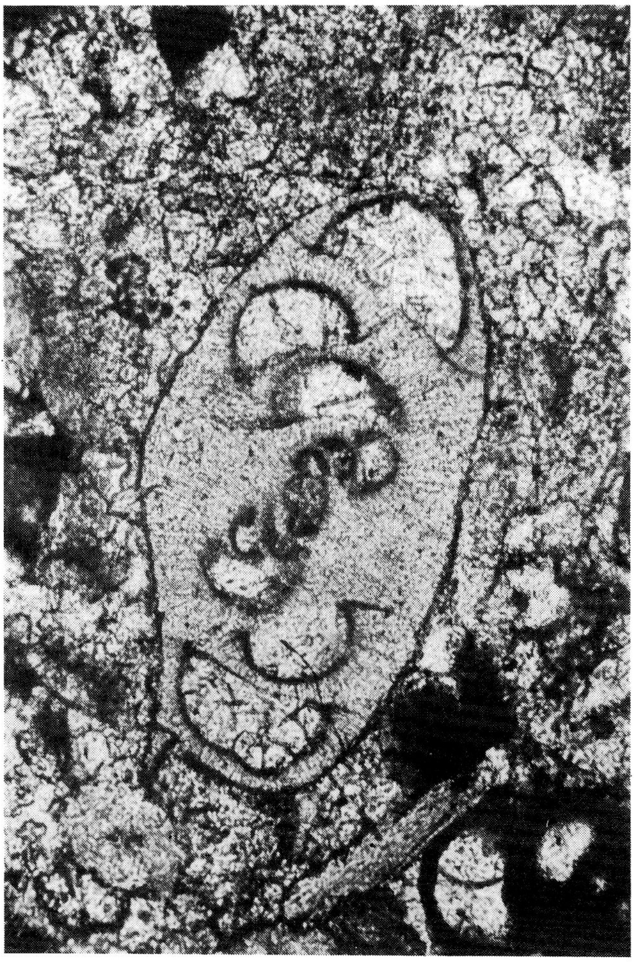
APPROACHES TO THE PREPARATION AND DEVELOPMENT OF CALCAREOUS FOSSILS FROM CALCAREOUS MATRICES

BY JOHN WILSON

INTRODUCTION

Carbonate sediment production is basically organic; it takes place in a range of marine environments and in some fresh water situations. Such sediments provide rich hunting grounds for palaeontologists whose interests can range from the calcareous algal microflora to the invertebrate macrofaunas familiar to all who work on museum or teaching collections. The problem presented to the preparator by carbonate sediments is that he or she must remove, with minimal damage, a fossil composed of calcium carbonate from a hard enclosing matrix of the same chemical composition; even where minor chemical differences do occur, they are difficult to exploit. This paper reviews some of the methods used to remove fossils from these matrices, presents some theoretical considerations, and looks at a number of ways in which it may be possible to improve or develop methods and techniques for the future.



I believe that many of the fine looking fossils, completely free of matrix, found in museum and teaching collections required no preparation subsequent to field collection. Where some host rock does surround the specimen, it shows none of the tell-tale bruises of chisel, needle or grinder. Such specimens most probably represent the collector's 'best specimens', with his incomplete or technically problematic material being discarded. This policy may have sufficed when the sole use was exhibiting, but the importance of a collection is enhanced by the plurality of its uses. Biostratigraphers, taxonomists and palaeoecologists want whole faunas and floras; preparative skills, techniques and knowledge are required to provide them.

In a recent paper on the history of preparative techniques in palaeontology, Whybrow (1985) listed the three basic mechanical methods which have been in use since the early twentieth century: grinding, percussion and sand blasting. Sand blasting (air abrasive) works best in situations where soft, poorly cemented rocks contain harder fossils; for example, English chalk fossils can be successfully developed by sandblasting, but the technique is a miserable failure for the same groups of fossils from the Ulster White Limestone which is precisely the same facies but much more heavily indurated. For the major invertebrate groups percussive methods are usually best, since grinding can be destructive to high relief ornament, spine bases or unexpectedly extended hinge lines (although, of course, serial sectioning has proved to be a crucial but destructive research technique).

It is useful to examine what happens when developing a fossil from calcareous sediment. If we look at a Lower Carboniferous microfossil (Fig.1), the entire fossil and its enclosing sediment can be seen in some detail. With a larger fossil the situation is merely scaled up. The fossil and its matrix have the same or similar chemistry, yet there are structural differences: the fossil has a microfibrous structure whereas the enclosing sediment has a grain size tens of times greater. The structural integrity of the fossil is therefore much greater than the matrix, and it is consequently possible to exert a controlled amount of destructive energy on the matrix which will leave the fossil intact. Too much energy will destroy both matrix and fossil. The junction between

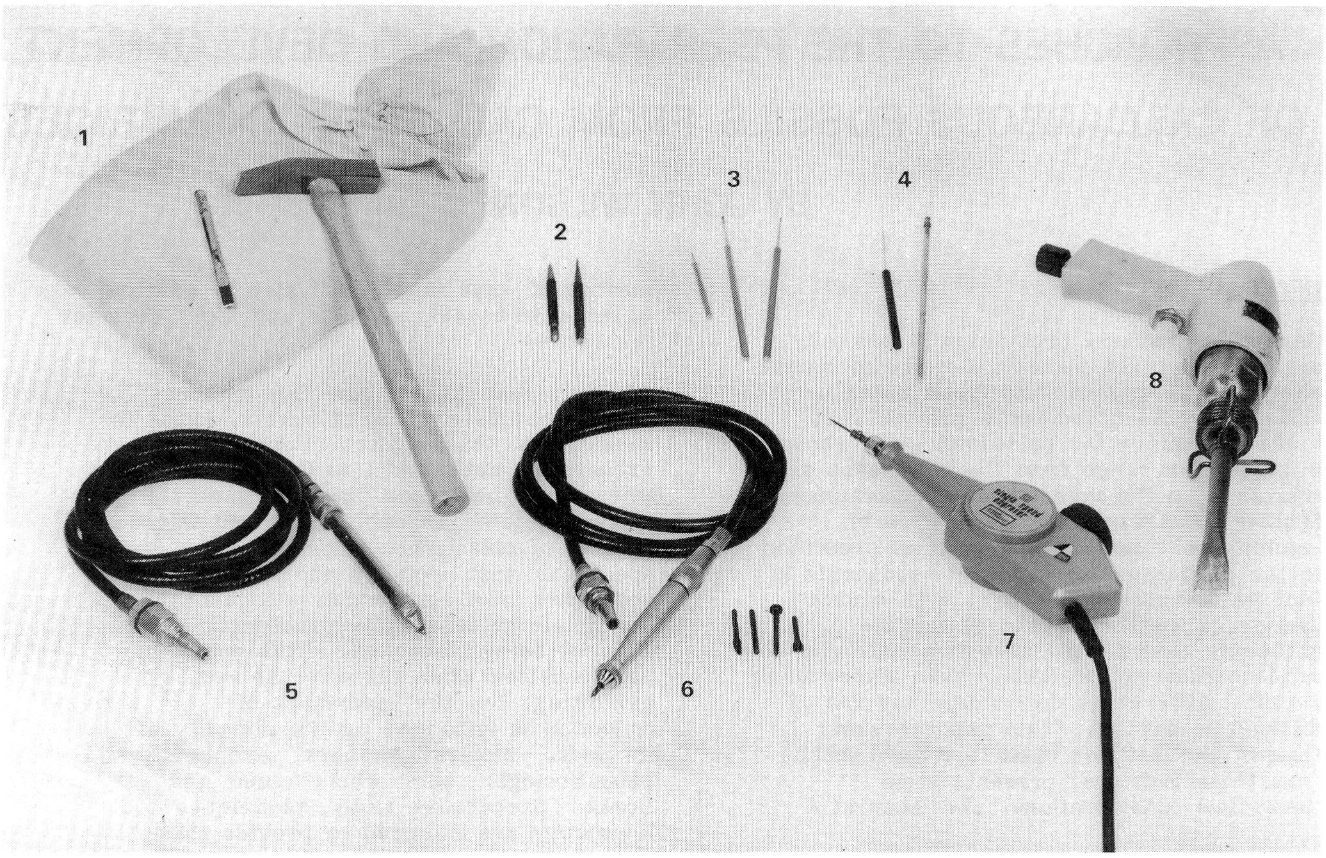


Fig.2. Some equipment used in the mechanical preparation of calcareous macrofossils. 1, small hammer, chisel and sandbag; 2, punches; 3, dental tools; 4, mounted needles; 5, Desoutter pneumatic engraving tool; 6, Chicago Pneumatic Company engraving tool; 7, electric engraving tool; 8, pneumatic chisel.

fossil and matrix is quite clean and distinct; this interface is exploited by percussive development techniques.

PERCUSSIVE TOOLS

A simple range of percussive tools (affordable by even small museums) is readily available (Fig.2). The simplest set-up is a small hammer and chisel (Fig.2.1); the sand bag is useful to hold the work in place and to protect the reverse side of the fossil if it has been prepared. Punches (Fig.2.2) can be ground to any shape from blade to point; but a warning - they are much too brittle to be used on sandstones or mudstones and can break up causing a safety hazard. There is now a range of fine, chisel shaped dental tools (Fig.2.3) with specially hardened tungsten carbide tips, and shafts that can be shortened to suit individual requirements. Needles (Fig.2.4) are particularly good for picking away biosparite matrix from both microfossils and larger specimens such as trilobites. The pneumatic tool most commonly used in the UK is manufactured by Desoutter for engraving purposes (Fig.2.5) and costs about £80 (1986 prices); the tip is of tungsten carbide steel with adjacent exit air ports which remove rock debris as it is chiselled from around the fossil. A similar tool supplied by the Chicago Pneumatic Company (fig.2.6) has several advantages over the Desoutter model: its strike can be controlled by a collar at the top of the tool and it also comes with a range of different tips. The electrically operated engraver (Fig.2.7) performs in a similar way but not as efficiently as the pneumatic tools. It comes with a similar point to the Desoutter 'pen' but can be modified to take a fine, hard needle (as in Fig.2.7) which can be used to develop small fossils under the binocular microscope. The 'Vibrotool' is similar in appearance and operation and can also be altered quite readily to suit individual work requirements. To remove a large volume of matrix quickly a pneumatic chisel (Fig.2.8) is very good for breaking up bulk samples to expose smaller invertebrates.

The range of tools outlined above, along with suitable eye protection and dust extraction equipment, can be regarded as a basic equipment set, but additional items such as ultrasonic probes would be a useful if costly addition. Safety precautions which should be adopted whilst using compressed air, and for dust, noise and vibration protection are outlined by Howie (herein).

METHODS

Consideration of preparation and conservation should begin in the field, and for calcareous material I suggest two guidelines: 1, keep trimming and development to a minimum (wait until the material is back in the laboratory so that a better assessment of the methods to be used can be made) and 2, where site conservation and transport permit, do not be afraid to take bulk samples (spare material can be used in later trials and investigations). Back in the laboratory, the use of both chemical and petrographic techniques can aid the more traditional, well documented methods associated with the standard percussive tools described above.

Acetolysis

Standard methods of acid preparation are obviously inapplicable to the release of carbonate fossils from a carbonate matrix. One method does, however, show promise and has already been used very successfully for the removal of microfossils (particularly foraminifera and ostracods) from Carboniferous and Jurassic limestones. This technique, first published in France by Bourdan (1957) and later modified (Bourdan 1962), utilises acetic acid in a very controlled way to exploit minor changes in solubility caused by structural differences between matrix and fossil, and by subtle chemical differences. Acetic acid in the presence of water behaves similarly to the strong inorganic acids, but if water is not present its ability to produce protons is greatly reduced - this is known as the acid levelling effect. The acid behaves as a solvent so without dilution the reaction between limestones and glacial acetic acid proceeds thus:

$2CH_3COOH \rightarrow CH_3COO^- + CH_3COOH_2^+$
$CaCO_3 \rightarrow Ca^{++} + CO_3^{--}$
$CO_3^{--} + CH_3COOH_2^+ \rightarrow HCO_3^- + CH_3COOH$
$HCO_3^- + CH_3COOH_2^+ \rightarrow H_2CO_3 + CH_3COOH$
$H_2CO_3 \rightarrow H_2O + CO_2$

The water produced at stage 5 destroys the process, but if a small amount of dessicant is added such water can be removed. Reactions of this type are known as solvolysis or in this particular instance acetolysis.

In practice the sample must be broken up, dried thoroughly and placed in a vessel with the acid (Fig.3). The most commonly used dessicant is anhydrous copper sulphate (1gm is sufficient for about 0.5l). As the reaction is best carried out at 60°C, the flask is heated using either a sand bath on an adjustable hot plate, or a thermostatically controlled heating jacket; a gas or electric bunsen should not be used. The dry sample, glacial acetic acid and anhydrous $CuSO_4$ are placed in the flask, and the temperature inside is monitored. The funnel at the top of the condenser prevents moisture entering the system and allows the carbon dioxide produced to escape. When the reaction has finished, the contents of the flask are neutralised immediately by pouring the mixture into excess diluted ammonia solution (10% aqueous). After decanting, the sample is washed copiously with distilled water.

For trials with macrofossils a different containing vessel is required, and exploitation of the acid levelling effect can also be extended to some of the higher acids, such as propionic and butyric acids, which are weaker than acetic acid and permit greater control over the process. So far the technique does not work on micrites, but it is very efficient on coarser biosparites, the length of time necessary to process a sample varying from 20 mins. to 3 days. It also works better if there are minor chemical differences between fossil and matrix, e.g, the magnesium and iron content of the fossils' calcite.

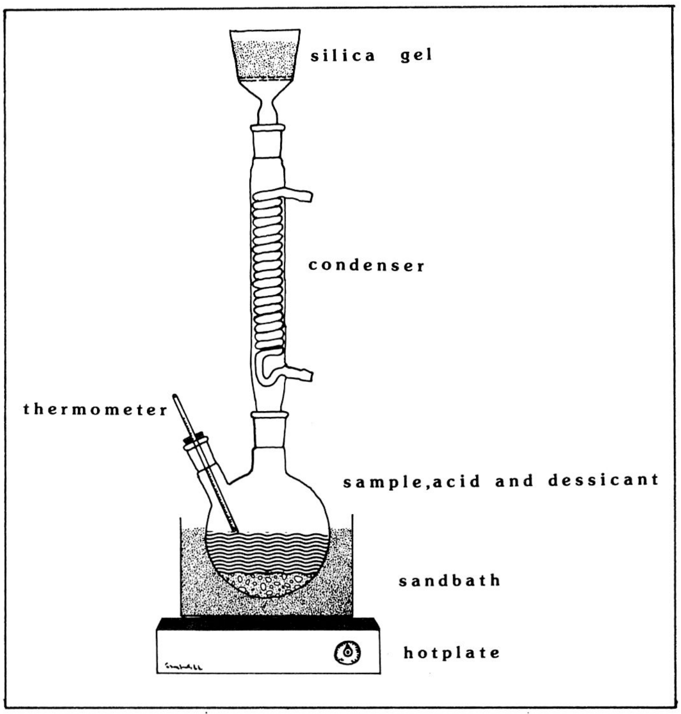


Fig.3. Solvolysis (acetolysis) equipment for the extraction of calcareous microfossils.

Essential safety precautions. 1, use gloves and goggles whilst handling acetic acid and ammonia; 2, carry out the solvolysis process in an efficient fume cupboard; and 3, allow the contents of the flask to cool before neutralising with dilute ammonia solution.

Petrography

Preparators should take a greater interest in the petrography of sediments and their fossils; Bathurst (1975, ch.1), Horowitz and Potter (1971) and Adams, Mackenzie and Guilford (1985) provide a good introduction. With such knowledge, preparators are better able to select methods and tools, and understand what is possible and what is not. Before preparing a large number of fossils from a particular horizon, I suggest that some thin or polished sections be made (preferably 10 x 7.5cm) from the fossiliferous parts of the sequence and the following questions answered:

1, what fossils are present?
2, what is the gross microstructure of the shell?
3, what is the grain structure of the matrix?
4, is the interface between the fossil and matrix sharp or ill-defined?
5, does staining yield chemical information about matrix and fossil which might permit the use of a chemical method?

This method of approach not only saves time but also helps the preparator select the correct method for the efficient development of technically problematic material. For example, thin shelled fossils filled with neomorphic spar are destroyed by a percussive method because, if sufficient energy is used to release the surrounding matrix, the inner filling disaggregates and causes the shell to collapse and fragment. This type of problem can be detected by a petrographic study.

ACKNOWLEDGEMENTS

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APPENDIX

Suppliers

Punches: local hardware or tool supplier.

Dental tools and probes: local dental materials and equipment supplier.

Mounted needles: laboratory equipment supplier, e.g. Griffin, 285 Ealing Road, Wembley, Middlesex HAO 1HJ, UK.

Pneumatic tools, including VP2 engraving pen, high speed grinders and pneumatic chisels: Desoutter Ltd., 319 Edgeware Road, Colindale, London NW9 6ND, UK.

Engraving tool ('Air Scribe'): Chicago Pneumatic Company, 97-107 Uxbridge Road, London W5 5PT, UK.

Electric engravers, including 'Vibrotool': local model shops and some hardware suppliers; also Frank W. Joel Ltd., Unit 5, Oldmeadow Road, Hardwick Industrial Estate, King's Lynn, Norfolk PE30 4HH, UK; or Burgess Power Tools Ltd., Sapcote, Leicestershire LE9 6JW, UK.

Chisels: local hardware and tool suppliers.

Geological hammers: local lapidary shops and some tool suppliers. Specialist dealers are, Gregory Bottley and Lloyd, 8-12 Rickett Street, London SW6 1RU, UK, and Whithear Lapidary, 35 Manor Way, North Harrow HA2 6BZ, UK.

Sandblasting equipment ('Airbrasive'): GEC Mechanical Automation Ltd., Birch Walk, Erith, Kent DA8 1QH, UK.

John Wilson
Department of Geology
Ulster Museum
Botanic Gardens
Belfast BT9 5AB

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THE TREATMENT OF DECAYING PYRITIFEROUS FOSSIL MATERIAL USING ETHANOLAMINE THIOGLYCOLLATE

BY LORRAINE CORNISH

INTRODUCTION

Pyrite occurs in two major forms in both fossil and mineral assemblages: one is compact, well crystallized and stable, while the other is porous, microcrystalline, often impure and very unstable. Pyrite decay, or more accurately oxidation, occurs rapidly only in the latter. The main characteristics of a specimen exhibiting pyrite oxidation are loss of surface shine, powdering of the surface with the development of white or yellow crystals, and the presence of a sulphurous smell (Fig.1A).

The treatment of oxidizing pyritiferous material varies according to specimen size and composition. In the Palaeontology Laboratory of the British Museum (Natural History) most specimens are treated with ethanolamine thioglycollate, which has three important properties (see Cornish and Doyle 1984):

1. It is alkaline, and in solution reacts with and effectively washes out acidic pyrite oxidation products (i.e. sulphuric acid).

2. Thioglycollates react with soluble and insoluble iron compounds (though not stable pyrite) and chelate or complex iron in solution as a violet coloured ferrothioglycollate.

3. It is readily soluble in ethanol or propan-2-ol (isopropanol), as are the products of its reaction with those of pyrite oxidation; thus contact of specimens with reagents containing more than a small proportion of water (which may be damaging) can be avoided.

Ethanolamine thioglycollate is supplied commercially as an aqueous solution containing 40% thioglycollic acid. Despite its fairly lox toxicity, precautions should be taken against the possible hazards associated with its use. Its corrosive action necessitates the wearing of PVC gloves and goggles for eye protection, and its use should be restricted to a well ventilated area (preferably a fume cupboard).

METHODS

Prevention of pyrite oxidation is achieved overall by storing material at low relative humidity (Howie 1979a, b). All specimens exhibiting pyrite oxidation should initially be placed in an environment of 40-50%

Fig.1. Dimorphohoplitid ammonite from the Gault Clay (Albian, lower Cretaceous; Folkestone, Kent) preserved in pyrite. A, before treatment, showing typical areas of pyrite oxidation speckled white. B, after removal of pyrite oxidation products with ethanolamine thioglycollate.

relative humidity until treatment can commence. At this stage it is important to note if the specimen has undergone any previous conservation treatments. Special care should be taken where consolidants have been used; resins such as polyvinyl acetal ('Alvar') or polyvinyl butyral ('Butvar') slowly dissolve in an ethanolamine thioglycollate solution and the specimen may break up during subsequent treatment. The specimen should be examined carefully and a record made of its general condition; if the specimen is of extra special value (e.g. a holotype), it is prudent to photograph it before treatment commences.

This treatment is used on specimens robust enough to survive complete immersion. All labels should be removed from the specimen since they may become stained during treatment; iron-based inks used on the label may dissolve in solution. Any surface markings (e.g. field location codes) made with ink pens should be noted on the treatment card for re-writing after treatment. Loose breakdown products on the surface of the specimen are removed by gentle brushing or scraping. Wax-based adhesives or fillers should be removed by the application of methylene chloride soaked tissues or pads (Rixon 1976; Howie 1979a), as they can impair treatment.

Ethanolamine thioglycollate must only be prepared in solution immediately prior to its use because it becomes unusable after only a few hours exposure to air. A solution of 2-5% ethanolamine thioglycollate in 95% industrial methylated spirit, anhydrous iso-propanol or absolute ethanol should be made up. In the case of IMS, the small quantity of water present in the final solution is not enough to endanger specimens during treatment. After cleaning, the specimen is lowered into the solution with forceps or wire hooks. Glass beakers are ideal containers for immersion as both the iron complexing reactions and the general state of the specimen can be watched. A grill or mesh made of 'Perspex' or some other insoluble product placed in the bottom of the beaker allows the specimen to rest above the surface of the sediment which usually accumulates. The ethanolamine thioglycollate solution should cover the specimen by 5-6cm to ensure adequate dilution of the reaction products (Cornish and Doyle 1984).

Initially the ferrothioglycollate complex emerges from the most oxidised parts of the specimen, turning the solution violet. The solution is changed after a maximum of four hours immersion (or earlier, if the colour is so intense that the solution becomes opaque) to prevent the violet complex ferrothioglycollate anion from oxidising to a brown insoluble precipitate which will coat the specimen. The treatment can be repeated, if necessary, provided the specimen is 'washed' in clean, dry alcohol between immersions. It should be washed at least three times longer than the treatment time to ensure removal of reaction products. When little or no violet ferrothioglycollate complex forms during immersion, the treatment can cease. The specimen is then given a final wash in several clean batches of solvent and allowed to dry, either in air or in a desiccator. Cleaned fragments can be reassembled and glued using 'Butvar B76' in acetone (1:1 by volume) or other solvent-based cement.

The same method can also be used on pyritised palaeobotanical material (e.g. fruits and seeds). The often microscopic size of such specimens can be a problem; extra care must be taken to ensure they are well labelled during treatment. In order to prevent distortion or splitting after cleaning and neutralizing with ethanolamine thioglycollate, the specimens should not be allowed to dry in air until a suitable storage method has been devised. Storage in silicone fluid is advisable for small specimens as this provides a stable environment at a reasonable cost, but it can only be used after transferring the specimen through a graded series of different solvent mixtures. This is because the clean dry alcohol used to wash the specimen after treatment is immiscible with silicone fluid. Recommended solvents and immersion times are outlined below:

Day 1	24 hrs	50% IMS 50% acetone
Day 2	48 hrs	100% acetone
Day 4	6 hrs	25% toluene 75% acetone
Day 4	overnight	50% toluene 50% acetone
Day 5	6 hrs	100% toluene
Day 5	overnight	25% silicone fluid 75% toluene
Day 6	permanent	100% silicone fluid

The silicone fluid used at present is 'Dow Corning 200/350 CS grade', although lower viscosity grades are being investigated in the BM(NH) Palaeontology Laboratory. Small glass jars with lids are ideal containers for this treatment as the solvents can be stored in them for several days without evaporating too much. They must be correctly labelled to avoid confusion during immersion.

Specimens that need to be examined in the future can be simply removed from the silicone fluid and placed in toluene. They must not be allowed to dry out as stresses can be set up which will destroy the specimen. After examination the specimens should be re-immersed in silicone fluid using stages 5 and 6 (above).

Sepiolite paste technique

For very large specimens suffering from pyrite oxidation which are impractical to immerse, or for very friable specimens which would be damaged by immersion, an alternative technique can be used. This method takes more time and is not as successful as the immersion technique.

A solution of 3-5% ethanolamine thioglycollate in 95% industrial methylated spirit or anhydrous iso-propanol is prepared and mixed with sepiolite (highly absorbent magnesium silicate) to form a paste. The paste is applied liberally over the oxidising part of the specimen. The whole area is then covered with polythene film or aluminium film to prevent rapid evaporation of the solvent. After 2-3 hours the covering is removed and the paste allowed to air dry. The sepiolite is then removed by gentle brushing and a paste of IMS and sepiolite applied for cleaning purposes. If the specimen is very friable a thin layer of gauze should be placed over the oxidised area prior to treatment; this provides a separator between the sepiolite and the surface of the specimen, thus enabling the dried sepiolite to be removed simply by lifting the gauze.

Shale reduction technique

Many dark coloured shales contain pyrite, both as nodules and as finely disseminated particles throughout the matrix. When exposed to moist air the pyrite oxidises, causing local swelling and discoloration around the nodules, and delamination and cracking where migrating oxidation products crystallise along bedding planes and cleavages (Howie 1979a). The most satisfactory way of dealing with specimens in unstable shales is to remove as much of the matrix as possible. Small blocks (less than 5cm) containing surface specimens can generally be reduced by the careful use of a scalpel to split or cut away matrix from the back of the specimen. For larger specimens the removal of shale or clay backing must be coupled with the application of a rigid jacket. The method outlined below has been used on several specimens at the BM(NH) with reasonable success (Howie 1979a).

Labels should be removed and kept. The specimen is coated with a thin layer of consolidant, which also acts as a separator, e.g. 10% PVA in methyl ethyl ketone. This is allowed to air dry and any large cracks filled using 'AJK dough' (see Howie 1979a) or plaster of Paris. Any filler which may have previously been placed round the specimen must be removed so that the specimen has a hollow ridge round its perimeter. Silicone grease is then applied over the entire surface of the specimen and a layer of tissue paper placed on top to act as a separator. A thin layer of latex is painted over the surface and allowed to dry. On top of the latex a layer of jute floc and latex mix is applied to a depth of 3-5mm; this mix is also applied around the perimeter of the specimen to hold it in place. Over the jute floc/latex jacket a glass fibre support is applied, consisting of two or three layers of chopped strand matt fibre glass reinforced with polyester resin.

The slab is then carefully inverted on to a flat piece of polyurethane foam. The shale backing is reduced by splitting along the laminations using small chisels until a thickness of 10-20mm is achieved. The exposed shale surface is consolidated carefully using a thin solution of PVA in methyl ethyl ketone. At this stage it is prudent to place a separator on the shale surface (which will ease future conservation or further preparation), by applying a layer of surface matt glass fibre in polyvinyl alcohol. This layer is allowed to dry before adding a layer of glass fibre reinforced resin. The slab should be carefully turned over and the jacket covering the specimen removed. The silicone grease on the surface of the specimen is removed with methylene chloride, and the cleaned surface hardened with thin layers of PVA in methyl ethyl ketone. The edges of the specimen should be trimmed and made smooth. If necessary, the specimen can be inverted and a final fine layer of glass fibre reinforced resin applied over the back and round the sides of the block. Where possible labels should be replaced, and all treatments must be recorded on a laboratory work card or in the specimen register.

Very large unstable slabs must be protected from fluctuations in relative humidity. Enclosure in glazed cases with holes at the base through which conditioned air (by passing through silica gel) can circulate is one method used at the BM(NH) (see Howie 1979b and Thompson 1978).

LABELS AND CONTAINERS

Labels and cardboard containers which come into physical contact with oxidising pyritic specimens can be totally destroyed. This is mainly due to sulphuric acid (a product of pyrite oxidation) attacking the cellulose present. Labels are especially important to treat; without them the specimen can be rendered scientifically worthless. Specimen containers should be replaced where possible and a record made of when this was done. If the label is not of historical value then it should be replaced with a fresh one, having transferred all details from the old to the new. If, however, the label needs to be kept, then it must be neutralised. Badly damaged labels can be treated by exposure to ammonia fumes or by gentle washing in a very dilute 1% ethanolamine thioglycollate solution in alcohol. The label can then be coated in a polymethyl methacrylate emulsion ('Primal AC73') and a tissue backing applied. Treated labels are then placed into small polythene sachets which can be heat or pressure sealed.

CONSOLIDANTS

No varnish or coating is totally impermeable to air or water vapour. In many cases where the specimen is robust no consolidant is necessary after treatment. If a consolidant needs to be applied,then several thin layers are better than one thick one. Consolidation of treated but friable specimens is often advisable. Consolidants such as PVA (5-10% in methyl ethyl ketone), paraloid or polyvinyl butyral are recommended (the last, however, shows poor adhesion in some cases: Howie 1979b).

POST TREATMENT STORAGE

Storage of all treated material should be in a low humidity environment (40-55% relative humidity), to help prevent further oxidation. Regular monitoring of the storage environment is essential. If relative humidity rises above c.60%, even for a few days, pyrite oxidation can occur. Thompson (1978) and Howie (1979a) described methods for controlling and modifying storage and exhibition environments using various techniques.

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Lorraine Cornish
Palaeontology Laboratory
British Museum (Natural History)
Cromwell Road
London SW7 5BD

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Supplier of ethanolamine thioglycollate.
Robinson Brothers Ltd., Phoenix Street, West Bromwich, West Midlands B70 OAH.

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THE ACID TECHNIQUE IN VERTEBRATE PALAEONTOLOGY: A REVIEW

BY WILLIAM LINDSAY

INTRODUCTION

Acid preparation of vertebrate fossils has many advantages over mechanical preparation techniques: it removes the risk of gross injury to a specimen from the mechanical force of chisel or saw; it enables the removal of rock matrix from the narrowest of gaps where mechanical tools cannot penetrate; it can more subtly and accurately differentiate between the matrix and fossil; and it also has the advantage that, while the acid is working, the preparator can attend to other tasks. Used properly on suitable material, acids can uncover the finest details and produce a quality of preparation which, until their introduction, had not been possible (Williams 1953) (see Figs.1, 3).

Acids, however, are only tools. They can seriously damage or destroy the fossil and they present particular health and safety problems for the preparator (Clydesdale 1982). Acid prepared specimens also present particular problems for the curator. The preparation process not only renders the fossil more fragile and requires the application of a variety of adhesives and consolidants but may also induce less obvious chemical changes. This paper sets out to acquaint curators and conservators with the processes involved in the technique and to document the chemicals and consolidants which may have been used on material now in their care. It does not describe how the technique is carried out.

The acid technique summarised

Acid preparation involves immersing calcareous rocks in aqueous solutions of acetic or formic acid (Fig.2), thereby dissolving the calcium carbonate of the rock and, usually, any calcium carbonate which fills the interstices of the fossil bone or teeth. The bone and teeth of fossil vertebrates are composed mainly of calcium phosphate, which is almost insoluble in acetic and formic acid. The bones and teeth keep their shape but may become fragile. After hours or days in acid, the fossiliferous block is washed, dried and the newly exposed bones and teeth covered with a protective lacquer (Fig.4); the process is then repeated.

Occasionally it is not possible to dissolve the matrix to reveal the fossil; instead, the fossil itself is removed by acid. Steen (1931) used this technique on amphibian remains, preserved in a coaly matrix. The fossilised bones, particularly the skulls, of these amphibians are commonly thin and flattened and held in the matrix by their ornamented surfaces. A weak solution of hydrochloric acid is used to dissolve the bone, leaving a natural mould in the rock. From this a rubber cast can be made.

In some cases it is possible to preferentially direct acid onto selected areas of a specimen in order to expose or remove a particular element (Fig.5A, B). In all cases the technique relies on the ability of the acid used to distinguish between matrix and fossil. In most cases the matrix is predominantly calcium carbonate, but it need not be a pure limestone; even where a little calcium carbonate is present, its removal may weaken the rock enough to ease further mechanical preparation.

HISTORICAL DEVELOPMENT

Acids have been used in the preparation of fossil material since the late nineteenth century; their application to vertebrates was noted by Bather as early as 1908, but they were not widely used until the late 1930s (Table 1).

Table 1. Development of the acid technique.

Transfer Method		Acid Preparation (Vertebrate)
Young (1877)		
Holm (1890)		
Walton (1923)		Bather (1908)
Lang (1926)		
Bulman (1931)	ACETIC AND FORMIC ACID	
White (1946)		
Toombs and Rixon (1950)		Toombs (1948)
	THIOGLYCOLLIC ACID	Rixon (1949)
		Howie (1974)

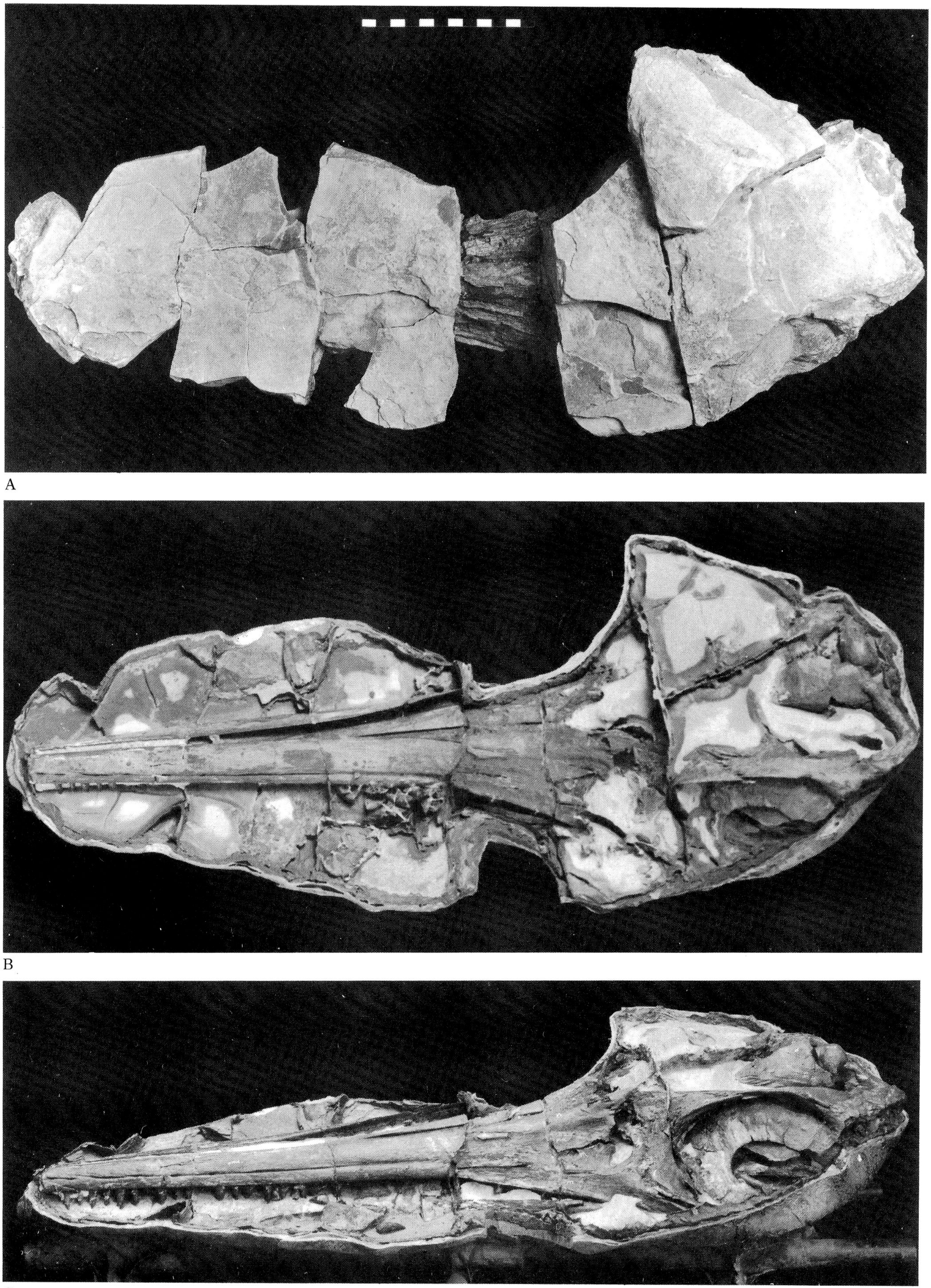

Fig.1. Ichthyosaur, Lower Cretaceous; Queensland, Australia. A, prior to treatment with acetic acid. B, after ten months of acid treatment (1985). C, oblique view, after twelve months of acid treatments. Scale bar in cm.

Fig.2. The initial acid immersion of the specimen shown in Fig.1.

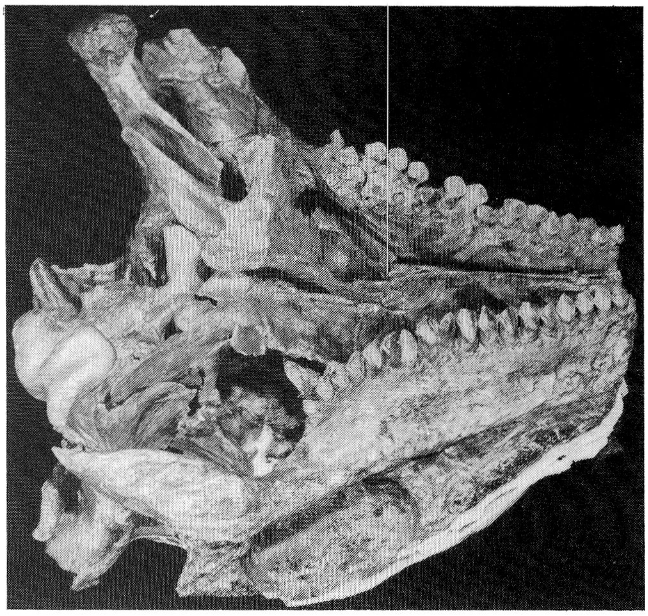

Fig.3. <u>Scelidosaurus harrisoni</u> Owen. BM(NH) R1111. Left ventral view of the skull showing the cranial morphology revealed by acid preparation in the round (prepared 1976).

The introduction of acids to vertebrate preparation methods came mainly via the technique referred to as the Transfer Method (Toombs and Rixon 1950). Although now considered as subordinate to acid preparation, the transfer method, developed in the late 1940s and used more or less unchanged today, had its origins in the nineteenth century (Table 1). The method relies on the attachment of the exposed area of fossil to a supportive medium while the matrix is being removed. Generally, the most heavily ornamented surfaces are embedded in the matrix.

Young (1877) used hot asphalt and brown paper to transfer thin, delicate fronds of Carboniferous bryozoans from shale, which he removed by soaking in water. Holm (1890) used the same principle to transfer graptolites from limestone to glass slides, using hydrochloric acid. Walton (1923) and Lang (1926) used hydrofluoric acid in the transfer of fossil plants and invertebrates from siliceous matrices. In one of the earliest applications of the transfer method to vertebrate palaeontology Bulman (1931) transferred the carbonaceous skeletons of an enigmatic Devonian fish, <u>Palaeospondylus gunni</u>, from calcareous sandstone to a glass slide, using hydrochloric and hydrofluoric acids.

By the late 1930s acetic acid had been introduced by Toombs as an advance on the mineral acids previously used. White (1946) adapted the transfer method to the extraction of bony plates of ostracoderms using a method devised by Toombs: the exposed fossil was coated with a supportive rubber solution ('Bostik') and the matrix was dissolved in a 20% solution of acetic acid. A major advance in the transfer method was made by Toombs and Rixon (1950) who introduced the use of a clear setting, acid resistant resin to support the fossil while it was etched free of matrix. This allowed both sides of the fossil to be viewed and studied, and it faithfully cast those parts preserved as natural moulds in the rock.

The classic acid preparation technique was developed by Toombs (1948) and Rixon (1949) to deal with specimens which could not be transferred or which were of more benefit in the round rather than attached by one surface to some support (Fig.3). The detailed process was described by Rixon (1976, pp.84-110).

<u>Acids and chemistry</u>

Acetic acid is the most commonly used acid in the preparation of vertebrate remains. Although Toombs introduced it, Bather (1909) was the first to suggest that acetic acid might be of use. [Bather himself used an acid which he called 'hypo-acetin'; Whybrow (1985) has suggested this to be a by-product of the manufacture of explosives.] From its initial use on fossil fish Rixon (1949) applied it to a variety of reptile fossils preserved in limestones and calcareous mudstones. It was also shown to be suitable for the bulk preparation of matrices, such as cave breccias, containing large numbers of small bones. Toombs developed the use of acetic acid in response to the failure of mineral acids to discriminate between the calcium phosphate of the bone and the carbonate of the matrix. Later Rixon (1949) sought an alternative to the 'unpleasant pungent odour' of acetic acid and tried formic acid, another weak organic acid, which is frequently used today.

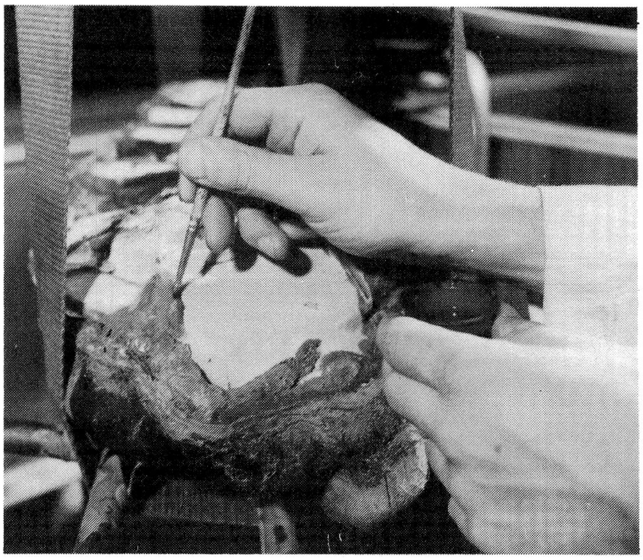

Fig.4. Applying a protective lacquer (polybutyl methacrylate) to bone newly exposed by acetic acid.

Acetic and formic acid are both weak acids in aqueous solutions as they dissociate incompletely:-

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$
Acetic Acid

$$HCOOH \rightleftharpoons HCOO^- + H^+$$
Formic Acid

For comparison, the degree of dissociation of a 0.IN solution of acetic acid is 0.013 (25°C whereas that of a 0.1N solution of hydrochloric acid is 0.95 (25°C). Weak acids dissociate to a lesser extent than strong acids and consequently there are fewer H^+ ions in solution. The weakness of both acids allows a slower and more easily controlled reaction with carbonates than would be obtained with a strong mineral acid, but acetic and formic acid do not just remove calcium carbonate from the specimen being prepared. Fossil bone prepared with either acid is liable to lose some phosphate, as well as significant amounts of carbonate infilling, which may remove some internal strength. Table 2 shows the solubility of calcium phosphate in acetic acid and formic acid (Braillon 1973).

While calcium phosphate, $Ca_3(PO_4)_2$, is almost insoluble in water at pH7 (< 1 mg/litre), it is clearly not insoluble in acid solutions.

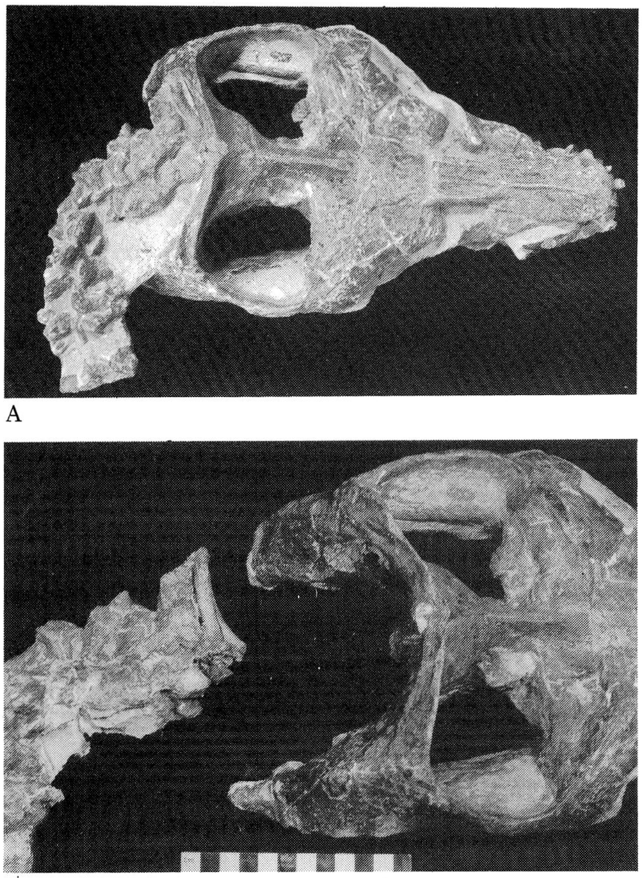

Fig.5. Plesiosaurus macrocephalus Owen. BM(NH) 49202. Lower Lias; Lyme Regis, England.
A, skull and attached cervical vertebrae before acid treatment.
B, cervical vertebrae separated from the skull after acid treatment limited to the occipital region. Scale bar in cm.

The classic method of acid preparation is only possible because calcium carbonate, $CaCO_3$, is more soluble than $Ca_3(PO_4)_2$. The reaction -

$$CaCO_3 + 2(CH_3COOH) \rightarrow Ca(CH_3COO)_2 + CO_2 + H_2O$$

occurs more readily than the reaction -

$$Ca_3(PO_4)_2 + 3(CH_3COOH) \rightarrow 3CaCH_3COO + 2(H_3PO_4)$$

The solubility of $Ca_3(PO_4)_2$ is suppressed by the dissolution of $CaCO_3$ which increases pH and releases calcium ions into solution (Braillon 1973).

Table 2. Solubility of calcium phosphate (mg/litre).

	½ hour	4 hours	24 hours
Acetic Acid (5%)	580	1240	1700
Acetic Acid (15%)	1580	2060	2700
Formic Acid (10%)	1810	2740	5140

Table 2 also shows the markedly higher solubility of calcium phosphate in formic acid than in acetic acid. Patterson (1968) commented on the destruction of the bone surface of fossil fish in chalk caused by a 2% solution of formic acid. Excessive solution of calcium phosphate removes surface detail and weakens the fossil structure. A number of strategies have been used to avoid this:

1. The length of each immersion period should be kept to a useful minimum. Too long an immersion period may not only cause loss of detail and strength but can allow individual elements to change vital orientations. [Movement of specimens and excessive exposure to acid is often countered by the use of a rubber-latex/jute-floc jacket encased in a glass reinforced plastic casing applied to one side of the specimen (Rixon 1968). Such a watertight covering prohibits acid access and provides a base for anchoring exposed bones. GRP is stable over long periods but rubber latex embrittles with age and may distort the enclosed fossil.]

2. A reduction in the concentration of acid. Early preparations used 15% or 20% solutions of acetic acid but concentrations of 5-15% or even less can be effective.

3. Addition of phosphate ions to the solution. Braillon (1973) recommended the addition of 2.7 gm precipitated calcium phosphate to each litre of 15% acetic acid.

The reaction between acetic acid and the carbonate matrix -

$$2(CH_3COOH) + CaCO_3 \rightarrow Ca(CH_3COO)_2 + CO_2 + H_2O$$

proceeds to the left as carbon dioxide gas is given off. However, after some time equilibrium is reached, the solution is charged with calcium and acetate ions, and further solution of the matrix is prevented. Braillon (1973) suggested that this solution, containing a relatively high concentration of un-ionised acetic acid and a relatively high concentration of acetate ions, could be regenerated by the addition of a strong acid (hydrochloric acid) with the result -

$$Ca(CH_3COO)_2 + 2HCl \rightarrow 2(CH_3COOH) + CaCl_2$$

In such a reaction, however, the rate of solution may become uncontrollably rapid, as shown in Fig.6. In addition the reaction may cause the solution of calcium phosphate unless the pH is carefully controlled at no less than 3. The addition of HCl introduces a number of risks which are not worth the small saving in cost of replacing spent acetic acid.

It cannot be overemphasised that all specimens prepared in any acid must be thoroughly washed to remove excess acid and salts. Where this is not properly done, the specimen may be disfigured by the growth of surface salts as the water evaporates. More severely, salts will also crystallise inside the specimen and can cause structural damage. A consequence of Braillon's addition of hydrochloric acid is that the acid solution becomes rich in calcium chloride.

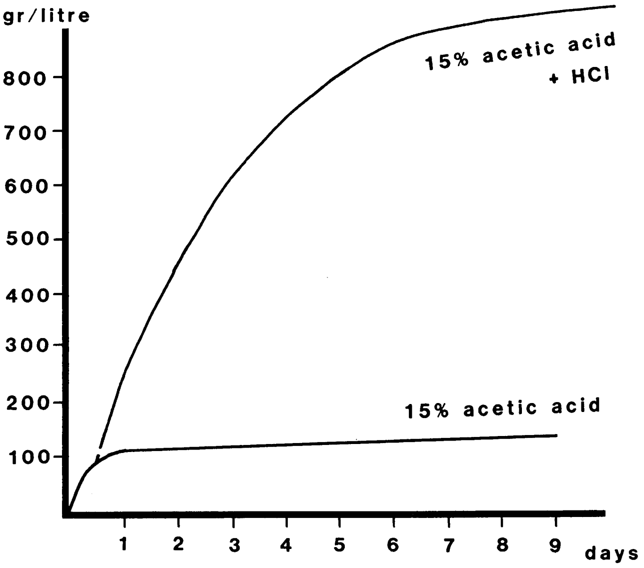

Fig.6. Solubility of calcium carbonate in acetic acid, and in acetic acid with hydrochloric acid added (after Braillon 1973).

Even when hydrochloric acid is not added the specimen will be saturated with calcium acetate in solution. Both salts are hygroscopic and their presence in insufficiently washed prepared specimens could pose serious problems for the long term care of the material, especially if pyrite is also present.

Thioglycollic acid

A significant advance in the use of acids for vertebrate preparation has been the introduction of thioglycollic acid by Howie (1974). Until then there had been no satisfactory method for preparing fossils enclosed in a haematitic matrix. Ferric oxide, Fe_2O_3, forms a hard cement in many matrices and the mechanical preparation of delicate and well preserved fossils is a difficult task.

Thioglycollic acid leaches iron from the matrix by reducing ferric ions to the ferrous state which then forms a soluble ferrous thioglycollate that is removed in solution. A similar chelating effect can be obtained using the alkaline ethanolamine thioglycollate (Cornish and Doyle 1984; Stringer et al. 1985).

Thioglycollic acid dissolves the phosphate of the bone at a greater rate than acetic acid but this can be countered by the addition of calcium phosphate. There is a tendency for the ferrothioglycollate ion to oxidise during washing, leaving a brown stain on the surface of both matrix and bone. This can be avoided by the use of detergents and chelating agents in the first stages of washing.

Consolidants and adhesives

As with all prepared vertebrate material, mechanical or chemical, conservation is part of the preparation process. The acid technique demands consolidation of the specimen, not only to see it through the hazardous preparation process but also to protect it through its hazardous life in a collection. As the matrix is removed, externally and internally, the bone requires protection from over exposure to the acid solution and additional structural strength from consolidants.

Bather (1908) used a solution of cellulose (probably cellulose nitrate) in amyl or ethyl acetate to which some castor oil had been added as a plasticiser. Although cellulose nitrate is insoluble in dilute acetic acid it tends to become brittle with time and to peel from non-porous surfaces (Rixon 1976). In his early work Toombs (1948) does not seem to have used any consolidant or protective coating, but Rixon (1949) used polystyrene in ethyl acetate as an initial protective lacquer on exposed plesiosaurian vertebrae. Rixon also applied a solution of 'Alvar [polyvinylacetal] 1570' in amyl acetate and methylated spirits as a consolidant. 'Alvar 1570' replaced the cellulose hardeners but is no longer manufactured, having itself been replaced by 'Butvar' [polyvinyl butyral].

Polystyrene was one of many polymers introduced to the conservation of geological material during the 1930s (Howie 1984). It is acid resistant but shrinks as it dries. Howie (1974) used it in preference to polybutyl- and polymethyl-methacrylate as the protective lacquer when preparing specimens in thioglycollic acid. Polystyrene in benzene was also used in the early years of the acid technique for fixing bones broken or separated during the acid development.

Polymethyl methacrylate is highly resistant to organic acids but shrinks markedly on drying with the result that, when used as a consolidant, the bone surface may peel away. It has been useful, however, as an acid resistant adhesive commonly dissolved in ethyl acetate, though chloroform and ethylene dichloride have also been used as solvents. Supplied as monomer and polymer catalyst, polymethyl methacrylate has been used as a gap filler in bone to be treated in acid (Rixon 1968) and as an adhesive to seal wide cracks in adjoining blocks. Shrinkage can be obviated by adding an inert filler such as micro-glass beads (Croucher and Woolley 1982).

Rixon (1976, p.88) considered polybutyl methacrylate to be the most effective consolidant for fossils being developed in acid, and it remains in general use for such work at the Palaeontology Laboratory, British Museum (Natural History). Previously supplied in white spirit as 'Vinalak 5911', it was normally used diluted in butanone; 'Vinalak' is no longer available and has been replaced by 'Synocryl 9123S', a solution of polybutyl methacrylate in ICI's 'Aromasol H'. 'Vinalak' withstands long periods of immersion in dilute acetic and formic acids and has been used in thioglycollic acid. It remains plastic but can become sticky if the specimen is handled too much.

Recently the cyanoacrylates - 'super-glues' - have been used to cement broken bones. Although most effective for small specimens, they have been used on a larger scale. The properties and long term stability of the cyanoacrylates used on fossil bone are not completely understood, but they seem resistant to the effects of acetic acid development. They are, however, practically insoluble when set.

CONSERVATION POINTS

The acid technique has been in regular use for nearly fifty years and there are now a significant number of acid prepared vertebrate specimens in museum collections. Acid prepared specimens often acquire major importance as the technique reveals the most subtle diagnostic features, but the specimens are almost inevitably made more fragile. Consolidants cannot be expected to replace the robustness afforded by an infilling matrix and prepared material needs to be handled and stored with care.

Brunton _et al_. (1985, p.C30) referred to the storage treatment of fragile silicified fossils. Similar attention should be paid to prepared vertebrate material, but it should never be stored with any form of fibrous packing material. Even if the delicate, fine features do not catch on the packing material, there is every chance that fibres will adhere to the consolidated fossil surface. The risks of damage are then compounded by the need to apply solvents to the specimen to remove the fibres. Some small acid prepared specimens can be temporarily stored embedded in a low melting point, water soluble wax such as polyethylene glycol 4000. The wax is easily removed, without damaging the specimen, by immersion in warm water or by careful heating (Rixon 1976, p.67).

It is essential that pictorial and written records of the vertebrate material, before, during and after preparation, are retained. The complexity of some acid prepared vertebrate fossils makes the repair of broken and detached pieces a frustrating task without a good record of how the specimen should be; any later reconstruction of a completely dis-assembled specimen will also be aided by good records.

Vertebrate specimens are often not completely prepared initially. Sometimes the desired information is obtained without needing to prepare the whole specimen. Sometimes a host of other jobs interfere with the work and the specimen may be placed in storage. It should always be remembered that someone at a later date may wish to further prepare the material; consolidants or other materials used in the conservation of the specimen may interfere with such later work.

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William Lindsay
Palaeontology Laboratory
British Museum (Natural History)
Cromwell Road
London SW7 5BD

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THE CONSERVATION OF SUB-FOSSIL BONE

BY ADRIAN M. DOYLE

INTRODUCTION

There is much sub-fossil bone material within the collections of the Palaeontology Department of the British Museum (Natural History), mostly Pleistocene in age (e.g. the American Mastodon americanus and Dinornithiformes, Moas, from New Zealand). Particular attention has been given to tusks and limb bones which required urgent conservation through their susceptibility to deterioration in storage cabinets.

Sub-fossil bone includes a non-mineralised component and may retain collagen and products of protein decomposition. It is liable to deteriorate due to excessive drying out in relative humidities below 40%, while higher values allow water vapour to permeate through the bone and weaken its structure before drying out. Damage can result in delamination of the surface layers, as well as internal cracking along a line of weakness (often associated with growth lines); some parts may break away completely and expose internal cancellar structures to environmentally induced stresses and strains. Conservation is therefore required to maintain the stability of the specimen in the fluctuating relative humidity of unfavourable storage environments.

METHOD

The synthetic resin polyvinyl acetate (PVA) emulsion has been successfully used over a number of years in palaeontological conservation; its physical properties are well known, as is its long term chemical stability. It is also relatively inexpensive, easy to use and, since it is water-based, does not require elaborate safety facilities such as ventilation or extraction during application.

Damaged bone should be removed immediately from its low humidity environment and placed in one of c.50% Rh, to prevent further decay prior to treatment. If possible, measures should be taken to stabilise the environment of the storage area at 40-60% Rh since on return the specimen may begin to deteriorate even after treatment. There are many methods for monitoring and providing stable storage facilities (see Thompson 1978 and Howie 1979); recording thermohygrographs can be used to provide a permanent record of an environment prior to or during its use. Furthermore, a suitable area for conservation must be prepared or facilities made for temporary storage during treatment.

Before work, a general examination of the bone is advisable since fragments will tend to fall off if only loosely attached or the ink on labels may run. Fragments can be glued firmly back in place with concentrated PVA emulsion and labels coated with a water-proof varnish such as 'Butvar B76' (polyvinyl butyral) dissolved in ethyl acetate or acetone. It is worth making a note of the information on a label, however, in case the 'Butvar' coating is inadequate.

A humidity tent can be purchased, or made from polythene sheeting supported on a rigid framework of laboratory scaffolding. Humidification is achieved by placing water filled trays within the tent, and a humidity dial (e.g. hair hygrometer) is used to check that Rh stays above 40%; it is a fairly simple task to regulate the relative humidity by opening or closing valves or openings in the sheeting.

If examination of the bone reveals large longitudinal cracks, it should be placed in the humidity tent, initially at 50% Rh, then increased to 80-85% Rh. Investigations show that at this level the bone will be at its maximum state of relaxation, i.e. the cracks or gaps will be at their greatest and the bone will be at its most flexible. At this point, concentrated PVA emulsion is forced into the gaps, by brushing or by syringe, and the gaps forced closed and held with clamps or string until set. Large holes can be filled with plaster of Paris but, since the plaster tends to soften, it is preferable to use a solvent based filler, such as 'A.J.K. Dough' (Howie 1979), which tends to hold better by retaining its strength while remaining flexible and can be easily removed with industrial methylated spirit or acetone. Alternatively, very large holes can be covered with polythene patches secured with masking tape. The main aim so far as possible is to prevent the PVA emulsion from seeping through the bone structure and running out without having had time to accumulate inside.

At these high relative humidity levels there is an increased likelihood that an outbreak of mould growth may occur. Severe growth can be treated with a wide spectrum fungicide such as 'Parmetol K40' which is water soluble and can be brushed over the surface repeatedly until the growth is destroyed. It is possible for mould to re-appear during the application of PVA, since the emulsion is an ideal medium for the growth of mould found in both sub-fossil bone and the atmosphere. Fungicide should be added to the PVA solution during dilution to prevent the spread of mould to other bones being treated with the same supply.

In general, an emulsion should have a high plasticiser content (no less than 20%) with a small particle size and a matt or semi-matt finish. The Palaeontology Laboratory at the British Museum (Natural History) has had good results from an emulsion called 'Tenaxatex WS 3956' (supplied by Williams Adhesives Ltd) which replaces 'Vinamul N9146' and satisfies

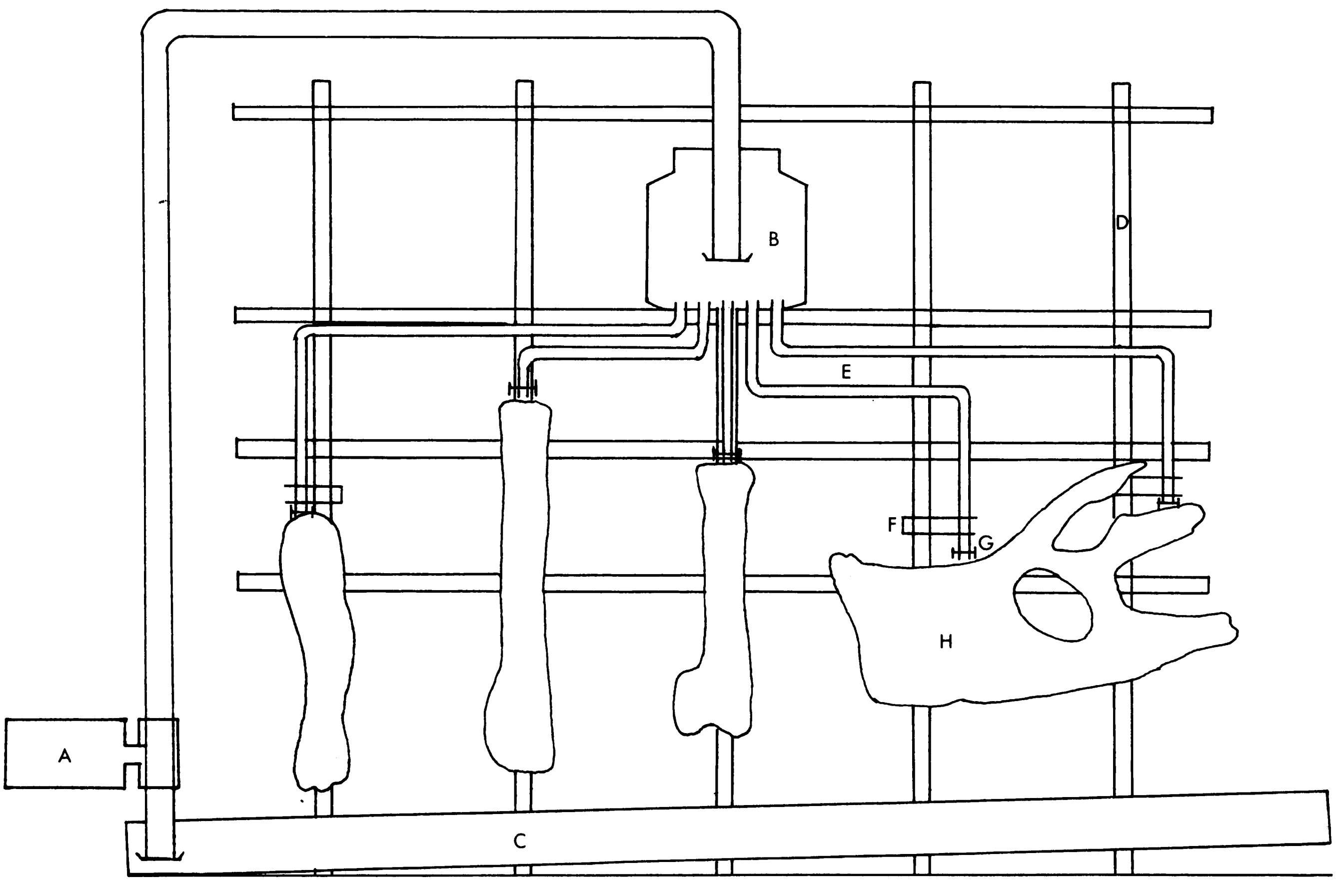

Fig.1. Diagram of the gravity drip impregnation apparatus. A, peristaltic pump; B, container of PVA emulsion; C, container trough; D, laboratory scaffolding; E, silicone rubher tubes; F, laboratory clamps; G, tube clips; H, bones.

these requirements. It is diluted with deionised water at a concentration of 10%, giving a solids content of approximately 5% based on the manufacturer's data sheet.

Once preparation of the bones for conservation has been completed, a gravity drip apparatus is used to apply the consolidant (see Doyle 1983; fig.1 herein). The apparatus can be easily modified to suit the requirements of different specimens. The basic objective is to flush PVA solution through a bone from a supply tank, positioned above the specimen, using silicone rubber tubes; the technique is similar in principle to a hospital drip. The PVA is allowed to flood out of the specimen, which should preferably be suspended (or placed on an inclined board if too heavy), and drain into a container from where a pump transfers excess back into the original tank for recycling. The system is therefore self sustaining and can be left to run unsupervised. This method has an immediate advantage over the conventional practice of brushing on PVA as it ensures adequate penetration of the bone without subjecting it to the sudden strain associated with immersion or vacuum impregnation techniques.

The process of impregnation is gradual as the solid particles of the emulsion begin to accumulate within the bone structure and the rate of flow must be regulated to achieve the optimum effect. The silicone rubber tube feeds must be re-positioned several times to ensure total impregnation, and hand held sprays can be used to prevent adjacent areas from drying out too soon. After a period of time, depending on the condition of the bone and the solids accumulated, the PVA has to be discarded and replaced with a fresh batch since it becomes very dilute. A comparison of the consistency of the used PVA with a fresh batch is usually a good indication. Fungicide ('Parmetol') can be added again if necessary. Cracks which have opened are carefully forced closed and secured with string, binding, or 'G' clamps before allowing the specimen to dry out.

If the specimen has to be left overnight for further conservation the following day, the emulsion is allowed to drain from the specimen for at least one hour before covering with polythene sheeting to prevent excessive drying out. The running time of the apparatus may be several hours before the bone is fully saturated (as in the case of bird limb bones); it is difficult to decide when impregnation should cease, although the bone does become very flexible and, if pressure is applied, PVA seeps out through any cracks or fissures. Once impregnation is completed, the process of drying out must not be hurried since this may result in new cracking or splitting. If this does occur, the specimen is returned to the humidity tent initally at a high Rh (80-85%) before opening the tent to allow the atmosphere to equate with the working environment (see Howie 1979). This prevents further strain being placed on the bone but may initiate an outbreak of mould which should be removed before drying. Once completely dry, it is unlikely that the mould will continue to grow and the specimen can be cleaned up with acetone prior to storage.

A specimen treated recently by this method is a skull of Mastodon americanus. It required several weeks of impregnation and several litres of emulsion before becoming thoroughly saturated. Some re-assembly was also necessary, in particular a tusk which had broken off. The tusk was impregnated independently of the skull prior to its attachment using a plastic reinforced tube secured in two holes drilled in the skull and the tusk, and cemented in place with plaster of Paris mixed with PVA emulsion. A small amount of cosmetic work was required to fill gaps where the tusk joined the skull, prior to painting with earth based powder paints mixed with PVA; any surface shine was removed with lint-free tissue pads soaked in acetone.

After treatment this specimen was mounted on a plywood board covered with polyurethane foam and lined with acid-free tissue paper. It was secured by brass strip covered with shrink wrap plastic and screwed to the board. The end result was a fully conserved specimen weighing several times more than it did (due to the absorption of solids in the PVA) but in a much more acceptable condition. It has remained stable in the Museum for eighteen months without any deterioration, although Rh is carefully maintained above 40% and below 60%. Within these limitations, the results are quite acceptable for the long term conservation of sub-fossil bone.

Adrian M. Doyle
Palaeontology Laboratory
British Museum (Natural History)
Cromwell Road
London SW7 5BD

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ARCHAEOLOGICAL CONSERVATION: SOME USEFUL APPLICATIONS FOR GEOLOGY

BY HELENA JAESCHKE AND RICHARD JAESCHKE

INTRODUCTION

Our work involves the conservation of a wide range of objects, mostly antiquities and archaeological material. In the last two years, thanks to Rosina Down (Curator of the Zoological Collection, University College London), we have had the opportunity to work with objects from natural history and geological contexts. As a result, we realised that many of the materials and methods used everyday in archaeological conservation could be extremely useful in the care of geological collections. Keene (herein, pp.421-425) gives an excellent introduction to some of the materials, while the present article provides more details of their use in practice.

CLEANING

One of the major tasks in the maintenance of collections is cleaning, particularly the removal of greasy, black dirt which accumulates on the surface of objects. Obviously, before treatment is begun great care must be taken to test that the object itself will not be damaged by the cleaning solution or the technique with which it is applied. Water alone is seldom sufficient and ordinary soaps or detergents may cause damage or leave deposits. One of the most commonly used compounds in archaeological conservation is a non-ionic detergent called 'Synperonic N'. This is sold as a clear, syrupy liquid which is concentrated, so only a few drops are required per litre of water. It can be used on a wide range of materials, from textiles and feathers to pottery and stone, provided the surface is reasonably stable in the presence of water. We have used it on a wide variety of stones, on fossil elephant teeth and on sponge skeletons such as Venus flower baskets; it has proved very satisfactory.

In cases where the object is unaffected by the presence of water and where the surface is very porous or intricate, cleaning may be carried out by immersion in a solution of a few drops of 'Synperonic N' in distilled or deionised water, followed by rinsing in clean distilled water. ('Synperonic N' leaves very little deposit, but whenever possible it is better to rinse). When soaking the object is undesirable, the solution may be applied on small cotton wool swabs at the end of small wooden sticks; the swab is gently rolled to and fro across the surface. Swabs can be thoroughly saturated with the solution or they can merely be dipped in the foam so that the object itself is hardly moistened. This is particularly useful when dealing with water-soluble dirt on objects which react to moisture, such as ivory and sub-fossil bone.

Water-miscible solvents can be used separately or mixed into the solution, either to speed evaporation or to act as further cleaning agents. For example, we cleaned a carved ivory tooth with a 1:1 mixture of acetone and distilled water to which a few drops of 'Synperonic N' had been added; the solution was applied sparingly on cotton wool swabs and immediately rinsed off with swabs of acetone. This removed the old animal glue with which the tooth had been repaired and the old cotton wool packing which had adhered to it, without wetting the ivory enough to cause a reaction.

Some objects are so sensitive to moisture that only swabs of pure solvent can be used. A variety of solvents and solvent mixes should be tested carefully to see which is the best in each case. Wherever possible, it should be the state of the object rather than its size which dictates the cleaning method chosen. Faced with a large object or collection of objects to clean, it may seem far easier to use quicker methods, such as immersing and scrubbing the entire object, but great damage can be done this way. In archaeological conservation it is not uncommon for fragile objects with a surface area of several hundred square metres (for example the painted walls of an entire temple) to be cleaned with tiny swabs a few millimetres in diameter. Such a task may seem daunting at first, but carried out steadily and carefully, it is quite soon accomplished. On the other hand, tiny objects with an intricate but very stable surface may benefit more from being cleaned by immersion than by swabbing, as the cotton wool fibres could catch on projections from the surface. Research is being undertaken in the USA to find alternatives to cotton wool (such as synthetic fibres or sponges) for use in cleaning, but at present cotton wool is still the cheapest and best.

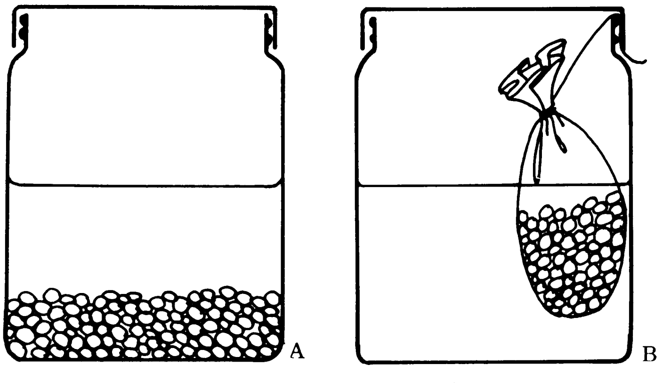

Fig.1. The resin can be added directly to the solvent in the jar (A) and stirred, or suspended in a small gauze bag to dissolve (B).

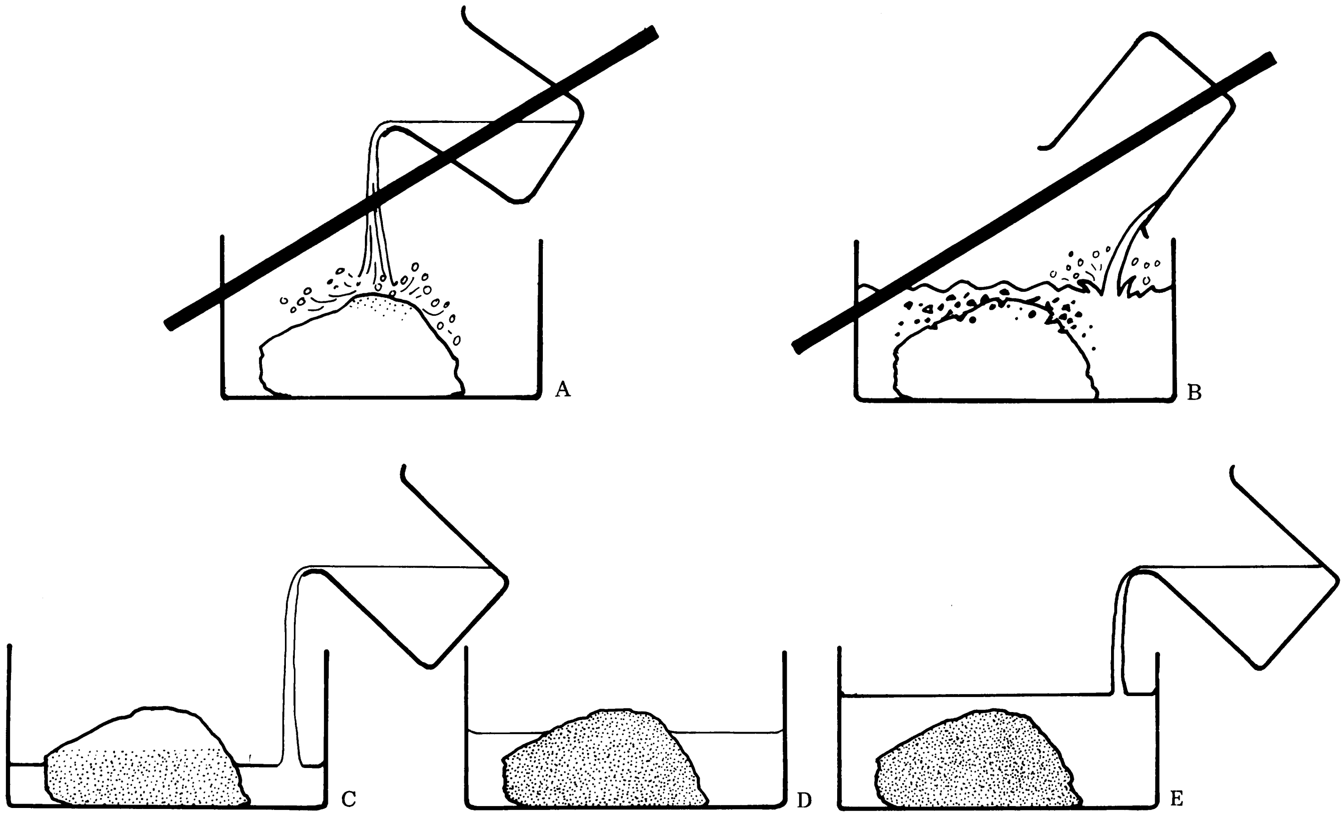

Fig.2. When immersing an object in consolidant solution NEVER pour the solution directly onto the object (A) or add it too quickly, as air bubbles may form within the object, breaking off parts of the surface (B). Always add the solution slowly in small amounts (C), allowing it to be absorbed into the object by capillary action (D), before topping up. Make sure the object is completely covered with solution for complete consolidation (E).

JOINING

Separate parts of an object may need to be joined together, or broken objects repaired. In most cases the adhesive should be readily resoluble, colourless, transparent, easy to use and relatively quicksetting. Until recently cellulose nitrate and polyvinyl acetate (PVA) were the most commonly used adhesives in this category, but the increased development of acrylic resins means that there are now alternatives with much better ageing properties. Paraloid (polymethacrylate) resins have proved to be extremely useful: of the different grades available we tend to use Paraloid B48 the most often, although excellent results are also reported for Paraloid B72. Paraloid is sold as loose pellets which can be dissolved in a small jar (with a well-fitting lid) (Fig.1) which is partly filled with the desired solvent or solvent mix and stirred or allowed to stand overnight. We use acetone because it is less toxic than many other solvents and is easy to use, but some people prefer to use xylene or toluene (see warning note on solvents below, and Howie herein) alone or mixed with acetone, to slow down the rate of evaporation. If a small-toothpick is kept in the jar it forms a very handy dispenser of adhesive ready at all times. If the lid is left off and the adhesive becomes too syrupy, it is easily diluted with solvent. If the adhesive is too fluid some of the solvent can be allowed to evaporate off.

We have found both Paraloid B48 and B72 very successful for joining surfaces which are porous (such as stone, pottery and wood), impermeable (such as glass), rigid (such as bronze and iron) and flexible (such as leather and paper). The surfaces to be joined must be clean and dry, and the adhesive can be applied to one or both surfaces. The two edges should then be brought together and held for a minute or so until the adhesive sets. Full bond strength will not be achieved for several hours. If the adhesive dries before the join is complete, it can be redissolved by brushing with a small amount of the pure solvent. When the surface is very porous a small amount of very dilute adhesive can be applied first and allowed to penetrate and dry before applying a second coat of the adhesive and making the join as usual. After the join is set, any excess adhesive can be cleaned off with a small swab of pure solvent.

If it is desirable to use an adhesive which is soluble in solvents other than the acetone-xylene-toluene range, Paraloid B67 is soluble in white spirit as well (see warning note below, and Howie herein). This is extremely useful when joining an object which has been consolidated with acrylic resin to strengthen it, since joins can then be made and taken down without softening the consolidant and weakening the object. B67 is treated in exactly the same way as B48, substituting white spirit for acetone.

Joins which are either extremely large or take a great deal of strain may need a more powerful adhesive. It is preferable to use an adhesive which is readily resoluble, but in some situations this is not possible. In such cases some people like to use epoxy resins, but we have found 'Sintolit' polyester adhesive to be extremely good, especially for large stone joins. 'Sintolit' is a two-part adhesive made in Italy and available in a range of colours (including 'transparent' which sets to a glassy, greenish-yellow). When mixed, the two parts form a thixotropic liquid which is easy to spread but does not drip or run - very useful when making joins at awkward angles. The instructions used to say that a piece of resin 'the size of a walnut' should be mixed with a piece of hardener 'the size of a coffee bean', but nowadays the percentage range of hardener to resin is given. Varying the proportions of hardener and resin slightly influences setting time, as does room temperature. A small trial batch should be mixed first to discover the handling characteristics and setting time under local conditions. If 5% hardener is used, the adhesive will set in about eight minutes at 20° C. This is extremely useful when dealing with large joins which would be difficult to hold in place for the several hours that many epoxies require. However, the join must be made accurately at the first attempt - it is extremely difficult to remove the adhesive once it has set, although methylene chloride (the main ingredient in 'Nitromors' paint stripper) will soften it. After the join is made, any excess adhesive can be cleaned off with acetone while it is still syrupy, or pulled off like a putty when it gels just before setting. It is advisable to test the placement of the pieces of the object several times before the adhesive is applied to make sure that an accurate join can be made quickly.

CONSOLIDATION

Objects which are very fragile or which have a powdery surface may require consolidation with a resin. Again, PVA and similar materials are being replaced by acrylic resins dissolved in solvent or as aqueous emulsions or dispersions. Paraloid B72 provides very good penetration and strength and seldom causes darkening or discoloration. We use it dissolved in acetone in the proportion of 3-15% weight per volume (30gms per litre up to 150gms per litre) depending on the strength required and the porosity of the surface. The choice of solvents and concentrations depends on the situation, but in general 3-7% solutions are usually sufficient (see warning note on solvents below, and Howie herein). The solution can be injected into cracks, allowed to flow onto the surface from a brush, or absorbed by immersion. When a fragile object is immersed in solution, it should be done so very slowly so that the solution is absorbed gently by capillary action. If the object is immersed too rapidly air bubbles will form which may push off pieces of the surface (Fig.2). If the object is extremely fragile or very dense it may need to be immersed in solvent first; then the consolidant (dissolved in more solvent) can be added slowly. This way the more volatile solvent fills the pores and cracks of the object first, helping to prevent the formation of air bubbles.

After the object has become completely saturated, it should be removed from the solution carefully, as it will be extremely fragile because of the increased weight and the lubricating action of the solution. The object should be allowed to drain over the solution and to dry slowly in the solvent fumes. This can be in a closed container on a rack over the solution, or in a closed container with a small dish of the solvent. Slowing down the drying helps to prevent any shine forming on the surface or darkening due to the presence of excess resin. If any excess remains on the surface it can be gently swabbed off with acetone.

Very delicate objects which are likely to break apart when immersed may be wrapped in gauze bandage before treatment. After removing from the consolidant and draining, they should be allowed to dry before the bandage is removed. If the bandage shows any sign of sticking to itself or to the object it should be moistened lightly with acetone to free it. Paraloid B72 is extremely convenient when used in this way, as it causes very little adhesion between bandage and object.

One advantage of consolidation is that it allows the soaking to remove salts of some objects which would not otherwise be strong enough. Within the object the resin forms a matrix which is permeable to water and the salt solution. We have soaked several dozen ancient ivories, badly damaged by salts, without any distortion or loss of fragments. Ancient wood can be treated similarly. After drying the object may still be fragile because the removal of salts has left gaps in the resin matrix; further consolidant can be added, either by immersion or by allowing it to flow onto the surface from a brush.

Perhaps the commonest use of consolidation before soaking has been for salt-damaged stone. For example, we treated a specimen of Egyptian limestone, so weakened by salts that it could not even be cleaned before consolidation, in the following way. After consolidation with 5% Paraloid B72 in acetone and drying, it was soaked in several changes of distilled water to remove salts. After the last wash, while the stone was still wet, swabs of acetone were rolled across the surface to clean it. The acetone removed the consolidated dirt layer but was prevented by the water from penetrating further and weakening the stone.

GAP-FILLING

Before using any gap-filling agent it is strongly recommended that the exposed surfaces of the object are protected with a thin, resoluble coating, such as Paraloid resin. This helps to prevent any possible interaction between the object and the gap-fill and forms a readily soluble interface facilitating later removal of the gap-fill if necessary. Even a gap-fill such as plaster, which is generally considered 'easily removable', can cause great problems if applied directly to the surface of the object. The hygroscopic plaster holds moisture against the object and salts can migrate from the plaster into the object, reacting with it. Plaster can penetrate into tiny pores and crevices of porous surfaces, becoming almost impossible to remove completely without damaging the object. We always protect the exposed surface of an object before gap-filling by painting it with a solution of Paraloid B48 or B72 in acetone and allowing it to dry. When the gap-fill needs to be removed, it can be ground down to within a few millimetres of the surface of the object, the barrier is then dissolved with acetone and the remaining gap-fill can be readily liberated. Small gap-fills can be removed completely once the barrier layer is dissolved, without being ground down first. Cavities which are undercut can be packed with an inert material such as polythene foam before the gap-fill is inserted.

The gap-fill which we use most commonly on stone, pottery and similar materials is 'Interior Polyfilla' (a sulphate plaster containing cellulose powder and some resin). This is supplied in powder form and can be mixed with water to the desired consistency, from a creamy liquid to a thick dough. 'Polyfilla' sets much more gradually than plaster of Paris, so some shaping can be done before setting. When dry the gap-fill can be carved or sanded to shape.

'Interior Polyfilla' is available in small boxes or in larger bags of 10-56kg. The powder in the bags behaves slightly differently from that in the boxes; it forms a more thixotropic mixture and has a more definite setting point. These characteristics allow a large volume of gap-fill to be applied at one time.

For objects where a large amount of gap-fill is required, but where weight must be kept to a minimum, we find that polyester resin mixed with expanded mica is satisfactory. The expanded mica is sold as 'Vermiculite' in bags; polyester resin is available in several grades, the one most commonly used being pre-accelerated laminating resin (as used in fibreglassing). The resin is mixed with 1-2% hardener and up to ten times its own volume of 'Vermiculite'. The mixture becomes stiffer as more 'Vermiculite' is added and forms a sticky, spongy mass which sets hard in about forty minutes. When completely set and tempered for a few days it is quite hard and extremely strong. It can be drilled, sawn, filed or sanded. It can be used alone or in association with other gap-fills, such as 'Polyfilla'. For example, the polyester/'Vermiculite' mix can be used to gap-fill the body of an object, then coated with 'Polyfilla' to allow fine surface details to be carved. Spills of unset resin can be cleaned off with acetone. The set resin softens very slowly in methylene chloride or 'Nitromors'.

For very fine gap-filling, especially where strength and fine texture are required, epoxy putties are very useful; their only major disadvantage is that of relative expense. They are almost insoluble when hard, so care must be taken to ensure that their later removal is possible (see above). 'Milliput' is a two part epoxy putty available in white, grey or metallic grades. Equal parts of hardener and resin are kneaded together and applied to the object as a soft dough which hardens gradually in two or three hours. It can be shaped while setting and has the added advantage that it can be worked and thinned with water; when set it can be carved, drilled, filed, sanded or polished. We find it particularly satisfactory for use on ivory and bone, although it can be used on a wide range of other materials.

Where the gap-fill is visible on the outside of an object, it can, if necessary, be coloured to match. Both 'Polyfilla' and 'Milliput' can be tinted with pigments, though this has several disadvantages. 'Polyfilla' requires a fairly large amount of pigment to give a strong colour, sets to a different colour from the dry mix, and is very difficult to match. If large amounts of tinted 'Polyfilla' are needed, it is better to mix sufficient dry powder and pigment for the whole task rather than colour several batches. 'Milliput', being an epoxy, reacts with certain pigments (changing their colour) and is difficult to tint. A better solution is, of course, to paint the gap-fill with acrylic paints. 'Rowney Cryla' acrylic paints have a complimentary range of gloss and matt media and varnishes and have proved very useful in archaeological conservation. They can be diluted with water, but once dry are waterproof and can only be removed with solvents such as acetone. Painting the gap-fill rather than tinting it has the advantages that the colour can easily be changed and that once the paint is removed the gap-fill is always readily distinguishable from the object.

A CASE HISTORY

It might be useful to finish with the brief case history of an object which required us to use several of the techniques and materials described above. A mammoth tusk in the Zoological Collection of University College, London was found to be laminating and losing fragments; it was very dirty, had several bad cracks on either end, and the interior tooth material was breaking up, with the outer layers buckling and flaking off. The tusk had three main needs: 1, the surface had to be cleaned; 2, the interior and exterior flaking had to be stopped; and 3, the entire tusk had to be made strong enough to withstand regular handling by students as part of a study collection.

The outer surface and the broken ends were cleaned by swabbing with a 50/50 mixture of distilled water and acetone containing a few drops of 'Synperonic N' and a few crystals of sodium hexametaphosphate (to remove calcareous deposits). This was followed by swabbing with pure acetone to remove more of a brown oily stain and to help dry the material. When completely dry a 10% solution of Paraloid B72 in acetone was dripped into the broken ends and penetrated deeply into the body of the tusk. This first penetrating phase was followed by a 30% solution of Paraloid B48 in acetone to fill gaps (some as wide as 2-3mm) in the shrunken and distorted interior tooth material; excess was allowed to drip out and was later removed with acetone. This consolidation did not penetrate far into the solid core of the tooth, so that if any future analysis is needed, untreated material could be drilled from the interior. In addition, all the loose flakes and fragments which had become detached over the years and which could not be joined back onto the object were collected and preserved as untreated material suitable for sampling. This is very important when considering consolidation of an object - the presence of a consolidant, if well documented, can sometimes be allowed for and eliminated from analytical results, but is completely incompatible with some forms of analysis.

The undercuts of large blistering flakes (2-8cm long) on the outer surface of the tusk were coated with the 30% B48. This enabled most of them to be stuck down firmly while a few of the largest were gap-filled with white 'Milliput', which was later coloured with acrylic paints. The ragged ends of the tusk were coated with a 30% solution of B48 in acetone. Several projections of the ragged ends which threatened to break off even when handled carefully were strengthened and held in place by filling the deep gaps between them with 'Milliput'. When this had set it was painted so as to be indistinguishable except on close examination. In this way the gap-fill is not visually intrusive, but is readily identifiable as part of a repair. The gap-fill in the ends and under the flakes can be removed at any time in the future by dissolving the barrier layer of Paraloid resin with acetone and picking the gap-fill free of the object. If preferred, the bulk of the gap-fill can be ground down first.

The entire outer surface was brush coated with a 5% solution of Paraloid B72 in acetone to hold down tiny flakes of the outermost layer; excess shine was reduced by swabbing with acetone.

WARNING NOTE ON HEALTH AND SAFETY

Polyester resin and epoxy are potential irritants and precautions must be taken during their use to ensure adequate ventilation and protection from liquids and vapours, and from the dust produced when hardened resins are being worked. Skin and eye contact should be avoided, especially with the catalysts: gloves and goggles should be worn.

Great care must be taken when using solvents because of their flammability and toxicity. Solvent fumes can accumulate surprisingly quickly and can be ignited by a spark from an electrical switch. In particular, long or repeated exposures should be avoided as even low levels of some solvent vapour can cause cumulative harm. Always check the hazard levels of solvents before starting to use them and make sure that safety precautions are adequate. Xylene, toluene and white spirit are moderately toxic and should only be used within a fume cupboard or local exhaust ventilation system designed for solvent use; or, if this is absolutely impossible, by staff wearing gloves and fullface masks with the appropriate organic vapour filter, in a well-ventilated area. Howie (herein) gives full details of the safety precautions which conservators of geological specimens should observe when using solvents and resins.

APPENDIX 1

Stockists and price Guide (February 1986):

'Synperonic N': from F.W. Joel Ltd., Oldmedow Road, Hardwick Industrial Estate, King's Lynn, Norfolk PE30 4HH. £2 (1 litre) and £7.65 (5 litres).

'Milliput': from model shops, DIY and hardware stores. Approx. £2.50 (4oz). Manufactured by The Milliput Co., Unit 5, The Marian, Dolgellau, Mid Wales LL40 1UU (Tel: 0341 422562).

'Polyfilla': from DIY and hardware stores. Approx. £1.45 (2kgm). Manufactured by Polycell Products Ltd., Broadwater Road, Welwyn Garden City, Herts. A17 3AZ.

Polyester resin (preaccelerated laminating resin): from Strand Glass Co., Unit 7, Woodford Trading Estate, Southend Road, Woodford Green, Essex (Tel: 01 551 6221). £3.50 (0.5kgm), £5.87 (1kgm), £20.80 (5kgm).

Expanded mica (e.g. Vermiculite): from builders' merchants and insulation companies. Approx. £4.76 (per bag: 4ft^3).

'Sintolit': from Pisani & Co., Transport Avenue, Great West Road, Brentford, Middlesex (Tel: 01 568 5001). £5.20 (1kgm) in various colours. [Pisani also stock General polyester adhesive at £4.20 per kgm. We have not yet had a chance to try this brand, but Pisani say it is very similar.] Sintolit is also available from F.W. Joel Ltd., Oldmedow Road, Hardwick Industrial Estate, King's Lynn, Norfolk PE30 4HH at £12.40 per kgm.

'Paraloid': manufactured by Rohm & Haas (UK) Ltd., Lennig House, 2 Mason's Avenue, Croydon CR9 3NB (Tel: 01 686 8844), who will occasionally supply small quantities as free or chargeable samples. Paraloid B67 costs £3.29 per kgm, B72 £3.34 per kgm and B48 £3.75 per kgm. Unfortunately the smallest quantity available at present is a 136kgm drum. [We authors would be prepared to organise a bulk purchase and distribute it if there was enough interest]. Paraloid is also available from F.W. Joel Ltd., Oldmedow Road, Hardwick Industrial Estate, King's Lynn, Norfolk PE30 4HH. B67 at £25.10 per kgm, B72 at £18.85 per kgm (B48 no longer stocked).

'Cryla' acrylic paints: from art and craft shops. Manufactured by George Rowney & Co., Bracknell, Berkshire.

APPENDIX 2

Useful sources of further information

Brommelle, N. *et al*. (eds.). 1984. *Adhesives and consolidants*. Preprints of 1984 Paris Congress of International Institute for Conservation. Available from IIC, 6 Buckingham Street, London WC2N 6BA at £12.50.

Koob, S.P. 1986. The use of Paraloid B72 as an adhesive: its application for archaeological ceramics and other materials. *Stud. Conserv*. 31 (1), 7-14 (available from IIC).

Wilks, H. (ed.). 19 . *Science for Conservators. Vol.3: Adhesives and coatings*. Crafts Council, London. Available from Crafts Council, 8 Waterloo Place, London SW1 at £5 (+75p p&p).

A variety of conservation publications are available which should prove useful to those considering the conservation of geological material. These include:

Art and Archaeology Technical Abstracts: issued in two parts each year; contains non-critical abstracts of articles and books on a colossal range of subjects, including conservation, geology and analysis (the second part of each volume contains an index). Supplements relating to specific subjects are published occasionally. The latest complete volume, 1985, is No.22. AATA is available from IIC and can be purchased separately. It is normally obtained free with ICC membership.

Studies in Conservation: the journal of IIC; it contains international articles on conservation practice and research, and can be purchased from IIC. It is normally obtained free with IIC membership.

The Conservator: the journal of UKIC (United Kingdom Institute for Conservation); it contains practical articles on current conservation work and research. Published yearly by UKIC, it can be purchased separately but is normally obtained free with UKIC membership.

Conservation News: the bulletin of UKIC; it contains current news, views, hints on materials and equipment, short articles about conservation in the UK, and progress reports of some of the UKIC subgroups (including Stone). Available free with UKIC membership.

It is highly recommended that all those interested in geological conservation become members of at least IIC or UKIC (preferably both):

International Institue for Conservation (IIC). 6, Buckingham Street, London WC2N 6BA. Membership costs £14 p.a. and entitles members to free copies of AATA and SIC (see above) and to reduced prices on other IIC publications such as congress preprints.

United Kingdom Institute for Conservation (UKIC) Membership costs £12.50p.a. and entitles members to free copies of *The Conservator* and *Conservation News*, and reduced prices on back copies (other publications at full price). Membership enquiries to The Treasurer, UKIC, c/o The Conservation Dept., City Museums and Art Gallery, Birmingham B3 3DH. Publications available from Victoria Todd, Conservation Dept., Tate Gallery, Millbank, London SW1P 4RG.

Scottish Society of Conservation and Restoration (SSCR). Publishes books and occasional papers on conservation and related topics (e.g. hazardous materials). Contact SSCR, c/o Dept. of Archaeology, The University, 9 Lilybank Gardens, Glasgow G12 8QQ.

Publications from the USA include those of the American Institute for Conservation, The Klingle Mansion, 3545 Williamsburg Lane, Washington DC 20008, and Technology and Conservation, 1 Emerson Place, Boston, Massachusetts 02114.

Progress reports from international study groups in conservation are published triennially by ICOM Committee for Conservation. Maison de l'Unesco, 1 rue Miollis, 75015 Paris, France

A variety of conservation-related literature is sold by the International Centre for Conservation Rome (ICCROM) who also hold training sessions. Contact ICCROM, Via di San Michele 13, 00153 Rome, Italy.

Finally, the authors would like to state their willingness to help anyone, curator or conservator, who is experiencing problems with their collection. Their experience with geological conservation is limited, but expanding rapidly.

Helena and Richard Jaeschke
3 Park Gardens
Lynton
North Devon EX35 6DF

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