the conservation of cultural property

with special reference to tropical conditions

Prepared in co-operation with
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museums and monuments

XI

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Foreword

The Organization of Museums: practical advice, and *Temporary and Travelling Exhibitions* (numbers IX and X of Unesco's Museums and Monuments series) were published as part of a programme designed to meet the needs of museums in countries which are in the process of rapid development.

During the past decade a large number of newly-independent States have emerged. Elsewhere also, rapid social and political changes have been taking place. As a result, in an understandable desire to preserve the major elements of their cultural traditions, museums and services concerned with the preservation of cultural property have been given responsibilities which impose a considerable strain on their staffs and resources. It is to the credit of the governments concerned that in many cases they have been willing to increase the budgets and staffs of such institutions, despite the many and high priority claims of development projects of greater economic significance.

The range of items which can be regarded as 'cultural property' is vast. In the past, and unfortunately today as well, efforts to preserve or to restore cultural property sometimes end in disaster. In other cases the results, while not entirely unsatisfactory, could be improved upon by the use of up-to-date techniques and materials. There is a constant and growing need for guidance as to how best to care for cultural property for which institutions or public services are responsible.

A number of technical texts are available, among which Plenderleith's *The Conservation of Antiquities and Works of Art* is a notable and comprehensive example. There are also many articles published in specialized journals, but they are naturally written on the assumption that the reader has more than a rudimentary knowledge of conservation problems.

Nevertheless most objects requiring attention can be safeguarded by applying simple and well-known techniques, and this manual has been written to meet this situation. If it is at all successful credit should be given to Dr. Harold J. Plenderleith, the director of the International Centre for the Study of the Preservation and Restoration of Cultural Property (the 'Rome Centre'). He selected most of the authors, all of them distinguished in this field, and scrutinized all the manuscripts. Unesco is grateful to him and to his colleagues who aided in preparing the texts which follow. The late Dr. Paul Coremans of the well-known Institut Royal du Patrimoine Artistique (Brussels) also took part in planning the outline of the manual, and his contributions are among the last of his works written before his untimely death. He had frequently worked as a Unesco expert or consultant and his loss is keenly felt.

The primary aim of this manual is to meet the needs of institutions in the tropical regions of the world. It may also be of value to specialists working in countries which have well-established programmes and laboratories devoted to the conservation of cultural property.

Finally Unesco's appreciation is due to the Rome Centre for permission to include 'Synthetic Materials used in the Conservation of Cultural Property', No. V of its *Works and Publications*, as an appendix to this manual. A common experience among specialists in conservation is the difficulty of obtaining locally some of the newer synthetic materials which have proved their worth. This difficulty is increased by the fact that similar products may have different trade-names in different countries. Again, in many tropical regions of the world, restrictions on the use of foreign exchange render importation of certain products impossible, while other products which are locally available may be overlooked in the absence of reliable information concerning their uses and specific properties. The Rome Centre's publication, which summarizes the qualities of most of the synthetic products and lists the principal manufacturers in different parts of the world, is therefore a most useful addition to the present survey. It is worth mentioning that the International Council of Museums (ICOM) gave a grant to assist the Centre with this publication in its original form, and that various contributors to this volume are members of the ICOM Committee for Scientific Museum Laboratories.

Contents

List of illustrations

Plates

Plates

Figures

Figures

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Hiroshi Daifuku

The significance of cultural property

1

DEFINITION

The term 'cultural property', coined to meet the need for a designation that would include almost all kinds of material objects associated with cultural traditions, is gradually coming into common usage. Cultural property is frequently classified in two major categories:

1. Movable works of art: books, manuscripts, other objects of artistic, historic or archaeological origin, including scientific collections.
2. Immovable: monuments of architecture, art or history, archaeological sites, and buildings of historic or artistic interest.

VALUES GIVEN TO CULTURAL PROPERTY

The above distinction is a relative one as a building or other monument which is classified as immovable, can in fact be moved, given sufficient reason.

Attitudes towards objects which come under the term cultural property can differ widely. Something which is considered to be of great value to someone or to a particular age may be considered later as worthless. The converse may also occur when objects in common use among one people are considered as valuable rarities by another or by later generations of the original people.

Among all known cultures, however, individuals consider some object or artefact as being valuable. It is very possible that our early ancestors also had this trait. For example, it is not improbable that some early tool-making hominid might consider a particular flint 'fist-axe' to be superior to others made in the same tradition. Just so, in later times, a sword could be personalized and named and thought to have special characteristics which set it apart from others. The same fist-axe, during the mediaeval ages in Europe was thought to be a spent thunderbolt. Today the uninitiated may simply pass it by as it lies in a gravel bank lost among other pebbles, but, for the archaeologist who found it, it would have scientific interest. For him the place where it was found, its probable date, its associations with other artefacts would be important clues to the understanding of early cultures. It might then be placed in a storage collection and, except for a brief mention or a photograph in a scientific monograph, largely ignored thereafter. Or it might be placed on exhibition as an example of an artefact made in a given tradition. Perhaps most of the visitors would give it only a cursory glance but some may examine it more intently to gain an appreciation of the relatively immense span of time separating the cultures of early hominids from the present.

The existence of this simple artefact and its distribution in time and in space may be the only information available. It will not reveal anything about the social organization, the language or very much about the non-material cultures of the species of man responsible for the traditions which led to its manufacture. In contrast, there is a vast amount of information available about many different cultures in the historic past and those that are still alive today. Books, archival records, collections held privately or in institutions, sites and monuments held in public domain present, at first sight, an almost overwhelming amount of information. Nevertheless, even casual examination shows that there are gaps in knowledge. For example, an intelligent non-specialist may often be unable to identify by name or function an object that was in daily use in the nineteenth century.

In many areas of the world comparable lack of information is found among contemporary cultures in the same country. For example, in West Africa the cultural gulf separating the educated urban dweller from the rural people may be the equivalent of centuries of change. It is not unusual to find, not too far from a paved highway, a people living a way of life which is basically similar to that of their ancestors. They may have special huts where idols are kept. The adults work in their fields using tools very much like those used a century or more ago. Yet signs of change are everywhere among such rural groups. The children may be going to school and learning to use a language different from that of their parents. Some of the youth may have already left the village to seek work for which they are paid in money rather than in kind. Very little may be known about such a group . . . brief notes in an official government report, a few scattered photographs, perhaps one or two objects have been collected which are gathering dust in a shack, euphemistically called a museum, in a nearby town. It is obvious that a cultural tradition, a way of life which has evolved over the course of generations, is about to disappear into limbo.

Modern civilization is a sum of many parts. The rapidity of transportation, the overwhelming impact of industrial production, and the rapid diffusion of technology have created everywhere new wants and aspirations. Many of the elements of the past that have shaped contemporary civilization have disappeared in countries which have become highly industrialized. However, the loss of so much of the past means that present and future generations will remain ignorant of many of the elements which make up the whole body of their traditions. The establishment of museums and services designed to protect monuments and sites are but a means to assure that some of the most important can be preserved. In countries of the tropical regions of the world the danger to cultural traditions is even greater. Instead of a gradual development, there industrialization brings abrupt and frequently overwhelming change so that the need is urgent to collect and preserve before all that is meaningful disappears. Moreover, as so many of the changes are due to external influences rather than to a self-contained evolution, the break between the recent past and the present is a much more radical one than in countries where industrialization is an old phenomenon.

The growth of human populations and the pressures of building have also affected large sections of the environment. Indeed, many species adapted to a particular environment have become extremely rare and are menaced by extinction. The preservation of these threatened species is not a subject to be dealt with in the present work, but the necessity of having complete collections which can be preserved imposes important responsibilities.

THE PROBLEM OF CHOICE

It is obviously neither possible nor desirable to preserve all the elements of the past. Modern technology, in terms of increased production, better health measures, education, etc., has contributed to higher standards of living. This being so, in their desire to attain these goals, people often speak of the 'dead weight of the past', or in seeking to accumulate the fruits of industrialization, they deliberately or unthinkingly destroy much of what is valuable of old traditions.

What should be preserved? Ideally, the answer would seem to be at least one example of each type of object. For natural history museums, particularly those dealing with the smaller species, this would mean acquiring the most complete collection of type specimens (taxonomy) possible, and the fullest data on their distribution and relationship with their environment. It is equally justified for scientific purposes to have not only a collection of type specimens but also, in specialized areas of research, of the variations to be found within a given species. Ethnographic and art museums may also have such complementary goals, but for larger items, particularly those classified as immovable, it would be impractical even to attempt to attain them.

The first decision then concerns the problems of choice, a comparatively simple matter in the case of natural history and ethnographic collections. In respect of immovables which usually take up a good deal of space and entail large budgets for protection and maintenance the problem is much more difficult. In countries having a system for the classification of monuments and buildings, outstanding examples are probably already protected by law. However, in countries having no legislation, the matter is much more complicated and an individual or a group must take action for the preservation, protection and maintenance of a monument. The choice is difficult and demands both an appreciation of one's own cultural traditions and an understanding of others. Unfortunately current standards cannot be trusted as an infallible guide. The Japanese block prints of the nineteenth century were largely ignored by the élite of that country and did not win appreciation until they were 'discovered' in Europe. Similarly, the revolt against 'Victorian styles' in Western Europe and the United States of America took such an extreme form that many items of this period—now once more attracting attention—were discarded or destroyed. Analogous dangers exist in the tropical regions where, in the understandable desire to gather the fruits of contemporary industrialization, much of what is worth while and of interest is pejoratively classified as 'primitive' or 'savage' and is being lost.

LEGISLATION

Adequate legislation is required to protect all cultural property, and the establishment of national museums for the collection, preservation and exhibition of movables is one important step. These museums must also have a staff and adequate budget to ensure that they accomplish their purpose of preserving objects and carry out their programmes of research, publication, and exhibition.

Immovables, too, need to be protected by legislation. Economic and social factors have frequently been responsible for short-sighted measures which have led to the destruction of buildings and the obliteration of sites in the name of progress. Neglect can also lead to destruction, and vandalism, whether careless or deliberate, is a further danger.

Many countries have enacted legislation for the protection of important sites and monuments and, in some cases, small communities characterized by a unique architectural style or historic quarters within a city are given the same protection.

Most successful examples of legislation also contain clauses which call for the repair of any destruction or impose punitive fines for the theft or destruction of cultural property. Zoning laws protecting a historic quarter usually mean that while a building may be renovated and facilities modernized, its character and that of its neighbours of historical value must not be destroyed. In addition, the State may assist the owner indirectly through tax exemptions, directly by underwriting part of the costs involved, or by supplying technical advice.

STAFF

In all institutions involved in the conservation of cultural property an adequate and trained staff is a prerequisite for a successful programme. Lack of technical knowledge and the use of out-dated methods can frequently do more harm than good. Some of the conservation measures used at the turn of the century have led to greater damage to cultural property than would have occurred had such property been left alone and simply sheltered. Even for trained staff, means should be found to maintain contacts and exchange views with colleagues abroad so as to keep abreast of the latest developments. Intellectual isolation is no excuse today when so many means exist for the interchange of information. The International Centre for the Preservation and Restoration of Cultural Property ('Rome Centre') is one. Others include various international non-governmental organizations such as ICOM (the International Council of Museums), ICOMOS (the International Council of Monuments and Sites), IIC (International Institute of Conservation), etc. The administration of cultural property is centralized in many countries under a single ministry. In others, separate services are responsible for movable cultural property (primarily museum collections, but also rare book libraries, depositories, etc.) and immovable cultural property (sites and monuments, national parks, etc.).

For historical reasons in some countries several independent administrations may be in charge of different aspects of conservation, preservation or restoration of cultural property, and there is sometimes little co-ordination or co-operation among them. In the pursuit of common goals, however, some sort of co-ordination is advisable and various solutions have been adopted, including, in some cases, the establishment of a commission or advisory body to the minister, on which the directors of the institutions or services are represented.

Certainly, the sharing of some services, such as laboratories for conservation, can lead to significant economies in equipment and staff. Whatever the service, in all countries, the recruitment of adequate staff presents problems. Trained architects, for example, can usually earn a great deal more in private practice than in government employment.[1] Again, the problem of recruiting qualified staff in most of the countries undergoing rapid development in the tropics is a severe one. A chemist or a physicist (preferably having a Ph.D. or a D.Sc.) may be sought as the head of a central conservation laboratory, but it is highly probable that he would be eligible for a better-paid job with commercial firms. Or the civil service post for the head of the conservation laboratory may be of lower rank than the post of head of an agricultural laboratory, and the latter laboratory may be much larger. One solution might be the creation of a central national laboratory serving both monuments and museums, thus building up a sufficiently large and important institution to justify upgrading such posts to competitive levels.

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1. The French solution to this problem is interesting. Under the official authority in charge of sites and monuments, government inspectors supervise restoration. Architects, however, submit bids for work to be done as private entrepreneurs, provided they have been specially licensed to carry out reconstruction. This licence is granted on the basis of State examinations.

CONSERVATION AND THE PUBLIC

Nature's threat to cultural property, the effects of weathering, vegetation growth and insects are but part of the endless cycle of tearing down and building up found on earth. Less constant but equally harmful are earthquakes, hurricanes, floods and volcanic eruptions. But however serious are nature's threats they pale into insignificance beside the destruction caused or provoked by man himself. War, vandalism, the very growth of human civilization, involving as it does the building of dams, highways, airports, pipelines and the accompanying urban renewal programmes, can and usually do affect cultural property adversely.

The threat to cultural property resulting from all these factors is enormous and few national or governmental services and institutions have sufficient resources to carry out conservation programmes on their own. Public interest and support are thus indispensable for the success of any programme, and in order to attract support, educational programmes, either through direct methods or through participation in conservation activities, have proved to be among the most effective means.

Many institutions have developed educational programmes which are closely integrated with the curricula of schools. Students come to the museum to visit the collections, and gain background knowledge and an appreciation of the objects shown. Such contacts may also have a secondary benefit, as when information is supplied to the curator leading to further acquisitions. Services for the protection of sites and monuments also have opportunities to arrange planned visits for school groups in connexion with the study of local or national history.

Volunteer work groups are another means of stimulating interest and support. Under the supervision of officials of the French Sous-Direction des Monuments et des Sites, a group of youths (for the most part young workers from the immediate neighbourhood, and some university students) are restoring an old building in Paris in the Marais district made famous in Dumas' *The Three Musketeers*. Similar groups of volunteers are organized for the reconstruction of ancient chateaux, abbeys, fortresses and other historic monuments elsewhere in France and in other countries of Europe.

Clubs, or associations have been formed under titles such as the 'Friends of the . . . Museum' which support and aid museums or assist in the protection of historically or artistically interesting monuments and sites. Many of these groups are local, identified with a given institution, a certain building or concentrating their activities in their own communities. National organizations can also be organized drawing such groups together: trusts, societies for the protection of ancient monuments, etc.

Publicity in the form of articles in newspapers and radio or television programmes is also a means of attracting public support and is possibly the most efficient means of combating vandalism. Museums which have well-organized exhibition programmes and other public services and monuments and sites which are well preserved are important tourist attractions and economically they justify the expense involved in preservation work. Access routes, accommodation for tourists, etc., built in connexion with important monuments tend to stimulate local agriculture and industry and at the same time provide new employment opportunities.

BILATERAL AND INTERNATIONAL PROGRAMMES

Countries of the tropical regions can benefit from various bilateral programmes offering fellowships and often providing consultants, arrangements being made through the embassies of the countries concerned. In some instances subventions are also given to aid the development of museums or the reconstruction of important monuments.

At the international level, the Rome Centre, in co-operation with the School of Architecture of the University of Rome, has arranged an advanced course for architects in the conservation of historic monuments and buildings. The staff is composed of internationally recruited specialists who come for a fortnight or a month to lecture on one or another aspect of conservation or restoration. Practical work and visits to outstanding monuments form part of the curriculum. The Rome Centre is also now planning (1967-68), with the co-operation of the Italian Government, the establishment of a large training laboratory where specialists in conservation can gain experience.

Unesco also aids its Member States through the dispatch of experts or consultants, provision of fellowships and of technical and scientific equipment at the request of the governments concerned. Such aid is financed under the Programme of Participation in the Activities of Member States or through the Expanded Programme of Technical Assistance (now included in the United Nations Development Programme). A Pilot Project for the Training of Museum Technicians has been established at Jos (Nigeria), in co-operation with the Federal Government of that country. The course is open to students from Africa south of the Sahara who spend two months there learning, among other subjects, the basic techniques in the preservation of museum objects. In 1967, in co-operation with the Government of Mexico, a second regional project in conservation will be started in Mexico City. A third project is also being planned for South Asia to begin at a later date in New Delhi.

CONSERVATION AND RESTORATION

If an item of cultural property, movable or immovable, is in good condition all that is required is adequate maintenance. Movables properly stored or exhibited with due precautions against damage can be preserved for many years. Immovables, of course, are much more exposed and subject to wear, but with care monuments may endure for a very long period. In Japan, the Golden Hall (Kondo), the pagoda, a roofed gallery and the gate of the monastery of Horyuji, have lasted for more than 1,200 years. The monastery was founded in A.D. 607 by the Empress Suiko (according to some documents it was destroyed by fire in 670 and rebuilt in 780, but most of the original statuary is said to have been saved) and the Kondo is today perhaps one of two buildings in the T'ang style still extant, and is probably the oldest wooden building in the world.

When an object is not in good condition, a problem arises concerning the degree to which treatment should be carried out. The minimum is to do only what is required for its survival. But what if such treatment should leave it unrecognizable? To what degree should restoration be undertaken? Here opinion is far from uniform. Coremans (1965) has remarked: 'It is far from easy to trace a broad outline of the history of restoration. Without referring to the very earliest stages, it can be said that restoration work began locally when the first large private collections were formed.

'In the beginning the restorer worked alone in his private workshop: it was there that he applied his art, and discovered new methods which became jealously guarded secrets. Later, when public authorities began to wake up, he became surrounded by a 'committee of wise men', revered but generally incompetent, who expressed their satisfaction when some form of aesthetic surgery was performed which gave a work of art a pleasant appearance, even if such surgery greatly accelerated its deterioration'.

In Europe, the example set by Viollet-le-Duc (1814-79) was responsible for much of the early interest in the restoration of historic monuments. However, the degree to which he carried out restoration (including the insertion of structural elements which may have existed in original plans, but which were certainly not part of the historic structure) provoked a reaction against restoration in favour of the stabilization of sites and monuments.

Similar differences in practice can be cited in the case of the preservation of movables. For example, a pot recovered in an excavation was once restored to the point where only detailed examination would show which areas were original and which restored. Indeed, it was not uncommon for skilled restorers to combine different pieces of pots or sculptures into a composite, thus producing a spurious object. In reaction, for a certain period, pots or statuary were repaired in such a way as to make the restored section strikingly apparent (e.g., sections in white plaster on a polychrome pot). This practice was also followed in the restoration of buildings.

With time, however, a middle course is being followed for the most part. Paintings, for example, are no longer 'restored' to the degree mentioned by Coremans above. On the other hand they are no longer left covered with old darkened varnish which obscures the work of art in a manner not conceived of by the artist. In a pot, the restored sections are now tinted so that they do not offer a glaring contrast to the original. However, even on superficial examination it will be clear to the viewer where the original ceases and where the restoration was carried out.

KEEPING RECORDS

From the scientific and administrative points of view, it should be a standard rule that careful documentation is kept of anything done to cultural property under the headings of conservation, repair or restoration. This should include both written records with dates and names of individuals responsible and photographic documentation. In the case of treatment requiring a good deal of work, whether for conservation or, in particular, for restoration where the appearance may be altered, photographs should be taken before, during and after treatment. In particular, where reconstruction is called for photographs should be taken during the progress of the work. When the person in charge has at hand the services of laboratories and awide range of other specialists to consult, he need no longer bear the sole responsibility of determining the course of treatment to be followed. The suggestions and comments made concerning a problem arising in connexion with a rare or important item should be retained in the dossier of the object in question. Thus in the interest of historical and scientific research all of the changes to which the object has been subjected will be a matter of record and this information should be readily available. Many national services may also have bulletins or other publications in which articles can be published describing the work done. For important items, it may be possible to have the article published in specialized national or international periodicals which have a wide distribution.

SUMMARY

Man's relationship to cultural property and the values he attaches to it are the result of the interplay of many different factors. But because an item of cultural property is valued, no matter how varied the reasons, there is the concomitant responsibility to preserve such objects whether they are small or large.

While it is neither possible nor even desirable to save all items of the past, it would nevertheless be reasonable to expect that the most important items should be preserved for the sake of posterity and an attempt made to have an adequate sampling of a wide range of cultural property. Hence, one of the key problems involved if a meaningful programme is to be established is the problem of choice. In part this would be based upon scientific requirements (such as taxonomy, distributional studies) and in part on aesthetic and historical values. In a properly constituted national service various specialities would be able to contribute to the decision as to importance when choices are being made. Very frequently commissions can be set up, possibly including specialists in other professions, e.g., university professors, specialists in other governmental services, members of national or regional organizations interested in conservation whose advice, aid and influence would contribute usefully to the programme.

Adequate staffs, the core of which should be trained professionals, are a *sine qua non* for a successful programme. In countries where conservation services are either non-existent or rudimentary, various programmes offer possibilities of aid in setting up such services. Public support and interest will prove of immeasurable help and educational programmes and publicity will rally support. In some countries volunteers have also made important contributions towards conservation.

Finally, to quote Coremans again, conservation has priority over restoration. He added that 'this is even more justifiable as restoration principles vary according to both the nature of the objects and their state of conservation . . . and even more decisively when the cultural heritage of a developing country is involved. Times have changed from the days when restoration was confined to the West and a few countries in the East. Today scores of new countries and hundreds of new museums in the five continents are looking for exact directives in this field. In these countries by far the most urgent problem in the cultural field is that of conservation of their archaeological and artistic heritage. From now on, these countries are responsible for the evidence of a past of which they are proud . . .'

The chapters which follow set out a number of basic principles which should serve as a guide.

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Paul Coremans

Climate and microclimate

2

CLIMATE: DEFINITION, TYPES AND DISTRIBUTION

Climate is the consequence of many elements and factors of varying nature. The main elements to be considered are temperature and sunshine, moisture (precipitation, condensation and humidity) influenced by factors such as latitude, altitude, land and water, mountains as barriers, ocean currents, prevailing winds and, for land areas: local topography and surface cover (absence or presence of vegetation and the nature of it, wetness or dryness, colour).

Physical geographers and climatologists have proposed many ways of classifying climates. Yet, all the suggested types are practically based on the variation of temperature and moisture and keywords are used such as equatorial, tropical, subtropical, monsoon, desert, marine, littoral, continental, sub-polar, and polar.

For the purposes of this manual the simplified Koeppe classification of climates can be adopted. A glance at a climatic map of the tropical zone, i.e., theoretically between the Tropics of Cancer and Capricorn (latitudes 23.5° N. and S.) will show that the climate is constantly hot and moist near the equator, that farther away it is still hot but can be either moist or dry depending on the period of the year (monsoon climate), and that at higher latitudes temperatures become lower and humidity lower still until a desert climate is reached. All this is expressed in five of the sixteen Koeppe types; the first three (Wet Equatorial, Trade Wind Littoral and Wet Dry Tropical) can be called Hot and Humid Climates, the last two (Semi-arid Tropical and Tropical Desert) corresponding to Hot and Dry climates still to be found in the tropical zone. For the sake of clarity, two other types of Dry Climate (Semi-arid Continental and Intermediate Desert) are added to Table 1, although they belong to the extra-tropical zone.

Geographically, the first three Koeppe types of climate include 90 per cent of the tropical zone, namely:

Central America and the Caribbean;
The main part of South America, north of a line passing through Peru, Bolivia, Argentina, Paraguay and southern Brazil;
Africa south of the Sahara and into southern Africa including Madagascar;
South Asia, the northern limit being the Himalayas and the Yunnan plateau and the western limit the Indus valley, and comprising the Philippines;
Indonesia and the South Pacific islands, also a strip of Australia along the northern and eastern coasts to the latitude of New Caledonia.

These three Hot and Humid climatic regions are bordered at their poleward margins by the two Hot and Dry types, together representing some 10 per cent of the tropical zone, mainly in: the central plateau in northern Mexico; the coastal strip west of the Andes (the climate in the high altitudes

TABLE 1. Main characteristics of Hot and Dry or Dry Climates

Characteristic	Semi-arid Tropical	Tropical Desert	Semi-arid Continental	Intermediate Desert
Mean annual temperature.	At least 21°C.[1]	At least 21°C.[1]	At least five months above 15.5°C. Coldest month under 4.5°C.	At least three months above 15.5°C. Coldest month under 4.5°C.
Annual ranges of temperature.	Under 13°C except in strong monsoon areas.	Usually large.	More than 20°C.	More than 20°C.
Annual precipitation	Between 250 mm and 900 mm. At least five months with less than 25 mm.[1]	Under 250 mm to 350 mm depending upon temperature.[1]	Between 150 mm and 400 mm on poleward margins, between 300 mm and 560 mm on equatorward margins. Summer maximum.	Under 150 mm on poleward margins and under 300 mm on equatorward margins. Summer or double maximum.

[1] Including areas where altitude may reduce the temperature (as a rule 1°C per 200 m) and the annual precipitation.

TABLE 2. Main characteristics of Hot and Humid Climates

Characteristic	Wet Equatorial	Trade Wind Littoral	Wet and Dry Tropical
Mean annual temperature.	All months 21°C or more.[1]	At least 21°C.	At least 21°C.
Annual ranges of temperature.	Less than 3°C.	Generally under 10°C.	Under 8°C except in strong monsoon regions.
Annual precipitation.	At least 1,500 mm. All months moist.[1]	More than 900 mm. No month rainless.[1]	More than 900 mm. Distinct winter dry season.[1]

[1] Including areas where altitude may reduce the temperature (as a rule 1°C per 200 m) and the annual precipitation.

TABLE 3. Selected climatic data[1]

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year[2]	Temp. range
Asunción (alt. 150 m)														
Mean temp. (°C)	28.3	27.7	26.6	23.7	17.7	16.6	17.2	17.7	21.6	23.7	25.0	27.7	23.7	11.6
Mean precip. (cm)	13.9	12.8	9.9	13.1	10.7	6.9	5.6	2.7	7.9	13.9	14.9	20.2	132.5	
Baghdad (alt. 36.5 m)														
Mean temp. (°C)	9.4	11.5	19.0	21.6	27.7	31.6	33.9	33.9	30.6	24.4	17.7	11.5	22.8	24.5
Mean precip. (cm)	2.3	2.5	2.8	1.3	0.25	0.25	0.25	0.25	0.25	0.25	2.0	2.5	14.9	
Bangkok (alt. 2.3 m)														
Mean temp. (°C)	25.5	27.2	28.9	30.0	29.5	28.3	28.3	28.3	27.7	27.2	26.2	25.0	27.2	5.0
Mean precip. (cm)	0.76	2.0	3.5	5.8	19.5	16.0	16.0	17.5	30.5	20.6	6.6	0.5	139.3	
Jakarta (alt. 8.5 m)														
Mean temp. (°C)	26.2	26.2	26.6	27.2	27.2	26.6	26.6	26.6	27.2	26.6	26.6	26.2	26.6	1.0
Mean precip. (cm)	29.7	45.6	21.2	14.1	9.9	9.1	6.6	3.8	7.1	10.4	14.4	19.3	192.2	
Khartoum (alt. 420.7 m)														
Mean temp. (°C)	23.7	25.0	28.3	31.6	33.3	33.3	31.6	30.6	32.2	32.2	28.3	25.0	29.5	9.6
Mean precip. (cm)	0.25	0.25	0.25	0.25	0.25	0.76	5.3	7.1	1.8	0.5	0.25	0.0	16.9	
Lima (alt. 109.7 m)														
Mean temp. (°C)	22.8	23.7	23.7	21.6	17.7	17.2	17.2	17.2	17.2	17.7	18.8	21.1	20.0	6.5
Mean precip. (cm)	0.25	0.0	0.0	0.0	0.25	0.5	0.76	0.76	0.76	0.25	0.25	0.0	3.6	
Mexico City (alt. 2,162 m)														
Mean temp. (°C)	12.2	13.3	16.0	17.7	18.8	19.4	17.2	17.2	17.2	15.5	13.9	12.8	15.5	5.5
Mean precip. (cm)	1.26	0.50	0.9	2.0	5.3	10.9	17.0	15.2	12.9	5.0	1.78	0.76	73.5	
New Delhi (alt. 234.8 m)														
Mean temp. (°C)	13.9	16.6	22.2	27.7	33.3	33.3	31.1	30.0	28.9	26.2	20.0	15.0	25.0	19.4
Mean precip. (cm)	2.3	1.8	1.3	0.8	1.3	7.4	18.0	17.3	10.7	0.9	0.25	0.9	63.0	
Rangoon (alt. 5.9 m)														
Mean temp. (°C)	25.0	26.2	28.3	30.0	28.9	27.2	26.6	26.6	27.2	27.7	26.6	25.0	27.2	5.0
Mean precip. (cm)	0.25	0.5	0.76	5.0	30.5	48.0	58.2	52.8	39.4	18.0	6.8	2.0	262.2	
Rio de Janeiro (alt. 66 m)														
Mean temp. (°C)	25.0	25.5	25.0	23.9	22.2	21.1	20.5	20.5	21.1	21.6	22.8	23.9	22.8	5.0
Mean precip. (cm)	12.6	10.4	13.9	9.7	8.4	5.8	4.6	4.8	6.6	8.5	9.4	13.9	108.6	
Stanleyville (alt. 450 m)														
Mean temp. (°C)	25.5	25.5	25.5	26.2	25.5	25.0	23.9	23.9	24.4	25.0	24.4	25.0	25.0	2.3
Mean precip. (cm)	5.3	8.4	17.8	15.7	13.5	10.4	13.1	16.5	18.3	21.8	19.8	8.4	169.0	

1. Adapted from: W. G. Kendrew, *The Climates of the Continents*, Oxford, 1961. 2. Yearly mean temperature and total annual precipitation.

of Peru and northern Chile being quite different); the desert region of north and central East Africa and practically the whole of southern Africa; the desert regions of Arabia, Jordan, Syria and Iraq; further east, a strip of land along the Persian Gulf and the main part of western Pakistan; a large part of the Australian desert.

As for the two remaining Dry types, they do not occur in the tropical zone but are to be found in its immediate vicinity, mainly from Turkey and the Black Sea to Central Asia.

Altogether, all these climatic regions correspond to a little less than 60 per cent of the land surface of the earth with about 45 per cent of its population, and they comprise almost all the economically less-developed countries.

HISTORICAL DISTRIBUTION OF EARLY CIVILIZATIONS

Historically, these climatic regions exclude the civilizations of North America and Europe, also those of the Far East along the North Pacific Ocean. They include the pre-Columbian civilizations of America; the Negro Kingdoms of Central Africa; the civilization of Central Asia; the civilizations of the Nile, and also of the Euphrates and Tigris and of the plains and plateaux to the west and east of them; the Hindu and Indianized civilizations of South and South-East Asia. In many ways, it could even be said that hot and humid/dry climates correspond to all the civilizations and cultures of the world except those born on the shores of the North Atlantic and the North Pacific Oceans and the northern Mediterranean.

CLIMATE, VEGETATION, SOIL AND HUMAN OCCUPATION

There is a constant interaction between climate, vegetation, soil and human occupation.

Vegetation

Under the constant hot and humid conditions which prevail near the equator, the characteristic vegetation corresponds to the equatorial rain forest (luxuriant, dense forest of tall trees). At higher latitudes in the tropical zone, where there is a distinct dry season, the savannah (tough, tall grass often combined with trees) is more usual. In dry climates, whether still in the tropical zone or at higher latitudes, many steppes and deserts are to be found; plant cover is either reduced to low-growing plants and grass (steppes) or is practically non-existent (desert). Nearer to the poles and well beyond the tropical zone, the tundra (small trees, if any, and some plants) or the icecap (practically no plant life) are to be found.

Soils

The reddish laterite is the most common residual soil of the tropical zone. High temperature and moisture provoke a considerable chemical and biological disintegration of the original soil, leaving the topsoil without mineral constituents and humus and leading, in extreme cases of laterization, to the formation of a reddish, porous rock mainly composed of insoluble aluminium and iron hydroxides. It happens that the less disintegrated soil of river banks is carried far away into the flood plains and deltas where alluvial deposits of good fertility can be found, as for example in parts of South Asia. At higher latitudes with a dry climate, the weathering is essentially mechanical and not chemical or biological, and the residual 'podzolic' topsoil contains much more mineral matter. The presence of humus and the availability of water will determine the production capacity of this clayish soil. Irrigation then becomes a very important factor, not only to ensure an acceptable distribution of water but also to provide for the extraction of excessive lime and gypsum from the soil: the decline of civilization in Mesopotamia began when the soil became too salty because general conditions no longer permitted proper care to be taken of the numerous irrigation canals in the Euphrates and Tigris valley.

In addition to the various natural stones (volcanic, metamorphic and sedimentary), the old, civilizations in the tropical zone turned to local soils to provide building materials for their monuments, Clay, sun-dried or baked, was very frequently used as was the porous laterite rock (mainly for substructures in flood plains as a protection against the upward absorption of water by capillary action).

Human occupation

Population density is generally low in tropical areas where temperature and humidity are high and even, and man's activity is reduced to a bare minimum: nature provides enough to live on, the climate is enervating, diseases are many, large distances have often to be covered with almost no transportation, the soils are rarely fertile. Ancient settlements were more numerous in the monsoon areas which have a distinct dry period, giving some physical relief to the human body, and a wet season during which man must work to ensure his survival throughout the non-productive months. During the periods when agriculture was man's principal occupation, dense populations were to be found chiefly along the rivers and in the alluvial plains and deltas which accounts in part for the early rise of civilizations in Ancient Egypt and Mesopotamia and also in South Asia and China.

CLIMATE AND THE DETERIORATION OF CULTURAL PROPERTY

Copper and bronze objects that had been kept for many centuries in a cave with an even, non-corrosive atmosphere have been found without a real corrosion layer. Old paintings that have always remained in the same collection and have never travelled are often preserved without the characteristic cracks. Archaeological remains can be in an excellent state when extracted from the soil where the physical conditions are constant, but they may be distorted and ruined forever after a few minutes' contact with the air. It is universally agreed that the best way of preserving cultural objects is to air-condition the museum room, thus maintaining around them conditions of constant temperature and humidity with an acceptable degree of atmospheric purity.

All this stresses the importance of climate, to be considered as the main factor affecting the decay or preservation of cultural property. Its effect is even more marked in the tropical zone than at higher latitudes.

We shall now consider briefly the general influence of temperature, humidity and impurities in the air as destructive climatic agents, separately or in combination, before going on to discuss these influences in the more localized conditions (microclimates) of cultural sites whether exposed to the atmosphere or in the enclosed premises of museums, collections, or other buildings.

Combination of high temperature and abundant moisture

These characteristics define the climate in the tropical zone. They favour both chemical disintegration and biological attack: chemical disintegration, since most reactions are based on the presence of moisture and are normally accelerated by a rise in temperature; and biological attack, since optimal conditions for cryptogamic growth (fungi, algae, mosses and lichens) at the tropical temperatures of 25° to 30°C are at a relative humidity of 70 per cent or higher. These conditions are also ideal for the development of bacteria and insects, including the white ants (termites) which are to be dreaded not only within the tropics but beyond them as well.

Combination of low temperature and abundant moisture

Many materials are hygroscopic, the surrounding moisture being taken up by them in the physical structure of the molecule or simply mechanically absorbed and released as in a sponge.

As there is an average reduction in temperature of 1°C for every additional 200 m of altitude, temperatures can drop to freezing point at higher altitudes in the tropical zone (e.g., in the Andes or the Himalayas). As it freezes the moisture contained in ancient materials increases appreciably in volume, causing such materials to crack and crumble. This phenomenon is known as 'frost action' and, next to sulphation, it is the worst enemy of historic monuments in temperate areas with cold winters.

Combination of high temperature and low humidity

This combination is characteristic of dry lands, which are defined as lands having an excess of evaporation over precipitation. Such areas are often also exposed to strong winds since vegetation is usually sparse. The sun shines through a clear sky and quickly heats soil and building materials, especially those of a dark colour; the nights, however, are cool so that the diurnal ranges of temperature are considerable. The result is alternate expansion and contraction of the outer layer of materials, causing them to crumble and break easily. The bursting of many large statues such as those in the Nubian desert may be accounted for in this way. In addition to the mechanical weathering of materials, a certain amount of chemical action is observed where occasional rains occur: soluble salts are brought to the surface of porous stones as a result of evaporation by the sun, crystallize there and cause deterioration of the outer layer of the stone.

Temperature as an isolated factor

Mean annual temperature. At latitudes near the equator and at sea level the mean annual temperature is 26°C as in Jakarta (Indonesia) (6° 11′ S.). At higher latitudes, average figures are of course lower: New York (40° 25′ N.), 12°C; Paris (48° 48′ N.), 10.5°C; Moscow (55° 45′ N.), 4°C. Theoretically, therefore, the effect of temperature on materials is greatest in the tropical zone.

Annual range. Annual temperature ranges in the tropical zone are from 0.5 to 2.5°C near the equator and increase at higher latitudes; they are of course dependent on other factors as well. Examples are: Jakarta (6° 11′ S.), 1°C; Lima (12° 02′ S.), 7°C; Rangoon (16° 47′ N.), 11°C; New Delhi (28° 39′ N.), 19°C; Baghdad (35° 15′ N.), 24°C; New York (40° 25′ N.), 23°C; Paris (48° 48′ N.), 16°C; Moscow (55° 45′ N.), 30°C.

Whereas the annual mean temperature is a theoretical level, the annual range gives an indication of variation throughout the year, which is a more important consideration for our purposes since materials are more sensitive to variations than they are to any absolute level.

Diurnal range. Diurnal ranges are characteristically greater than annual ranges in the tropical zone. Marked and abrupt diurnal changes are much more harmful than seasonal variations because of their frequency and cumulative effect. Continual expansion and contraction within the crystalline or amorphous structure of building materials, especially near the other layers which are alternately heated and cooled, must lead to 'fatigue' and rupture. Indeed, in many cases, notably in monuments exposed to a continental climate with large diurnal ranges, temperature changes are recognized as being the main factor of degradation. Exact figures of diurnal ranges are not readily available, and it is even more difficult to obtain the daily extremes of temperature from which they are taken. Kendrew notes, by way of comparison, a maximum of 52°C and a minimum of 21°C recorded in Salah (Sahara). Sand and stone surfaces reach temperatures even hotter than the atmosphere, as readings taken on the surface of stones show:

Borobudur (Indonesia): from 25° to 45°C in four hours;
Abu Simbel (Egyptian Nubia): from 15° to 41°C in less than eight hours;
Persepolis (Iran): from 2° to 34°C in six hours.

Yet this excessive heat does not penetrate far, and at a depth of 5 cm or so the temperature of the stone will be very close to average. It should be remembered, however, that the repeatedly heated and cooled stone skin cannot resist indefinitely. This is the main reason why at Musti (Tunisia) an inscription on limestone was hardly legible six months after its excavation; it also explains why some of the marvellous limestone reliefs at Persepolis have lost most of their sharp outline only thirty or forty years after their extraction from the soil that kept them intact for two and a half millenia.

Moisture as an isolated factor

The word 'moisture' embraces all forms of precipitation and condensation (rain, mist, hail, snow) as well as humidity. Hail and snow, of course, are exceptional in the tropics.

Relative humidity.[1] What has been said about temperature could be repeated for relative humidity: the annual means give the general level to start from, but they are less important than the seasonal ranges and much less than the daily ranges and extremes. It should be noted also that the maxima of relative humidity occur a little before sunrise, the minima in the early afternoon (approximately the reverse of temperature): the most favourable time for cryptogamic growth on outdoor monuments is from sunset onwards, and indeed also for corrosion of outdoor and indoor museum objects such as bronzes.

Near the equator, relative humidity is 80 per cent and more throughout the whole year. Annual ranges increase with latitude, but even in areas with a distinct dry season, relative humidity remains constantly high. Near the borders of the tropical zone where the continental lands have a hot and dry climate relative humidity may be low during the whole year or may vary from 10 or 20 per cent to 80 per cent and more. These constantly recurring changes have a damaging effect on ancient materials, especially those with a cellular structure sensitive to moisture.

Precipitation. Here again the annual means have less importance than the distribution of precipitation (mainly rain within the tropics) throughout the year. Degradation is less when distribution is even, whether the total amount is large or small, since the material is maintained in a certain state of equilibrium. This is not the case when the winter monsoon brings down 80 per cent or so of the total annual precipitation within a period of four to five months and when each fall of rain is followed by bright sunshine which rapidly heats monuments and evaporates the water absorbed: the constant changing from wet to dry, from cool to hot, combined with the mechanical effect of rain beating down on roofs, vaults and walls, eventually results in considerable degradation. In addition to this essentially mechanical effect of rain, it should also be remembered that rain-water has an appreciable dissolving power on many building

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1. Relative humidity: the ratio of the amount of moisture present in a given volume of air at a given temperature to the amount that would be present if the air were saturated at the same temperature.

and ancient materials in general. Rain-water always contains carbon dioxide and other contaminants. If the water is not drained away quickly solvent action is increased.

A good example of this is the Buddhist temple of Borobudur: since its restoration (1907-11) and consequent exposure, the surface of the andesite stone has become powdery, many joints are open and analyses have shown that the original calcium, iron, silicon and aluminium compounds are disintegrating locally into components largely consisting of calcium and iron oxides, calcium carbonate, silica and kaolin. These salts crystallize at the surface of materials, the process being known as efflorescence. Too often, in many countries, lack of funds for conservation or plain thoughtlessness have left valuable ancient monuments in a deplorable condition, unprotected from rain pouring in from all sides, doomed to disintegration and early disappearance. This applies even more particularly to buildings of soft natural stones, bricks baked at too low a temperature, or unbaked clay. It is all too common to see streaks of rain-water ruining important tempera paintings on the inside walls of buildings of historical or artistic interest.

Capillary action. Many ancient sites are situated in flood plains. Every year, during the wet season, enormous amounts of water suddenly come down from higher levels in the hinterland, often bringing the water table up to or even above the surface of the ground. Water then penetrates the walls of the buildings and migrates upward by capillary action to additional heights of 2 or more than 3 metres above the water table. This incessant yearly wetting and drying of substructures and walls lessens the cohesion of the materials, weakens them considerably and is often the beginning of serious structural damage.

Ground water almost always contains salts in solution or in suspension. Examples of this are sodium chloride (near the sea), sodium carbonate and sodium sulphate (gypsum) and many other constituents of soil or rock which may have been transported from afar by floods. During the dry season the salty water gradually moves to the outer layers of walls and structures, evaporates and finally leaves saline deposits (efflorescences) on or near the surface. Here again is one of the causes of degradation both of whole buildings and of the murals, sculptures, etc., housed within them.

Atmospheric pollution

The chemical composition of air, mainly its oxygen content, makes it an active agent of decay. This action can be notably amplified by additional impurities brought in by man or nature.

Sulphation. This is a phenomenon characteristic of large cities and industrial areas using sulphurous fuels. Mineral oils and coal may contain up to 1 or 2 per cent sulphur. This oxidizes easily, forming sulphurous and finally sulphuric acid, with which are deposited fine particles mainly of soot. Alternating black and white streaks on churches are a familiar sight in western countries where even museums such as the National Gallery in London have to take special precautions against the infiltration of soot in rooms and showcases. Building materials, especially those with a calcium basis, are very sensitive to sulphuric acid. Cross-sections show that, next to the surface deposits of black soot, calcium carbonate is converted into calcium sulphate, with a corresponding increase in volume causing fissures to appear underneath. Continuous replacement of the decayed stones by new ones is an easy but also a very expensive solution which results in systematic faking of the original monument and its decoration. The United Kingdom, Belgium, and France have started washing façades, and it is hoped that Unesco and the specialized international organizations will encourage research in laboratories to discover useful chemical preservatives.

There is practically no domestic heating in the tropics, but as industrialization is now getting under way in many regions sulphur contamination is no longer merely a distant fear. Moreover, volcanic activity gives rise to sulphurous gases and there are more than a few examples (the Dieng plateau in Java provides a notable instance) of severe damage to ancient buildings from such causes.

Chloridation. Many ancient sites and monuments (e.g., Carthage in Tunisia) are near the sea and exposed to onshore wind and fog which carry minute particles of sodium chloride. These particles are deposited on walls and roofs, crystallize and dissolve there, are carried down to lower or deeper levels of the building where they crystallize again, setting up powerful mechanical stresses. Sodium chloride is also a very active chemical reagent; it attacks many materials (copper alloys being the best-known example) and is often the cause of the continuous corrosion of objects in coastal museums.

Erosion. When they were at the height of their activity, many of the large cities and religious communities of ancient times were protected against prevailing winds and dust by belts of trees and vegetation in general. One of the most striking experiences of the modern-day visitor to these ancient sites is to discover such numerous and notable ruins in the middle of a desert with raging winds chasing myriads of sand particles against what is left of walls, roofs and vaults. Examples of this are Baalbek in Lebanon, Palmyra in Syria, Hatra in Iraq, Persepolis in Iran, Pagan in Burma and many sites in the United Arab Republic and India too numerous to name. And very often almost the sole cause of so much destruction is simply: erosion.

Tropical cyclones originating in the equatorial low-pressure belt (doldrums), winds descending from highland to lowland, local prevailing winds, have eroded many historical sites. Nothing much can be done unless a well-organized archaeological department has the manpower and the financial means to tackle the problem systematically.

Tectonics. Specialists are now beginning to locate with some precision the seismic belts of the earth's surface where volcanic activity and earthquakes are most frequent. To a large extent the areas thus affected lie within the tropical zone, of which fact the eruption of the Gunung Agung in Bali is a recent reminder. What is not so well known is that a number of ancient sites in these regions are subject to quite frequent volcanic vibrations, although of very limited amplitude, and that this may account for the instability of their substructures. Generally, however, their poor condition is attributable to several factors, including, particularly, damage by water through capillary action and the marked changes in the water content of the subsoil brought about by urbanization and engineering works, dam construction, etc.

FROM CLIMATE TO MICROCLIMATE: ANCIENT SITES AND MUSEUMS

Knowing that climatic conditions can be responsible for the decay of materials of all kinds, an expert sent to a specific country to report on the main causes of deterioration of sites and objects of cultural importance and on possible methods of preservation will set about defining the general characteristics of the climate so as to apply this knowledge to special cases, i.e., to outdoor conditions on historical sites, or to indoor conditions in museums. In doing so he has narrowed his field from climate to microclimate.

In other words, the term climate and the classification of general climatic types are applicable only to large areas of the world. It is thus said that the occurrence of 'hot and humid climates' corresponds broadly to the coverage of the tropical zone. Yet, even this very general statement is not absolutely true for all regions of the world. Mainly because of the uneven distribution and orientation of the vast continental masses, the northern border of the hot and humid climates coincides with the Tropic of Cancer only in Central America, being at a considerably higher latitude in South Asia and at a much lower one (approximately 10° to 15° N.) in Africa.

Climatic subdivisions

Even more reservations have to be kept in mind when it comes to defining the climate of a single country. In Mexico—a narrow strip of land between vast masses of water—the climate is far from being the same throughout the country. In general, it can be called hot and humid on the east and west coasts, but it is clearly tending towards 'Wet and Dry Tropical' on the west and 'Trade Wind Littoral' on the east, while the interior northern plateau is quite different again, corresponding to the 'Semi-arid Tropical' type. Altitude is also a modifying factor; areas between sea level and 2,000 metres or more are known respectively as *tierra caliente, tierra templada* and *tierra fria.*

The city as microclimate

By narrowing the field of observation even further, the investigator finds the specific climatic characteristics of a given limited area assuming particular importance against the general climatic background of the surrounding zone. Here the study of microclimate begins.

One of the best-known examples of this is the microclimate of a large city. In comparison with the general climatic characteristics of its surrounding area, a city like Paris receives less direct solar radiation but more artificial heat from domestic and industrial fires, precipitation is heavier but the relative humidity is lower, and atmospheric pollution is much more pronounced. For these reasons, the Paris microclimate affects the degradation of historical monuments and museum objects in a way that is quite different from what is experienced, let us say, in Versailles, only 20 km distant.

Historical sites

Similarly, many a historical site can be said to have a microclimate of its own.

In Mexico the numerous Maya sites in the northern lowlands of Yucatan have a general climate different from the microclimate at Bonampak (with its famous Maya murals). It overlooks this plain but faces westward, sheltered by the mountain slopes and by typical forest cover.

Like many other monumental ensembles in South Asia, the famous Khmer site of Angkor in Cambodia is an open space in the middle of a huge forest. Its microclimate will therefore be very different from sites without such a natural barrier to protect them from erosion by strong winds and sandstorms. The worst erosion is experienced in desert regions, as on the Parthian site of Hatra (Iraq), the Roman sites of Palmyra (Syria), or Baalbek (Lebanon), and many sites in India. Damage will be less serious, though still noticeable, where some vegetation has survived, as in Ayudhya (Thailand), or, to a lesser degree, Pagan (Burma).

One of the world's most important Buddhist sites is Pagan, some 400 km north of Rangoon, the capital of Burma. Yet, despite their proximity, the respective microclimates of Pagan and Rangoon are completely different (the annual rainfall is about four times greater at Rangoon) and the preservation of ancient monuments in each place has to be planned accordingly.

Although located in an area where the average annual precipitation is no more than 5 cm or so, many old pre-Inca and Inca remains in 'adobe' dried mud bricks along the narrow coastal strip of low Peru suffer from onshore winds carrying salty mist inland. Conditions are completely different in archaeological sites on the adjacent slopes or higher altitudes of the Andes (Machu Pichu and Cuzco).

The high plateau of Iran is classified as having a Semi-arid Continental type of climate. Yet, within it, the Achaemenian site of Persepolis has a distinctive microclimate of its own. On the east a hill hides the rising sun for one to two hours, then suddenly the full sun irradiates the site and within half an hour the temperature of the white stones rises by some 16°C.

The soil in which archaeological objects are buried has its own climate and it is sometimes exceedingly dangerous to expose such objects suddenly to the air. After many centuries in a stable environment, whether moist or dry, they have reached a state of equilibrium. This equilibrium is upset by sudden contact with air of a different moisture content. In such conditions the cellular structure of an organic material may collapse and all materials may quickly turn to dust.

One of the very best examples of microclimate in the field of conservation is to be found in deep grottoes with a thick rock cover that stabilizes the physical conditions inside. For this very reason, during the Second World War, many works of art and antiquities were safely kept in such underground depositories as in Festiniog (Wales) and Alt Ausee (Austria), which are characterized by a generally low but even temperature and a high but also even relative humidity. Sometimes, however, storage in underground environments may be complicated by factors such as infiltration of water, salt efflorescence, cryptogamic growths and certain forms of insect life. It is well known that many of the earliest cultural remains are to be found in caves, as at Altamira (Spain), Lascaux (France), Bagh (India), and in thousands of other less publicized sites in the Americas, Europe, Africa, Asia and Oceania. In such cases the effect of local outside conditions must be assessed purely in relation to the subterranean microclimate on which all further study and action will be based.

Indoor storage

Similarly, the preservation of archaeological and artistic treasures indoors—as in many museum buildings—must be studied in relation to the confined microclimate produced by the surrounding walls, roofs, vaults or showcases.

The damaging effect of climate is of course less to be feared indoors, particularly in regions of moderate or cold climate where the exhibition rooms and storage spaces of museum buildings are almost completely isolated from the outside air. Mr. H. J. Plenderleith (1956) gives a striking illustration of the protective value of outer walls and enclosures. Under the heading 'Synchronous variations in the temperature and relative humidity of the atmosphere in different locations' (page 7) he shows the wide ranges of temperature and relative humidity experienced outdoors in London, the much smaller variations experienced inside an exhibition room of the British Museum, and the almost even line characterizing the atmosphere inside a showcase. Since atmospheric stability is the most important factor in conservation, indoor museum conditions are obviously much safer than the continuous exposure to which most ancient sites are subject. Yet, in regions nearer the tropics and the equator, it is common practice to build museums with less effective insulating materials, the consequence often being that the purity, moisture content and temperature of the air inside the museum scarcely differ from the outside atmospheric conditions. And since tropical climates normally have high temperatures and relative humidity, chemical, physical and biological disintegration is to be feared more here than elsewhere.

SUMMARY AND CONCLUSIONS

Many aspects of conservation are discussed in *The Organization of Museums* (1960).[1] On the other hand, the main causes of damage to objects found in museum collections are summarized in the accompanying table by Plenderleith (1956; p. 15). A number of general conclusions can be drawn from all this, with particular reference to conditions in the tropics:

1. Air pollutants can be ruled out in most cases, thus leaving temperature and moisture as the principal causes of deterioration of cultural property.
2. In the tropics, the effect of temperature is particularly marked (much more than is shown in Plenderleith's table since he had in mind conditions in cooler latitudes). Nothing much can be done at low cost to combat the effects of high temperatures; in many cases, next to air-conditioning, thick protective walls and roofs, or double walls enclosing an air cushion, or an outside corridor parallel to the exhibition rooms (as in old Moslem buildings), are possible solutions.
3. Where relative humidity is constantly high, as in Wet Equatorial areas, special precautions should be taken against cryptogamic growths and damage caused by micro-organisms and insects. Proper air circulation and ventilation combined with refrigerating 'units' are simple safeguards against condensation.
4. Where moisture varies throughout the year, as in Wet and Dry Tropical climates, it is this very alternation of wetness and dryness that damages ancient materials, causing efflorescence on objects containing salts. Excess moisture in showcases can be absorbed by silica gel.
5. Further from the equator, for example in Semi-arid Tropical and Tropical Desert regions, constant excessive dryness of the atmosphere becomes the main concern, especially with hygroscopic organic materials whose cellular structure is liable to collapse in such conditions. Impregnation of these materials with protective substances or spraying water in the exhibition rooms should help; but it should be borne in mind that any moisture thus diffused must be in vapour form and not emitted as small drops which fall on the objects and become nuclei for further decay.

All these measures are very simple indeed and can be carried out by an intelligent technician who has received ordinary basic training. Such a person should have a thorough knowledge of local climatic conditions both in the open and in the various sections of the museum, including storage areas. Readings of temperature and relative humidity should be taken regularly, not with the usual but very unreliable hair thermohygrometer, but with the much better rotating wet and dry bulb psychrometer. Starting from regular readings, the technician will soon become aware of the phenomena of dryness, humidity and condensation, of how the various materials react to these phenomena, and of how simple commonsense measures can often be of greater help than many more complex and costly solutions.

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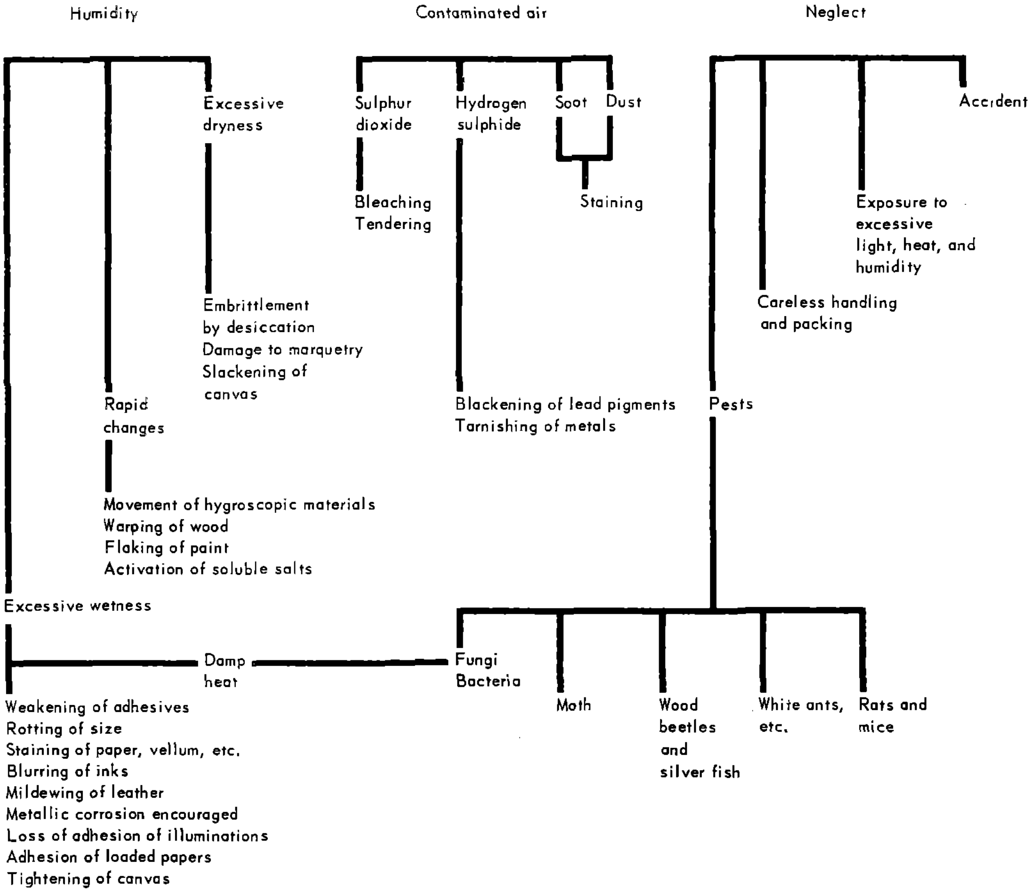
[1] See: Chapter VII, 'The Museum Laboratory' by Coremans and Chapter VIII, 'Collections: Their Care and Storage' by Daifuku.

APPENDIX

CAUSES OF DAMAGE TO MUSEUM OBJECTS[1]



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1. From Plenderleith, 1956, p. 15.

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Roger Heim, Françoise Flieder and Jacqueline Nicot

Combating the moulds which develop on cultural property in tropical climates

3

INTRODUCTION

The coloured patches which are frequently found on old documents in libraries and archives are usually produced by pigments secreted by certain moulds. This flora is thus of great concern for conservation, and has been the subject of various research projects in which the present writers were directly concerned. In this chapter, it is proposed to list and give brief descriptions of fungi found in various kinds of cultural property kept under tropical climate conditions which have been isolated by the Laboratoire de Cryptogamie of the French National Museum of Natural History over the past fifteen years. To this list have been added some of the species liable to attack building materials, including materials sometimes used in buildings of artistic interest. Thus there are brief mentions of several species of micro-organisms recently isolated by P. Fusey and G. Hyvert on sandstones from the Khmer ruins, particularly those at the site of Angkor, in the course of a joint investigation conducted by the Ecole Française d'Extrême-Orient and the National Museum of Natural History in Paris.

PREVENTIVE MEASURES

Preventive measures should be taken at the time of construction of the buildings designed to house cultural property.

LOCATING THE BUILDING

The site selected should be such as to ensure optimum climatic conditions inside the building and provide constant protection from light, insects and dust.

The location chosen for the building is of the utmost importance. If it is a museum, it should not be situated in an industrial centre; it should be as far as possible from coastal regions and in an area with the least climatic variation.

Since it is often difficult to find a site which fulfils all these requirements, special arrangements must be envisaged for museums which, perforce, are located in areas where prevailing climatic conditions are such as to be definitely harmful to the objects in their collections.

BUILDING MATERIALS

The materials used should be sturdy, and wood should always be treated beforehand with fungicides and insecticides; all metal parts should be coated with a protective insecticidal and fungicidal varnish, and window-glass with a substance which absorbs some of the ultra-violet and infrared rays.

DESIGN OF THE BUILDING

The foundations should be raised sufficiently to provide maximum protection for the materials stored. Walls and roofs should be insulated, and windows should be fitted with fine-mesh screens and should be small, weatherproof and sufficiently numerous.

SANITATION OF PREMISES

The premises should be spacious, with plenty of ventilators. The rooms should be completely independent of one another, and should be not more than 200 m^3 in volume so that they can be disinfected separately if necessary.

The premises should be kept thoroughly clean. Cleaning should be done regularly, using powerful vacuum cleaners rather than feather dusters (which stir the dust without removing it). In addition, preventive treatment should be carried out at least once a year. The objects need not be handled, and the work should be done on the spot by spraying with fungicides—preferably with lauryl-dimethyl-carbethoxy-methyl ammonium bromide dissolved in water at a strength of 1 to 2 per cent as required. An extremely fine spray at a pressure of 2.5 kg/cm^2 should be applied to the objects to be treated for 10 seconds at a distance of 1.5 metres.

The degree of atmospheric pollution should be checked from time to time. This can easily be done in the following way: Petri dishes containing a solidified (gelosed) culture medium are placed at a number of points and left exposed for a short time (10-15 minutes). The spores held in suspension will settle on the medium. The dishes are then left for a week in an incubator at 25 °C so that the spores will generate fungal colonies as they germinate, from which the nature and extent of pollution can be determined. Doors and windows should be kept closed while the operation is in progress so as to avoid draughts and the risk of contamination from outside. If pollution is found, the premises must be disinfected.

It is important that objects should never be placed in direct contact with external walls (in order to avoid damage from condensation) or near a source of heat.

AIR-CONDITIONING

However effective the structural insulation of a building may be, air-conditioning will always be necessary at certain times of the year, at least for the most valuable objects in the collection.

General air-conditioning. The decision to install air-conditioning for the whole building, or a large part of it, must be made when the architect's plans are being drawn up so that provision can be made for a central air-conditioning plant with air-ducts leading off from it, thus allowing the atmospheric conditions in each room to be regulated separately. The cost of installation at a later stage may well prove to be prohibitive.

Air-conditioning of individual rooms. If the funds available are insufficient for general air-conditioning, or if the objects to be conserved are not important enough to make it necessary, partial air-conditioning may be installed.

Most of the appliances in use are neither bulky nor costly, but they are not particularly powerful. They can be used successfully in small rooms; for larger rooms several units may be required. Unfortunately a good many of them are unattractive to look at and rather noisy.

REMEDIAL MEASURES

Where mould colonies are obviously present, specific remedial action is called for. Samples are taken so that their vitality can be tested and the fungus which produced them identified. The samples are placed in a test-tube containing a suitable culture medium (e.g., agar-agar with glucose or with 1 to 2 per cent of malt), by means of a seeding loop. The tubes are then placed for a few days (or a month at the outside) in an incubator at a temperature of between 18° and 25°C, depending on the origin of the material, in order to germinate the spores and enable the mature fungus or fungi to be identified.

Before the treatment is actually begun, care should be taken to remove the mycelium by brushing the object vigorously so that the fungicide will be easily absorbed. This operation should always be carried out in the open air so as to avoid any risk of contamination.

We have found the following two methods of disinfection satisfactory.

DISINFECTION IN AN OVEN

This method, which has been used at the Bibliothèque Nationale for nearly six years, does not require costly equipment, but can only be used for a limited number of objects at a time. We have used it to disinfect books, parchments and even pastels from the Château de Versailles. Formaldehyde vapour is used. The operation is carried out in an oven which is hermetically closed, and kept at a temperature of 30°C. Formaldehyde is then vaporized inside in the proportion of 250 g/m^3, a similar quantity of water also being vaporized in order to moisten the air and prevent the leather or parchment from cracking. The objects are kept in the oven for 24 to 48 hours, depending on the amount of damage. Samples are taken a few days after the treatment is finished in order to make sure that it has been effective.

DISINFECTION IN A VACUUM AUTOCLAVE

The advantage of this method, which requires a special type of autoclave and a high vacuum of 10-60 mm of mercury, is that it is very quick and enables a considerable number of objects to be disinfected in one operation. It has been used for years in insect control. The gases generally used are methyl bromide and sometimes ethylene oxide.

We have recently been experimenting with a method of fungus control using ethylene oxide (Flieder and Boissonnat, 1961). This gas is used either alone or in combination with carbonic acid for disinfecting herbaria. We found that 333 g/m^3 of gas mixed with air, applied for 12 hours is a reliable fungicide. Documents in the National Archives were treated in this way in 1960 with excellent results.

DECONTAMINATION OF STORE-ROOMS AND EXHIBITION ROOMS

Where climatic conditions are unfavourable, or if the objects contained in store-rooms are very mouldy, the atmosphere may be a serious source of contamination. The degree of atmospheric pollution must therefore be checked before objects are placed in store-rooms (see above under 'Sanitation of Premises').

If there is a high degree of pollution, the premises must be disinfected. This may be done in either of two ways:

Fungicide sprays may be applied by means of an air compressor and spray-gun with a very fine-mesh grille (so that the droplets are broken up and a very fine spray obtained).

Atomization of fungicides can be carried out with a 'swing-foot' type of atomizer. This is much the better of the two methods, as the fungicide is far more widely dispersed and the substance can be used in a less concentrated form with greater effect. C. Moreau (1952) has shown that 'a cubic millimetre of an active agent sprayed on in droplets of 50 microns diameter produces 92,000 heavy droplets which settle quickly, whereas a cubic millimetre of the same agent scattered by an atomizer in the form of droplets of 2 microns diameter produces 500 million light-weight droplets which remain in suspension in the air for several hours'.

Active fungicide agents. We have used two types of agents for the disinfection of rooms. The quaternary ammonium salt, lauryl-dimethyl-carbethoxymethyl ammonium bromide in a 5 per cent alcohol solution (so as not to rehumidify the atmosphere by spraying an aqueous solution) in the proportion of 5 cm^3/m^3 of the space to be disinfected. To reduce the risk of fire, denatured alcohol at 70° is used. A mask must be worn during the operation, as this product irritates the mucous membranes. Used as a spray, it has given good results for seven years in various libraries and archives.

The other agent is an organic compound of boron, decahydrate of triethanolammonium diborolactate, which has so far been applied with an atomizer, but never as a spray. Its fungicidal effect is almost the same as that of the quaternary ammonium salt, but it is not so irritating for the operator. It is used in an 80 per cent aqueous solution of the active product, at the rate of 5 cm^3/m^3 of atmospheric volume. It has lately been successfully used in a very large store-room of the French National Archives. A check should be carried out following treatment to verify its effectiveness.

KEY TO THE PRINCIPAL MOULDS ATTACKING MATERIALS IN TROPICAL CLIMATES ACCORDING TO THEIR RESPECTIVE GENERA

RARELY WITH PERITHECIA; EXOGENOUS SPORES

WITH SPORODOCHIA

Bi- or multicellular spores, curved (*see* Fusarium)

Unicellular spores, not curved (Myrothecium)

M. verrucaria (Fig. 1): woolly colonies, at first white, then dotted with small glaireous heaps, then black, ± confluent; hyaline conidiophores, erect, branched, terminated by hyaline phialides producing conidia; the latter are elliptic, with truncated base, smooth wall, almost hyaline, pale olive-green, 6-10 × 2-4.5μ; strongly cellulolytic; found on manufactured products and plastics materials (New Guinea, Florida, etc.).

WITHOUT SPORODOCHIA

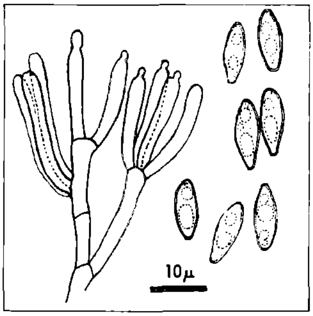
Brown conidiophores and conidia; dark colonies (Dematia)

A. Two- to six-celled conidia, muriform, irregular: *Acrospeira* (on graphic documents in temperate regions).

B. Unicellular or irregularly septate conidia; *Cladosporium.*

Cl. herbarum: dark-green colonies with a blue-green underside, fuliginous; dark mycelium and conidiophores; 1-2-3-celled spores, brown, budding in ramified chains; bushy, slightly cellulolytic; found on wood, paintings, plaster, leather, wool (cosmopolitan).

Cl. (Hormodendrum) cladosporioides (Fig. 2): same characteristics except that the conidia are generally unicellular, ± ovoid and narrower.



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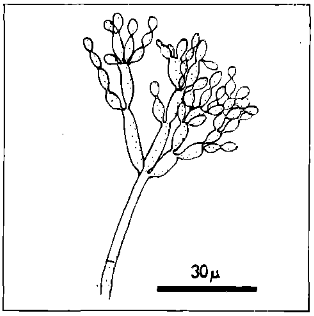

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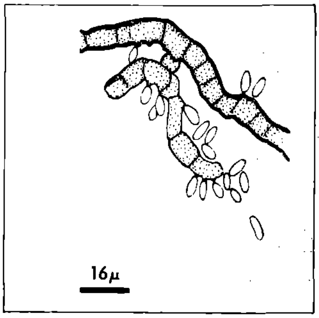

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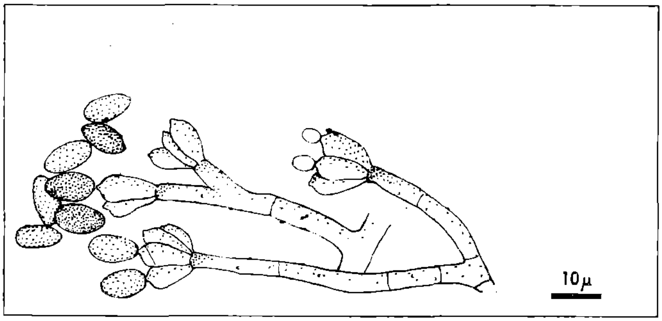

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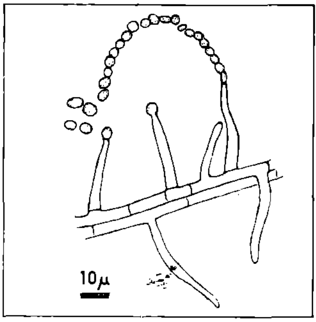

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Figures
1. *Myrothecium verrucaria*
2. *Cladosporium (Hormodendrum) cladosporioides*
3. *Pullularia pullulans.*
4. *Stachybotrys atra.*
5. *Gliomastix convoluta.*

C. Conidia always unicellular:

1. No conidiophores, budding spores, growing laterally: *Pullularia.*

P. pullulans (Fig. 3): dirty-white colonies, ceraceous, shortly afterwards greenish, finally black, fumagoid, conidia of varying forms; not markedly cellulolytic; found on varnish, paintings (in common and associated with *Phoma*), cotton and leather (cosmopolitan).

2. Distinct conidiophore:

(a) Conidiophore swelling at the tip to form a vesicle bearing *metulae* covered with *phialides* (see *Aspergillus*).

(b) Conidiophore not swelling at the tip to form a vesicle but bearing phialides; no metulae; ± cellulolytic species.

(i) Conidia not catenulate but grouped in globular and slimy masses: *Stachybotrys* (*S. atra* (Fig. 4) on plastics materials in temperate climates).

(ii) Catenulate conidia: *Memnoniella.* *M. echinata:* colonies at first pale (white, pink) then becoming dark; verrucose conidiophore bearing a cluster of phialides (8-10μ); conidia in chains, brown, globulose or ovoid, rugose, 4-6 × 4μ; strongly cellulolytic; found on plastics and nylon materials, manufactured products, various other materials (Pacific, India, Madagascar, etc.).

(c) Simple conidiophore, not swelling at the tip, giving conidia directly, catenulate at the end, sometimes grouped in twisted spiral chains: *Gliomastix.*

G. convoluta: (Fig. 5): conidiophores growing from funicles formed by the meeting of mycelial hyphae; light-brown conidia, globulose or ovoid, 4-6μ, smooth wall, isolated; cellulolytic; found on shoes, leather, cotton, stones, (Mexico, etc.).

(d) Simple conidiophore, swelling at the tip, terminated by a spike more or less thickly covered with conidia; curved ellipsoidal spores, triseptate or quadriseptate, central cells larger and darker than the distal cells: *Curvularia.*

C. lunata (Fig. 6): dark or sooty-grey colonies, triseptate; on stones (Angkor).

Conidiophores and hyaline conidia; colonies of a light or bright colour (Moniliales)

A. Multicellular spores, arched; often ovoid microconidia, without or with only one partition, sometimes chlamydospores: *Fusarium.*

F. solani (Fig. 7): microconidia with a fairly thick wall, narrowing slightly towards the ends, macroconidia with a moderate curve; 4-6-celled, 22-43 × 3.6-4.6μ; chlamydospores; cellulolytic; found on plastics materials, rubber (U.S.A., equatorial Africa).

Numerous other species, also cellulolytic: *F. javanicum, semitectum, moniliform.*

B. Unicellular spores.

1. Lateral conidia, not catenulate and without a globulose head; erect conidiophore bearing verticillate ramifications terminated by a sinuous-geniculate rachis; conidia on both sides of the latter: *Tritirachium.*

T. roseum (Fig. 8): pinkish colonies; found on plastics materials, particularly nylon (U.S.A., tropical regions).

2. Conidia with globulose and slimy heads.
   (a) No metulae:
   (i) Arbuscularly ramified conidiophores, terminated by swollen phialides tipped by globulose-ovoid conidia, 2.5-5.3μ, groups of 10-20 in slimy heads, spherical; highly cellulolytic; *Trichoderma.*

   T. viride (Fig. 9): moss-green colonies, becoming dark-green, gritty, yellow underside; found on all substrates, manufactured products, paper, wood, plastics materials, particularly nylon (cosmopolitan, cellulolytic, very widespread and resistant).

   (ii) Simple straight conidiophore narrowing from base to tip; having a slimy head with spores: *Cephalo-sporium.*

   C. acremonium (Fig. 10): white colonies, becoming pink; ellipsoidal conidia, 4 × 1-1.5μ; cellulolytic; found on canvas, clothing, cotton, plastics materials (temperate regions).

(b) Phialides and metulae, conidial system brush-like, conidia not catenulate but grouped in a slimy mass (+ 20 conidia per cluster); *Gliocladium.*

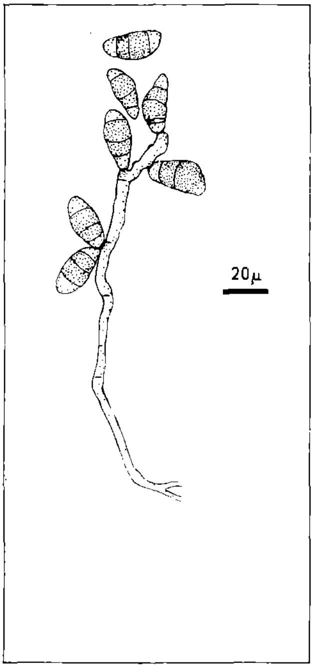
G. roseum (Fig. 11): pink colonies, becoming white; ovoid-cylindroid conidia, 5-7 × 3-5μ; cellulolytic; found on clothing, wool, manufactured products (cosmopolitan).

G. catenulatum: white mycelium; dirty-green conidia, in tenacious chains; cellulolytic; on various products (cosmopolitan).

3. Catenulate conidia. Conidiophores swelling at the tip to form a vesicle: *Aspergillus,* series of phialides thickly set around the head, intermediate metulae, no perithecia.

(a) *A. terreus:* ochre or cinnamon-coloured colonies; smooth conidiophores and conidia, the latter being very small (1.8-2.5μ) and globulose; strongly cellulolytic; xerophilous, grows well at 40°C on plastics, wool, leather (equatorial Africa as well as in the temperate climates).

(b) *A. flavus:* green colonies; hyaline, rugose conidiophores; variable conidia; not markedly cellulolytic; found on plastics materials, wool (tropical America, Florida, Pacific regions, especially Australia, and the temperate regions). Considered to be responsible for certain cancerous conditions.



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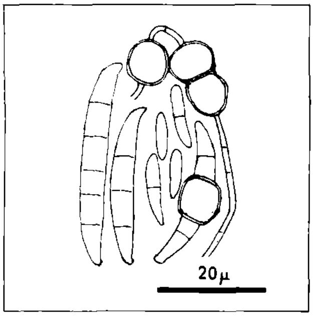

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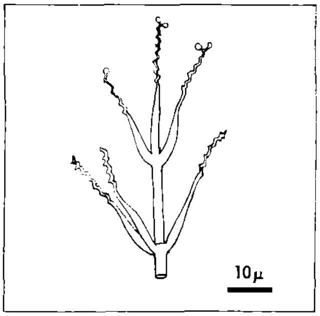

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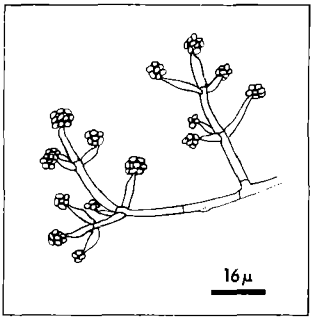

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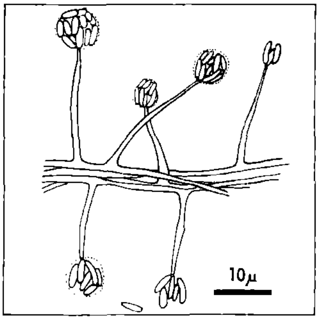

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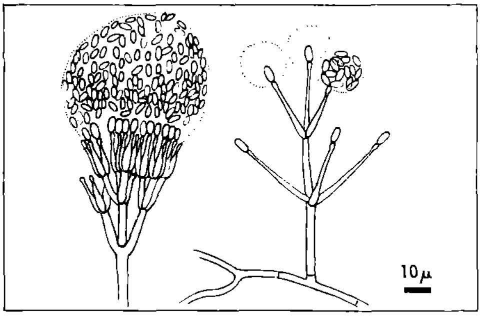


11

Figures

6. *Curvularia lunata.*
7. *Fusarium solani.*
8. *Tritirachium roseum.*
9. *Trichoderma viride.*
10. *Cephalosporium acremonium.*
11. *Gliocladium roseum.*

(c) *A. niger:* black colonies; smooth, colourless conidiophores; brown, verrucose, globulose conidia, $<5\,\mu$; strongly cellulolytic; on many substrates, including plastics materials, leather, wool, etc; (cosmopolitan, especially equatorial Africa, as well as temperate climates).

(d) *A. ustus:* colonies at first white, then green, olive-grey and brown; fawn conidiophores; verrucose conidia, 3-5μ, with thick membrane; not markedly cellulolytic; found on manufactured objects, vinyl chloride (cosmopolitan, including warm regions: South-East Asia).

(e) *A. versicolor* (Fig. 12): colonies at first white, then rapidly turning green, underside orange-yellow to carmine in culture; hyaline conidiophores; verrucose conidia, 2.5-4μ; on plastics materials, rubber, vinyl chloride, stone (Mexico).

(f) A series of phialides clustered around the head, no intermediate metulae:

(i) Perithecia (late appearing):
A. glaucus (Fig. 13): bluish-green colonies; smooth conidiophores; conidia ± ellipsoid, verrucose, globulose, small, not markedly cellulolytic; xerophilous, osmophilic; perithecia globulose, small (75-100μ diameter), golden yellow, appearing on dried-out substrates.

(ii) No perithecia:
A. fumigatus: colonies at first almost colourless, then bluish, greenish and finally dark, smoky grey; smooth conidiophores, globulose conidia, slightly echinulate, green, 2.5-3μ; strongly cellulolytic, thermophilous, human and animal pathogene; on various materials and paper (South Pacific, India, U.S.A.).

4. Conidiophores not swelling at tip to form a vesicle, colonies usually green.

(a) Phialides squat; conidial system brush-like and more or less complex: *Penicillium.*

Phialides borne on metulae:

(i) *P. lilacinum:* woolly colonies, pale lilac to wine-pink in colour, underside the same colour but deeper. Irregular conidian brushes, phialides isolated or grouped in more or less complex and divergent verticils, elliptical conidia, 3 × 2μ. Found on stones (Angkor sandstones).

(ii) *P. rubrum* (and *purpurogenum*): green, velvety colonies; culture medium-coloured deep purple; biverticillate conidian brushes; conidia smooth or verrucose, round and small, 2-4μ; no perithecia; on nylon, vinyl chloride (South-East Asia and temperate climates).

(iii) *P. citrinum:* green, velvety colonies, exopigment yellow; unbranched conidiophores at the tip; small conidia, globulose to subglobulose, 2.5-3μ; cellulolytic; antibiotic pigment; no perithecia or sclerotia (South Pacific, Central America, Florida).

(iv) *P. chrysogenum* (Fig. 14): asymmetrical conidian brushes, differs from *P. citrinum* in that the conidiophore is branched at the tip, and the conidia are 3-4μ; antibiotic pigment, as in preceding species (penicillin); on paper and numerous substrates (cosmopolitan).

(v) *P. brevi-compactum, cyclopium, tardum, variabile, funiculosum:*
P. puberulum: colonies at first bluish-green then dirty-green; conidiophores finely spotted, with few ramifications, spherical conidia, 4-4.5μ; on vinyl chloride (South-East Asia).

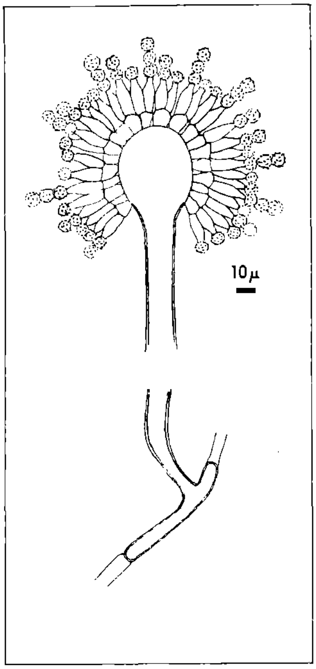
(b) Phialides not borne on metulae.

P. frequentans (Fig. 15): conidia chains remain grouped in long columns (on rubber, vinyl chloride (equatorial Africa).

(c) Phialides slender, colonies never green, conidian system simpler: *Poecilomyces.*

(i) *Poecilomyces Marquandii (Spicaria violacea)* (Fig. 16): pale lilac or violet colonies, exopigment yellow, conidiophores simple or ± penicillate, phialides divergent; found on sands, and stone (Mexico), similar to *Penicillium lilacinum:* easily distinguishable from it by the yellow pigmentation of the underside and of the culture medium: *Scopulariopsis.*

(ii) *S. brevicaulis* (Fig. 17): beige or brownish-ochre colonies; conidiophores simple or ± penicillate, the cell producing the conidium is an annellophore; on substrates rich in protein and on parchment (cosmopolitan).



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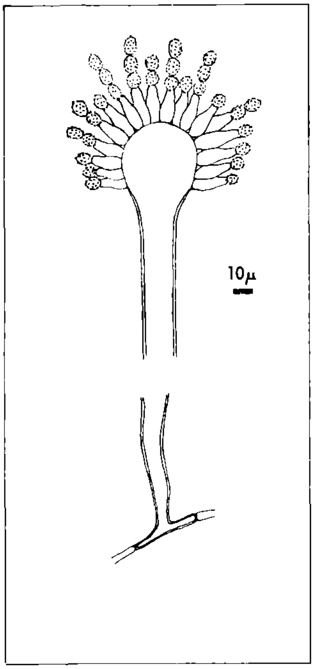

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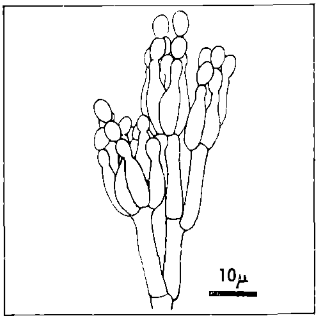

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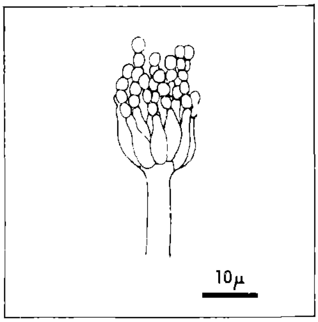

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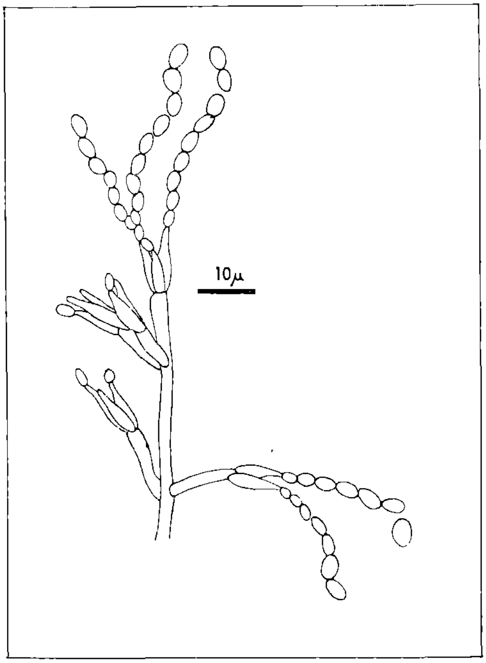

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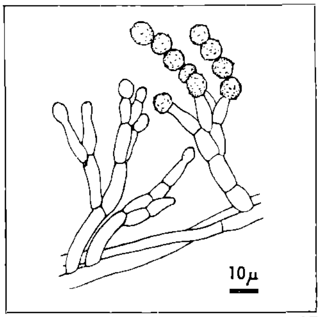


17

Figures

12. *Aspergillus versicolor.*
13. *Aspergillus glaucus.*
14. *Penicillium chrysogenum.*
15. *Penicillium frequentans.*
16. *Spicaria violacea*
17. *Scopulariopsis brevicaulis.*

WITH PERITHECIA; ENDOGENOUS SPORES (ENCLOSED IN ASCI)

WALL OF PERITHECIUM NOT FLUFFY

Wall of perithecium hard and brittle; terminal hairs ampullaceous: Ascotricha

Found on paper, maps, archives. Two species: *A. erinacea, A. chartarum.*

Wall of perithecium fragile; terminal hairs not ampullaceous: Chaetomium

A. Terminal hairs straight, slightly bent or wavy; *C. globosum* (Fig. 18): perithecia brown, 200-320µ; abundance of brown, wavy hairs, finely rugose, rarely segmented; ascopores oval, almost globulose, lemon-shaped, 9-13 × 6-9.5µ; strongly cellulolytic; found on plastics materials (vinyl chloride) and manufactured products (cosmopolitan, especially South-East Asia and temperate climates).

B. Terminal hairs dichotomically branched.

1. Large perithecia (<300µ):

C. elatum: large brown lemon-shaped ascopores, 11-13 × 8.5-9.5µ, apiculate at the ends; on graphic documentation and wool (South Pacific, including Australia, temperate climates).

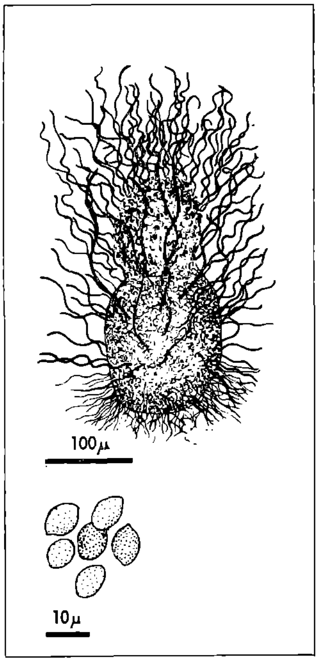
2. Small perithecia (<200µ):

(a) Terminal hairs of one type only:

C. indicum: globulose perithecia, 100-200µ; ovoid, slightly apiculate ascopores, 5-7 × 4.5-5.5µ; markedly cellulolytic; found on vinyl chloride, cloth (India, New Guinea).

(b) Terminal hairs of two types:

C. funicolum: dichotomal and single straight hairs; perithecia 130-160µ; ascopores 5.5.-6.5 × 3.7-5µ; strongly cellulolytic; found on paper, fibres, cloth (cosmopolitan, especially tropical regions: New Guinea, Australia, India, Florida).



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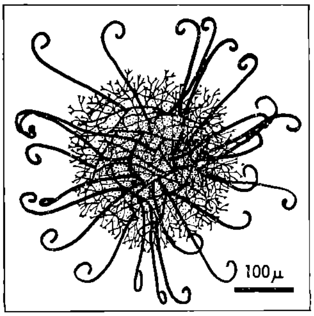

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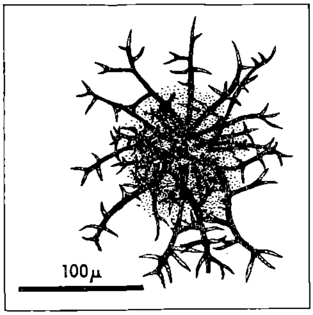

20

Figures

18. *Chaetomium globosum.*
19. *Myxotrichum chartarum.*
20. *Eidamella spinosa.*

WALL OF PERITHECIUM FLUFFY, FORMED OF A NETWORK OF FILAMENTS WHICH ARE ± DENSE AND DIFFERENTIATED SPIRAL HAIRS (FULCRA): *Myxotrichum*

M. chartarum (Fig. 19): perithecia 120-350μ; hairs 50-175μ long, with tips curled round in the shape of a crook: orange-brown ascospores, 2.4-2.6 × 4.3-5.2μ; chlamydospores; on paper and Indian maps painted on ivory.

SPINY HAIRS (FULCRA): *Eidamella*

E. spinosa (Fig. 20): spinous fulcra, as indicated; ascopores almost hyaline, orange-yellow when seen in a mass, lenticular, 4.6-5.2 × 2.6-2.9μ, finely striated; mole-grey colonies, wine-pink exopigment; on paper (metropolitan).

A NOTE ON OTHER DESTRUCTIVE PLANT ORGANISMS

MICRO-ORGANISMS WHICH ATTACK STONE

Among the micro-organisms which attack monuments and buildings of stone are the following: thio-bacteria, silico-bacteria, nitrifying bacteria, Actinomycetes and algae (Chlorophyceae such as the *Pleurococcus*, Cyanophyceae such as the *Scytonema, Tolypothrix, Gloecapsa, Chloroglea, Porphyrosiphon*) (P. Fusey and G. Hyvert, Pochon, Kauffman). Particular mention should be made of the Actinomycetes which attack monuments made of sandstones. In the case of the Angkor temples several *Streptomyces* species have been isolated *(S. griseus, S. fradiae, S. griseolutus,* etc.*)* and their biochemical characteristics identified (G. Hyvert). The frequency of occurrence of these micro-organisms on weathered stones would seem to indicate that they play a part in the complex process of the deterioration of such materials. They are capable of transforming nitrates into nitrites and sulphates into sulphides, and are often associated with thio-bacteria and particularly with nitrifying bacteria.

MICRO-ORGANISMS WHICH ATTACK TIMBER

On the other hand, timber is subject to damage by the action of higher lignivorous fungi, most of which belong to the Porchydnae, and particularly to the lower forms of Polypori. The latter include fungi forming crusts completely overlaying the substrate and either smooth or studded with indeterminate and variegated protuberances *(Corticum)* or containing large numbers of microscopic pores separated by emergences *(Porogramma)* such as *P. Borbonica*. The protuberances sometimes simulate short spines (Odontia) or are regularly aculeated (Radulum). The *Stereum (St. lobatum)* has a (smooth) hymenium partly separated from the substrate, as in the case of the *Hymenochaete (H. cacao)*, with a hard and brittle trama which is yellow or brown.

The Polypori may be no more than a hymenial surface overlaying the substrate and riddled with pores corresponding to tubes of varying depth: *Poria* (e.g., *P. xantha*).

The tropical Polypori, so abundant on rotting or rotten wood in forests and among crops, are also to be found on structural timber. In this connexion, mention may be made of the most common genera Merulii (Heim, 1942) *(Merulius)* or *Gyrophana lacrymans*, mortal enemy of wooden structures and libraries, occurring only in temperate regions; the tropical *G. similis* is less harmful; *Trametes* (thick stemless fungi with tubes penetrating the trama): *Trametes persoonii* (frequently found); Hexagonae (with large pores, often polygonal: *Hexagona tenuis*); Leptopori (fleshy species becoming hard; with a colourless trama: *Leptoporus rufo albus*); *Phellinus* (thick, with a subereous yellow trama: *P. extensus*). Ungulinae (with firm crust: *Ungulina melanopora*).

CONCLUSION

In view of the great variety of materials found in objects of artistic and cultural value and of the wide range of destructive agents likely to attack them, particularly in tropical climates, the problem of the preservation of cultural property is clearly an extremely complex and extremely difficult one. Protective and remedial treatment to combat the many possible types of destruction may thus easily yield results ranging from excellent to disastrous. The fight against destructive agents must therefore be conducted with the utmost care, common sense and patience. If, for example, disinfection has been badly carried out, using an over-concentration of pulverized products or if disinfectant substances have been applied at too close a range to such delicate objects as, say, documents, the results will be bad—perhaps even catastrophic. There are all too many preservation techniques which, if misapplied, can defeat their objective completely. One could quote a number of actual and regrettable instances of such errors, one of the most serious being that affecting the Lascaux cave paintings. A first precaution against mishaps of this kind would be to have on the staff of all museums, libraries, archives, and services in charge of the protection of monuments, fully trained specialists in conservation techniques with the advanced professional qualifications required for the job. Such advanced training is an absolute necessity if the methods briefly described above are to be carried out effectively. Furthermore, in certain special but important cases, it is essential that the commissions appointed to carry out particular conservation projects, should for the most part be persons of well-established reputation with practical experience and understanding of the problems and methods involved.

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J. J. H. Szent-Ivany

Identification and control of insect pests

4

GENERAL CONSIDERATIONS

The earliest recorded instances of insects attacking cultural property date back to almost 2,300 years ago (Weiss and Carruthers, 1937). Aristotle in his *Historia animalium* mentions 'animalcules resembling the grubs found in garments' and a 'creature resembling a scorpion'. There is little doubt that he referred to the larvae of certain species of clothes-moths (Tineidae) which occasionally attack books and archives and to the cosmopolitan book scorpion, *Chelifer cancroides* L., a pseudoscorpionid which is said to prey upon book-lice. Various authors of ancient and classical periods recommended the use of cedar oil, saffron, and containers made of polished cypress wood to prevent insect damage to books. In fact, cedar oil was probably the first insect repellent ever to be used for the preservation of cultural property.

Following a few general remarks on insect pest control in collections of cultural property, we shall proceed to a discussion of the various pests encountered. The insects referred to in this chapter all have biting mouth parts (some only in their larval stages) and represent eight distinct orders.

Distribution of insects

Many insects attacking cultural property in the tropics are cosmopolitan or tropicopolitan storage pests of a polyphagous nature. Most of these pests infesting study collections or exhibits can be controlled or eradicated by chemical means.

Design of buildings and furniture

Much unnecessary work and damage caused by insects can be avoided by the adoption of proper preventive methods. Careful architectural planning should precede the construction of new museums, libraries, art galleries, etc. When new buildings are erected for the housing of cultural property in tropical countries it is recommended, because of the risk of termite and beetle damage, to use insect-proof materials, such as steel, concrete and brick. Cabinets, drawers, shelves, etc., should preferably be made of metal. Timber used in buildings, furniture or equipment should be of termite-resistant species or properly treated to render it proof against insect attack. Air-conditioning and humidity control in buildings, the effect of which is to exclude a number of thermophilous and hydrophilous tropical insects, are important means of preserving and protecting cultural property against fungus attack. Electrostatic air filters incorporated in air-conditioning systems control dust and to a certain extent also dust-inhabiting insects such as book-lice.

Treatment by fumigation

One of the safest methods of keeping collections and exhibits free of insect pests is fumigating all newly purchased materials with a lethal gas. Thus it is essential to include in the building a properly constructed fumigation room in which all material is treated on arrival.

The fumigation room can also be used for the disinfection of study collections or exhibits which have become accidentally infested with insect pests. This rarely happens in air-conditioned buildings. If air-conditioning cannot be installed, many insects can be kept out of the building by covering all windows and doors with fine-mesh wire screening.

Modern methods of fumigation allow the treatment of a very large building under plastics sheets (Page and Lubatti, 1963). Under tropical conditions it is recommended that fumigation of all buildings in which cultural property is housed should be carried out frequently. However, such fumigation treatment is expensive. One way of reducing fumigation costs is to have the air-conditioning system so designed that a gas such as methyl bromide can be circulated through the air ducts.

Fumigants recommended

Various fumigants are recommended for the eradication of pests in stored products, in museums and libraries. Some examples are sulphuryl fluoride, methyl bromide, hydrogen cyanide, ethylene oxide, carbon tetrachloride, ethylene dichloride and ethylene dibromide (ibid.). One of the most useful is methyl bromide. It kills most insects in all stages. It breaks down rapidly and it does no damage to the majority of materials. Experiments conducted during recent years have shown that sulphuryl fluoride is even more toxic to a number of insects than methyl bromide (Kenaga, 1957).

Most fumigants are very poisonous to human beings and fumigation should always be carried out under the supervision of an expert, a chemist or the representative of an insecticide firm.

We now proceed in the following sections to list the insect pests that are most destructive of cultural property and to describe the various methods of control that can be used. Every insect order is dealt with under a separate heading. The orders are arranged in philogenetical sequence (Imms, 1957).

IDENTIFICATION AND CONTROL

THYSANURA (bristle-tails)

The most primitive forms of the class Insecta belong to this order. The popular name 'bristle-tail' refers to the appendages found at the end of the abdomen, e.g., a pair of cerci and a median cereous-shaped 'tail' which is actually the prolongation of the last abdominal segment. Bristle-tails, like all other insects of the subclass Apterygota, are wingless (apterous), which is believed to be a primary condition.

Identification of species

Various species of this order are pests in libraries and museums. The best known is the common silverfish *Lepisma saccharina* L. (Fig. 21): a shiny silvery-grey insect of 8 to 13 mm in length which probably originated in Europe but is now almost cosmopolitan. The silverfish is a fast-moving creature which feeds mainly at night and hides during the day. Another common species is *Ctenolepisma longicauda* Esch., a whitish creamy-coloured insect with a very long tail. This species originates in Africa but has spread to many other tropical countries. A third species, *Acrotelsa collaris* F. is tropicopolitan.

Various other bristle-tails enter houses, libraries, archives and museums in the tropics. Such are *Ctenolepisma urbana* S. in Hawaii, *Ctenolepisma reducta* F. in Puerto Rico, *Ctenolepisma nigrum* O. and *Pielolepisma calvum* R. in Ceylon and *Thermobia aegyptiaca* L. in the United Arab Republic and Hong Kong.

Material attacked by Thysanura

Silverfish and their allies cause damage to the surface of paper, book-bindings, pasteboard boxes; they eat the glue and even the Indian ink of labels of collections on display. They damage photographic prints, paper linings of walls and they sometimes feed on dry plant specimens in herbaria. *Ctenolepisma logicauda* has been observed feeding on dried specimens of Echinodermata. In Puerto Rico *Ctenolepisma reducta* was found infesting envelopes containing scale insects.

Controlling Thysanura

Various methods of chemical control have been developed for the reduction of silverfish populations in living quarters, libraries, archives, herbaria and museums. A simple method is the application of a bait consisting of one part of sodium fluosilicate and five to eight parts of flour (Marcovitch, 1933). DDT dust, a low concentrate of DDT spray (0.25 per cent) and pyrethrum dust (Weiss and Carruthers, 1937) have been also successfully used against Lepismatidae in museums, libraries and herbaria.

A new technique for the control of silverfish in libraries has been developed recently by scientists of the Division of Entomology of the CSIRO (Canberra) under the supervision of Mr. S. W. Bailey. Foolscap-sized sheets of brown paper were treated with dieldrin. A deposit of 0.3 to 0.4 per cent weight for weight was specified and each sheet of paper was clearly marked 'dieldrin treated'. These sheets were very successfully used for the control of silverfish in the archives of the National Library in Canberra. The dieldrin-treated sheets were placed at the back of each box file, on the shelves beneath the books and in map drawers. It is anticipated that the residual effect of the chemical in the treated sheets will last at least ten years. The advantage of this method is that the insects moving about actively on the shelves and in the drawers come into frequent contact with the poison-impregnated paper whilst the library staff has minimal contact with the dieldrin after the initial placing of the sheets.

ORTHOPTERA (crickets, grasshoppers and their allies)

Identification of species

There are only a few insects in the large order which could be considered pests of cultural property. The house cricket (*Amphiacusta caraibea* Sauss. was reported as destructive of books from the Lesser Antilles (Ballou 1912). Another cricket was found to have caused damage to books in India. In New Guinea a large brown species of the mainly tropical family Gryllacrididae (sometimes called 'tree-crickets') (Fig. 22): enters houses at night, attracted by electric light. It makes cuts of various lengths in clothes, curtains, fabrics and sometimes also in paper (periodicals, office files, etc). The damage is caused by the sharp mandibles and probably also by the long serrate tibiae; the insect does not actually eat the materials (most Gryllacrididae are believed to be predaceous). In Papua it is commonly known under the name of 'calico-eater'. Another species, *Paragryllacris combusta* Germ. has been found to damage curtains in Australia. It is believed that this species cuts a piece from the material to form a flap under which it hides (McKeown, 1944).

Protective measures

Damage by such large insects as crickets and tree insects rarely occurs in air-conditioned buildings which are more or less hermetically closed, or in buildings which are protected by wire and have fast closing flap-doors at their entrances. In buildings with neither air-conditioning nor wire screens, it is as well to keep ethnological exhibits under cover of glass. This will protect fabrics from damage by large Orthoptera and cockroaches.

DICTYOPTERA (cockroaches and mantids)

Identification of species

Mantids are carnivorous, predaceous insects; they do not damage cultural property. Cockroaches, however, especially the so-called domestic species, are almost omnivorous and can cause severe damage to cultural property, especially to books. They have a large shield-like pronotum which usually overlaps the head. Most species have wings; however, apterous and brachypterous forms are also known. In some species the shape and the size of the wings is different in the two sexes. Such is the case of the Oriental Cockroach *(Blatta orientalis* L.*)*. The females have rudimentary wings (Fig. 23) whilst the wings of the males (Fig. 24) are longer but do not cover the full length of the abdomen. The abdomina of the Australian Cockroach *(Periplaneta australasiae* F.*)* (Fig. 25), of the closely related American Cockroach *(Periplaneta americana* L.*)* and of the smaller German Cockroach *(Blattella germanica* L.*)* (Fig. 26) are fully covered by the wings.

The German Cockroach and various other cockroaches lay their eggs in a sclerotized ootheca (Fig. 27) which is usually divided by a partition into two rows of pockets. Each pocket is occupied by an egg. The German Cockroach is ovoviviparous: the female carries its eggs during most of the time of the incubation period. It drops the ootheca shortly before the eggs are ready to hatch. Before the young cockroaches (Fig. 28) are ready to emerge from the eggs, the ootheca splits in two halves.

Cockroaches have a long life cycle. The female American Cockroach has eleven and the male has twelve instars (or different forms the insect may have between moults). Its cycle lasts 250-270 days at 29°C (Griffiths and Tauber, 1942).

Distribution

All the above-mentioned cockroaches are practically cosmopolitan. Other widely distributed species are the Brown Cockroach *(Periplaneta brunna* B.*)*, the Brown-banded Cockroach *(Supella supellectilium* S.*)* and the species *Eoblatta notulata* Stal., *Stylophaga rhombifolia* Stoll and *Ectobia lapponica* L. (Essig, 1947; Girard, 1877).

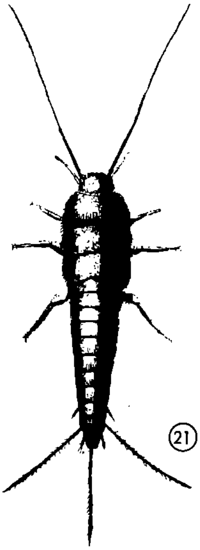
The distribution of domestic cockroaches by man throughout the world probably began in the early days of navigation and damage caused by them to cultural property, especially to books in tropical countries, was reported by a number of nineteenth-century authors.

Damage caused by Dictyoptera

Cockroaches are mainly active at night. Domestic cockroaches feed on a great variety of foodstuffs and materials. They damage wool, leather, leaves and bindings of books *(Plate 1)* and periodicals. The species of the genus *Periplaneta* are strongly attracted to the glue in the bookbindings. The Brown-banded Cockroach is so much attracted to gum that small nymphal instars sometimes get drowned in gum-bottles. Mounted insects on setting boards, if left uncovered overnight, are frequently eaten by cockroaches.

Protective measures

A means of protecting herbarium specimens from cockroaches, certain beetles and other insects is to treat the plants at the time of mounting with an alcoholic solution of corrosive sublimate [500 g. corrosive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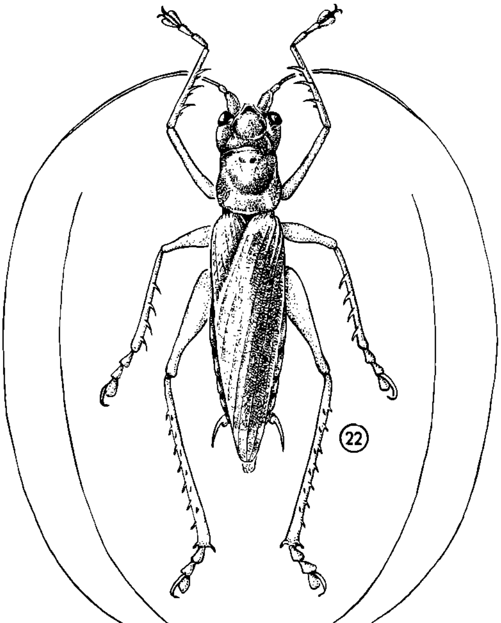
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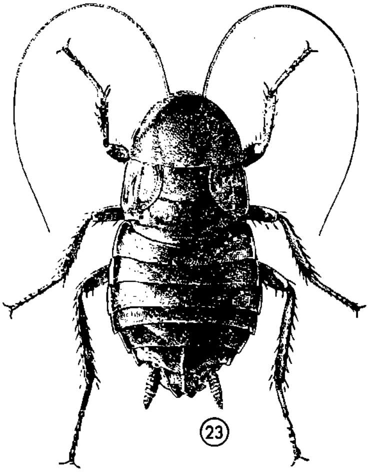
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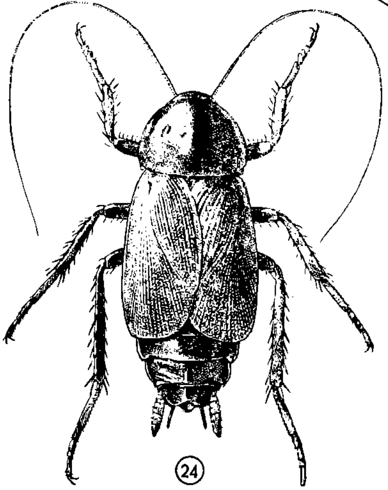
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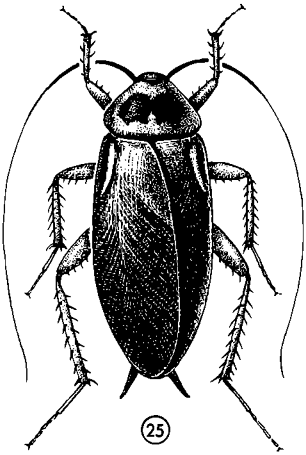
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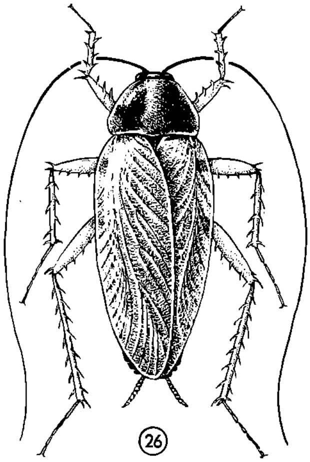
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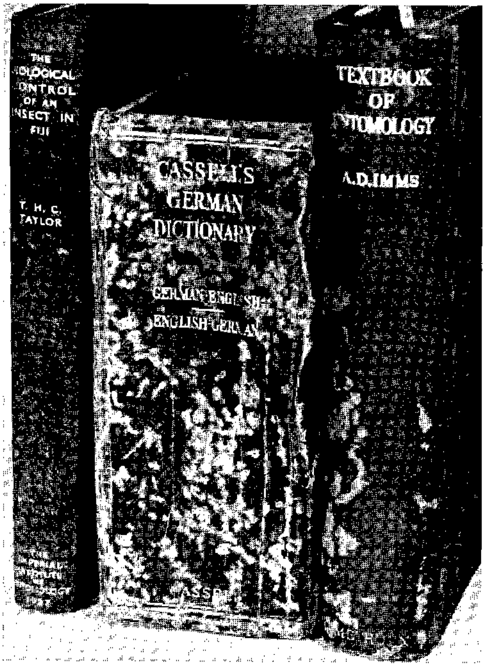
Figures

21. Thysanura. Silver fish, *Lepisma saccharina* L. (after Lubbock; reproduced with the kind permission of the Royal Society, London).
22. 'Tree cricket', a gryllacridid, undescribed species from New Guinea.
23. Oriental cockroach, *Blatta orientalis* L., female [reproduced from British Museum (Natural History) Economic series No. 12; with the kind permission of the Trustees of the British Museum (Natural History)].
24. Oriental cockroach, *Blatta orientalis* L., male [reproduced from British Museum (Natural History) Economic series No. 12; with the kind permission of the Trustees of the British Museum (Natural History)].
25. Australian cockroach, *Periplaneta australasiae* F., female.
26. German cockroach, *Blattella germanica* L., female.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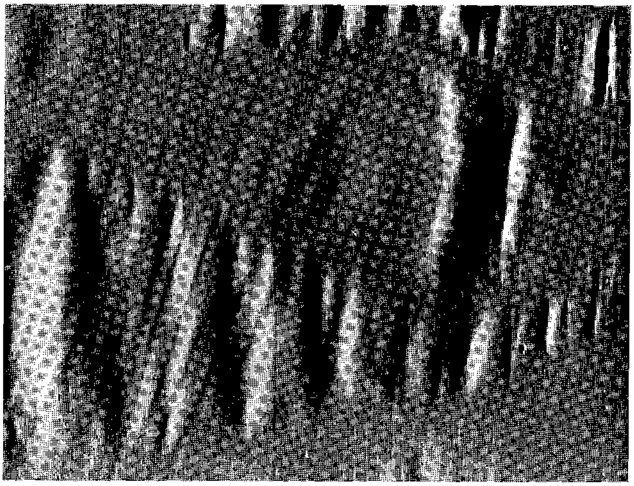

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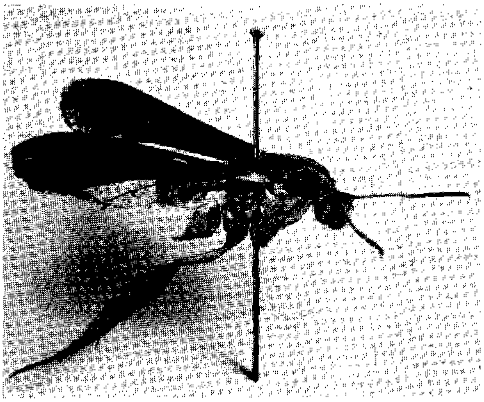

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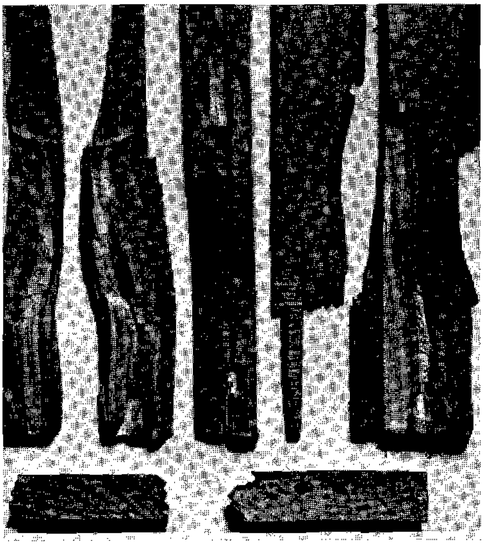

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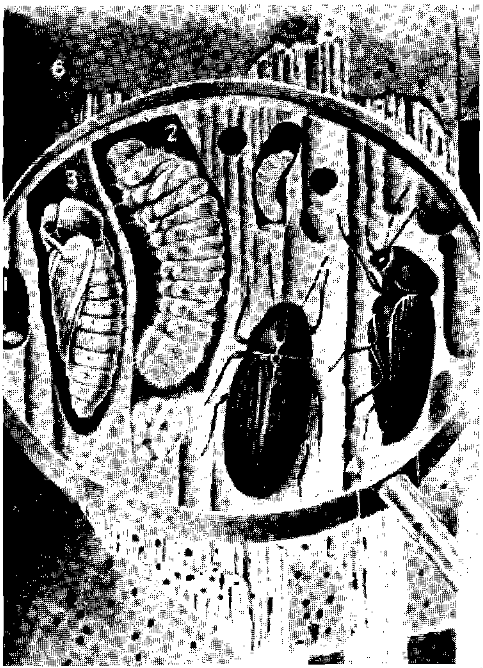

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Plates

1 Books damaged by the Australian cockroach, *Periplaneta australasiae* F.

2 Damage caused to the leg of a desk by the dry-wood termite, *Incisitermes,* in Port Moresby (photo: N. Moderate).

3 Panelling of a painted door. The dry-wood termite, *Cryptotermes,* has tunnelled beneath the indentations (photo: N. Moderate).

4 Damage caused to furniture by the dry-wood termite, *Cryptotermes.* Note the accumulated frass on the plywood (photo: N. Moderate).

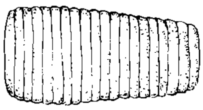
5 Damage to a mounted sesiid moth caused by the book-louse, *Psocatropus microps* (photo: N. Moderate).

6 Eggs, larvae, pupa and adults of the furniture beetle, *Anobium punctatum* (reproduction authorized by the Department of Agriculture, Sydney, N.S.W.).

7 Damage to soft woods caused by the European House Borer, *Hylotrupes bajulus* (reproduction authorized by Forests Commission of Victoria, Melbourne).

Figures

27. Ootheca of German cockroach, *Blattella germanica* L.
28. German cockroach, *Blattella germanica* L. First instar nymph.
29. Typical termite damage to building timbers: A. *Kalotermes*, dry-wood termite; B. *Reticulotermes*, moist-wood termite; C. *Coptotermes*, tropical moist-wood termite; D. *Odontotermes*, ground-dwelling termite filling excavations with soil (after Harris; reproduced with the kind permission of Mr. W. Victor Harris).
30. *Mastotermes darwiniensis* F., a very destructive giant subterranean termite of tropical northern Australia; recently it was accidentally introduced to New Guinea (after Froggatt; reproduced with the kind permission of the Editor of Publications, Department of Agriculture, New South Wales).
31. Soldier of *Cryptotermes havilandi* (Sjostedt), a circumtropical dry-wood termite (after Harris; reproduced with the kind permission of Mr. W. Victor Harris).
32. Soldier of *Coptotermes niger* Snyder, a subterranean termite; major pest in Panama, Guatemala and British Honduras (after Harris; reproduced with the kind permission of Mr. W. Victor Harris).
33. A book-louse, *Liposcelis* sp.



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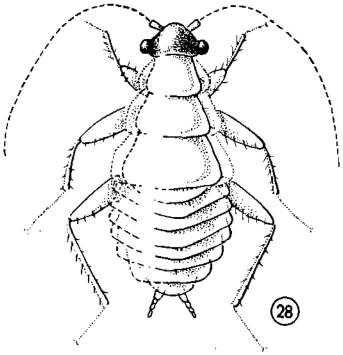

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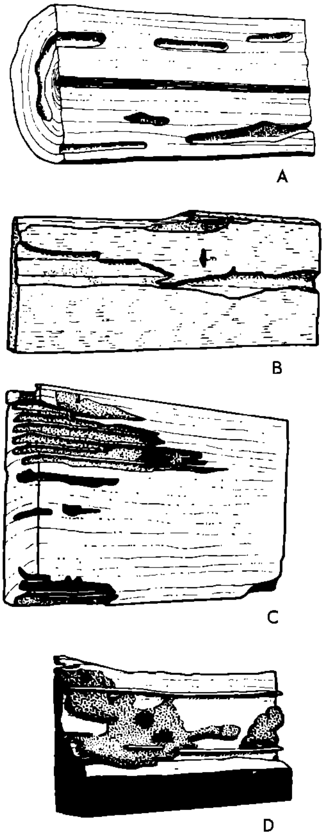

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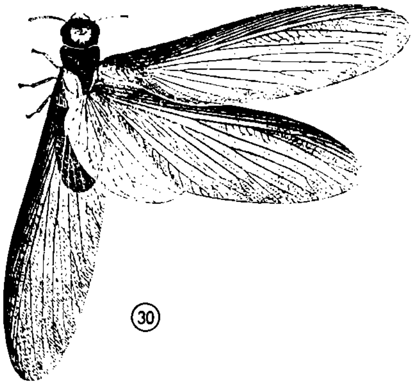

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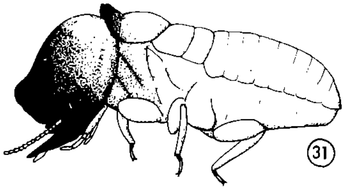

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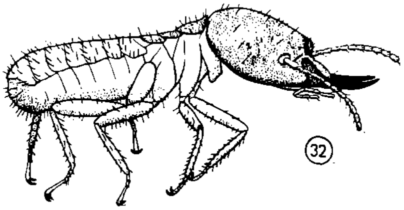

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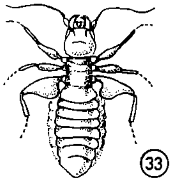

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sublimate (mercuric chloride) to 18 litres of 40 per cent ethyl alcohol] or a solution of lauryl-pentachlorphenate in white spirit. The advantage of the latter is that it is almost non-toxic to human beings whereas corrosive sublimate is highly poisonous.

Many insecticides have been tried and may be recommended for the control of cockroaches in houses. Some examples are chlordane, diazinon, dieldrin, malathion, pyrethrum and DDT-pyrethrum aerosol. A mixture of pyrethrum and borax has been very successfully used in New Guinea against *Blattella germanica* and *Periplaneta australasiae.* One of the advantages of pyrethrum is that its human oral and dermal toxicity is very low. On the other hand, it is not very persistent and requires more frequent applications than chlorinated hydrocarbon insecticides.

In some areas cockroaches (especially *Blattella germanica*) have built up resistance to dieldrin, chlordane and DDT.

The treatment of books with varnishes and lacquers against cockroaches has been known and practised for many years. An effective one is used in the library of the Botanical Garden at Singapore.[1]

The Department of Chemistry, Experiment Station of the Hawaiian Sugar Planters' Association, Honolulu has recently developed a new book lacquer and a repellent to protect books against cockroaches and other insects. Both the lacquer and the repellent are very successfully used in the libraries of the Experiment Station and of the Entomology Department of the University of Hawaii. They are equally good for the protection of books against insects and fungi.[2]

ISOPTERA (termites)

Termites represent some of the most destructive pests of structural timber in the tropics (Fig. 29). They are more harmful to buildings where cultural property is housed than to cultural property itself *(Plates 2, 3, 4)*. However, several species have been recorded as attacking books.

Isoptera, although a very ancient group, with their specialized apterous forms and with their highly-developed social organization, have many similarities to the ants, members of an order which is morphologically and philogenetically very distantly related to termites.

Termites have wingless workers, soldiers and nymphs and they have alate males and females. The winged males and females, after having left their nests and found a mate, shed their wings and become reproductive 'kings' and 'queens'. The termite queen develops a very large abdomen which grows from year to year for a considerable period, reaching 130 mm in some species *(Macrotermes)* (Harris, 1961).

Most termites lay their eggs singly, sometimes in quick succession. An exception is *Mastotermes darwiniensis* F. (Fig. 30): a giant North Australian species which lays its eggs in small batches of 16 to 24.

The nymphal stages of the termites have several instars and the adults have a longer life span than most other insects. The worker caste represents a young stage which discontinues its development some time after the second moult. Workers have well developed chitinized mandibles. The soldiers have very large heads and very strong mandibles (mandibulate type) (Fig. 31, 32) or they have a medium frontal rostrum but relatively small jaws, (nasute type) (Imms, 1957).

All termites build nests and a colony sometimes consists of several million individuals. Species of the family Kalotermitidae establish their nests in dry wood, those of Thermopsidae in damp wood;

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[1] See Appendix, this Chapter, p. 68.

[2] See Appendix, this Chapter, p. 68, and also discussion, p. 283.

others, such as *Coptotermes* make their nests in the soil, round tree roots.

We are primarily interested in those which attack structural timbers. The tropical species are classified in two main groups: (a) dry-wood termites; and, (b) subterranean termites. Harris lists a large number of both types arranged according to the countries where they occur (Harris, 1961, pp. 158-163).

Cultural property attacked by Isoptera

Some termite species are restricted to relatively small areas, e.g., there are several endemic major dry-wood termite pests in Ceylon; some others such as *Cryptotermes brevis* W. and *C. havilandi* S. have circumtropical distribution. Species of this last genus may attack shelves, storage boxes, drawers and ethnological specimens (wooden carvings) in museums.

Books are sometimes attacked by termites. The subterranean termites *Coptotermes formosanus* S. and the dry-wood termites *Cryptotermes brevis* W. and *Incisitermes immigrans* S. have been recorded as pests of books from Hawaii (Fullaway, 1926). Other termite pests that attack books are: *Heterotermes gertrudae* R. in the Indian Himalayas, *H. tenuis* H. in South America, *Odontotermes patruus* S. in Africa (Mulungo, Congo), *Reticulotermes flavipes* K. in Guyana, *Coptotermes vastator* L. in the Philippines and *Cryptotermes* sp. in Indonesia (Kalshoven, 1938).

Preventive measures

The best way of protecting objects of cultural interest against termites is to make the buildings in which they are housed as termite-proof as possible, by such means as:

1. Using termite-resistant timber wherever possible. A large number of species of such timber from many tropical countries are listed by Harris (1961, pp. 123-124).
2. Building or incorporating mechanical barriers (concrete slabs, metal caps, concrete barriers) (ibid., pp. 144-147).
3. Setting up chemical barriers such as soil barriers treated with persistent insecticides (Harris, 1961; Beesley, 1957).
4. Applying modern methods of wood preservation. All structural timber used for the erection of buildings or for the manufacture of furniture, shelves, etc., should be pre-treated with chemicals.

Types of protective treatment

Various methods of wood preservation are used in tropical countries, the most important being 'diffusion methods,' 'pressure processes' and 'hot and cool treatment'.

Diffusion treatments are probably the most suitable for application in the tropics. These depend on the diffusion of a concentrated solution of preservative chemicals in the free water naturally present in timber. After application of the solution the timber is held under non-drying conditions to allow diffusion to take place. Only green sawn timber can be treated. The advantage of diffusion methods is that both sapwood and heartwood are treated. Various combinations of inorganic salts are used as preservatives (Colwell, 1964). The CSIRO in Australia has developed and patented a borofluoride chrome arsenic preservative for diffusion treatment of green building timber (Anon., 1960). Certain types of concrete can also be successfully treated against termites with dieldrin or aldrin (Gay, 1961).

If a building is attacked by subterranean termites, the nest should be located, dug out and broken up or destroyed with arsenic trioxide powder. If the nest is not readily accessible a small quantity of arsenic powder should be blown into holes drilled into the centre of the nest (Beesley, 1957, p. 5). A very little quantity of this substance is sufficient to kill a large number of termites. Tests carried out by scientists of the CSIRO (Australia) showed that quantities as low as 1.75 g will kill an entire colony of some 1.5 million individuals of the termite *Nasutitermes exicitiosus* H. within two weeks (Gay, 1961).

Cables and electrical fittings are sometimes attacked by termites (Kalshoven, 1962). It may therefore be advisable to treat them with a chemical before they are installed and to pack the wiring entrances with a persistent insecticide, such as aldrin.

The control of dry-wood termites is not easy. If the presence of such termites is detected at an early stage it may be possible to exterminate them by spraying with a mixture of 1 litre dieldrin (15 per cent emulsion) to 14 litres of water and 125 g ether, or by fumigation with methyl bromide or sulphuryl fluoride (Kenaga, 1957). Spraying should be carried out with a pressure sprayer fitted with a needle jet.

Ornamental carvings, if they are not painted with natural pigments, can be dipped in a mixture of dieldrin and dichlorethyl ether or alternatively can be sprayed or brushed with such a mixture. Copper naphthanate or zinc naphthanate can be also applied to termite or wood-borer infested artefacts, either by brushing or by spraying. Various materials are used for the fixing of natural pigments. One part of Bedacryl 122 X (a polymethacrylate-ester marketed in a 40 per cent solution of xylene) diluted with 5 parts of toluene is currently used in the Art Gallery of New South Wales (Sydney) to spray bark paintings (private communication, by Mr. F. W. McCarthy, Australian Museum, Sydney). Because of the toxicity of the spray, the operator should wear a safety mask and gloves.

PSOCOPTERA (book-lice or dust-lice and their allies)

Identification of species

Minute species of this order, representing various families (Liposcelidae, Phyllipsocidae, Psyllipsocidae, Trogidae), are pests in libraries, herbaria and museums. Book-lice are small to minute insects with relatively large heads and strong toothed mandibles. Some species have well developed wings, others have rudimentary wings in the female or in both sexes, some others are wingless. Such are the species of the genus *Liposcelis* (Fig. 33).

Cultural property attacked by Psocoptera

In entomological museums, book-lice mainly devour the scales and hairs on the bodies of insects, but they can cause more serious damage to mounted specimens *(Plate 5)* if the storage boxes are not regularly treated with chemicals. In libraries they damage books by eating away the paste and the glue. *Liposcelis* has been observed eating the gelatine of slides of mounted *Echinodermata. Trogium pulsatorium* L., a common pest in museums and libraries in Europe (Acloque, 1913; Hansen, 1930) has been spread by man throughout the world. Another species *Liposcelis divinatorius* M. is probably tropicopolitan. *Liposcelis entomophilus* E. has been found in museums and libraries in the Philippines; other species of *Liposcelis* have been observed in Africa, Hong Kong and Hawaii. *Psocatropus microps* E. is the common species in New Guinea, but is also found in Africa, Java and Formosa. *Psocatropus lachlani* R., *Psyllopsocus minutissimus* E. and *Ectopsocus maindroni* B. have been reported from Hong Kong, species of *Nepticulomina, Micropsocus, Tropusia* from Indonesia and *Archipsocus fernandi* P. from Ceylon.

Treatment recommended

Psocoptera damage can be prevented to a large extent by careful attention to cleanliness: frequent dusting of cabinets, drawers, shelves, storage boxes, books, periodicals and plant-folders. Insects in temporary storage should never be kept in cardboard boxes. Flake naphthalene should be kept in all insect drawers and temporary storage boxes. In actual cases of infestation an immediate measure of control is to place paradichlorobenzene in the container affected. Both naphthalene and paradichlorobenzene should be kept in a muslin bag and the bag safely pinned in a corner of the box to prevent its rolling about and damaging specimens (McKeown, 1944). A simple and effective method of killing dust-lice is to place paradichlorobenzene in every corner of the infested box and then keep it in a thermostatically regulated electric drying cabinet for 24-36 hours at 50°C. Heavily infested containers, however, should be fumigated.

In tropical countries, where temperatures and relative humidity are high, disinfectants which act as insecticides and mouldicides at the same time may be used. An example is the British Museum Mixture: 'Flake naphthalene is added to a quantity of chloroform till the latter is saturated. An equal bulk of Beechwood creosote is then added and the mixture kept well stoppered' (Smart, 1940). This mixture may be painted on the inner surface of boxes or drawers before mounting insects in them.

LEPIDOPTERA (butterflies and moths)

Identification of species

A few species of moths, mainly of the family Tineidae, are known as pests of natural history specimens (especially mammal and bird skins), of books and of fabrics on ethnographical specimens. Most moths have four well-developed wings. They are holometabolous insects; they have four stages: egg, larva, pupa and adult. The larvae, which cause the damage to cultural property, have biting mouth parts.

Materials attacked by book moths

Book-bindings are sometimes eaten by the widely distributed common clothes-moths *Tinea pellionella* L. and *Tineola biseliella* H. (Fig. 34). The larvae of *T. pellionella* live in portable cases made of various substances whereas the larvae of the other species web together the particles of the material on which they feed.

Preventive treatment

The best method of preventing damage by moths and carpet beetles to mammal and bird skins is to treat the skins soon after collecting in the field, mammals with alum and arsenic trioxide, birds with borax. Mammal and bird skins in study collections should be kept in hermetically closed sheet metal cases or drawers. Paradichlorobenzene should be placed into the containers every two or three months, but it is advisable to check all cases and drawers monthly since paradichlorobenzene evaporates very rapidly in tropical climates. In addition to these preventive measures, study collections may be fumigated with methyl bromide once or twice a year.

Paradichlorobenzene may be hung in gauze bags in the glass cabinets where stuffed birds or mammals are kept on display, and the insides of the cabinets may be sprayed with dieldrin periodically. Dieldrin can also be used to spray the interiors of cabinets in which ethnological specimens are kept. In the case of heavy infestation in museums and libraries, fumigation should be carried out.

Modern book lacquers and book insect repellents also provide effective protection against lepidopterous larvae.[1]

HYMENOPTERA (ants, wasps and bees)

Identification of species and preventive measures against ants

Some species of ants, a few wasps and carpenter bees may cause damage to cultural

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[1] See Appendix, this Chapter, p. 68, and also p. 283.

property in the tropics. Dried insect specimens are eaten by ants if they are not kept in tightly sealed containers. A very good ant-repellent is Beechwood creosote which may be painted on the sides of temporary storage boxes. To keep ants from entering buildings, a low concentrate of dieldrin or chlordane emulsion should be painted or sprayed at regular intervals round the base of the building, at the entrances and openings or any other place where ants may gain access.

Identification of species and preventive measures against wasps and bees

Wasps of the family Sphecidae often build their mud-nests in drawers, on shelves and on books. In New Guinea the widely distributed species *Sceliphron laetum* S. (Fig. 35) has been observed on several occasions pasting together the backs of two or three books. Carpenter bees *(Xylocopa* species*)* bore into structural timber. The only protection against these large flying insects is insect-proof wire screens.

COLEOPTERA (beetles)

There are some important pests of cultural property amongst the beetles, the largest order of the class Insecta. Those which damage cultural property, can be divided into two main groups: (a) beetles damaging timber; (b) beetles damaging other materials, such as textiles, fabrics, furs, hides, feathers, dried insects, plants, etc. Books are attacked by members of both groups. Some omnivorous beetles seem to feed on almost every type of organic matter.

Identification and characteristic materials attacked

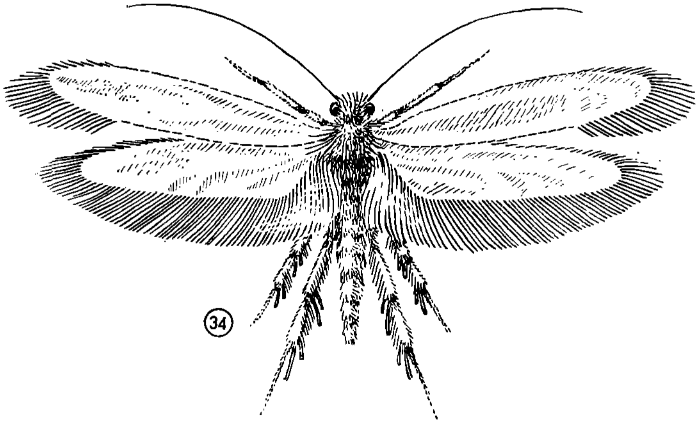
Important pests of cultural property are found in the following beetle families.

Dermestidae (carpet beetles). These are small- to medium-sized insects which have conspicuous dark-coloured hairy larvae. The most important pests are species of the genera *Dermestes* and *Anthrenus* which attack dried specimens of insects, Crustacea, chitons (Polyplacophora), Echinodermata, mammal and bird skins, shooting trophies, hides, carpets and sometimes also books (Bohatta, 1927). The best-known species are *Anthrenus museorum* L., *A. lepidus* Lec., *A. pimipinellae* F., *A. thoracicus* M., *A. varius* L. (Tillyard, 1926), *A. verbasci* L. (Fig. 36), *Dermestes cadaverinus* F., *D. lardarius* L., *D. maculatus* De Geer, and *D. vulpinus* F., most of them being almost cosmopolitan species. The species *Attagenus gloriosae* F. (Fig. 37) has been found damaging specimens of insects in New Guinea and *Orphinus vulvipes* G. has been observed feeding on insects and the woollen strings of portfolios in Indonesia.

Anobiidae. These are small, usually uniformly dark-coloured beetles. Many of them are serious pests of seasoned timber, dried plant specimens and books. One of the most severe pests of seasoned timber is the almost cosmopolitan furniture beetle *(Anobium punctatum* De Geer*) (Plate 6)*, which was also recorded as a library pest (Anon., 1878; Bohatta, 1927; Hansen, 1930).

The two most serious cosmopolitan library pests are *Stegobium paniceum* L. and *Lasioderma serricorne* F. The latter also attacks herbaria. The species *Dorcatoma bibliophagum* M. is a severe pest in libraries of Brazil (Faria, 1919; Magalhaes, 1926) and in Peru (Wille, 1934). Species of the genus *Catorama (C. herbarium* Gorham, *C. mexicana* Pic., *C. pusilla* Sharp.*)* have been recorded in various tropical countries as library pests. *Catorama mexicana* (Kotinsky, 1906) was for a long time, and probably still is the most serious pest of books and leather in Hawaii. *Gastrallus laticollis* damages books and bamboo objects in Indonesia (Kalshoven, 1938) and *Ptilinus pectinicornis* L. has been recorded as harmful to books in the United Arab Republic and Hong Kong.

The death watch beetle *Xestobium rufi-*



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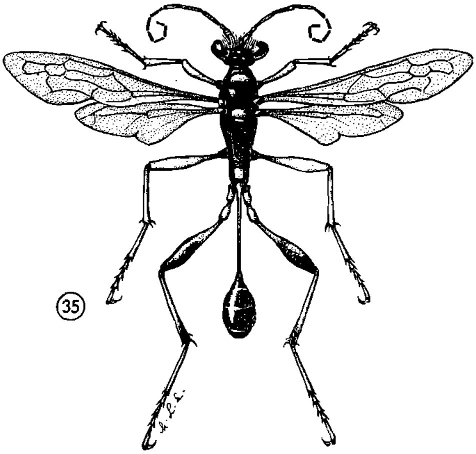

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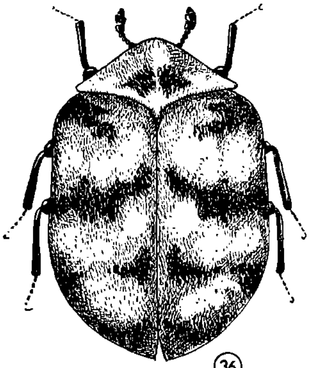

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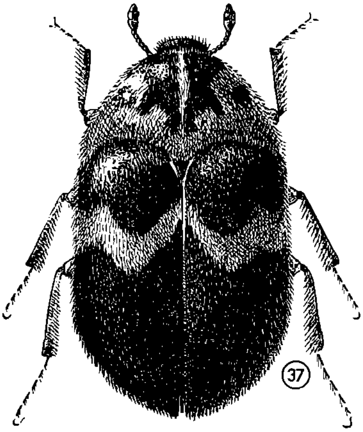

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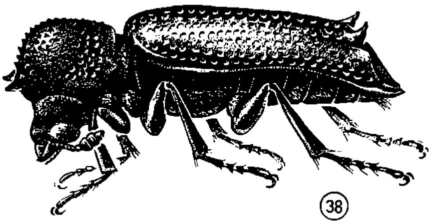

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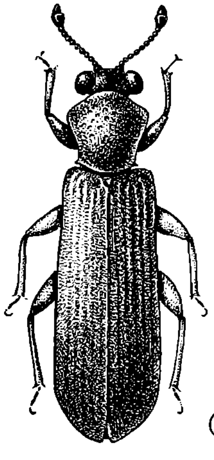

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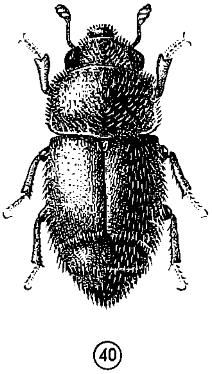

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Figures

34. Common clothes-moth, *Tineola biseliella* H.
35. *Sceliphron laetum* Sm., a sphecid wasp which often builds mud nests on the backs of books in New Guinea.
36. *Anthrenus verbasci* L., a widely distributed museum beetle.
37. *Attagenus gloriosae* F., a dermestid beetle found damaging dried insect specimens in New Guinea.
38. *Heterobostrychus aequalis* Waterh., a destructive pest of building timber, especially floor-boards in tropical countries.
39. *Lyctus brunneus* Steph., a cosmopolitan powder post beetle.
40. *Carpophilus dimidiatus* F., a cosmopolitan pest of stored products, which sometimes damages museum specimens in the tropics.

villosum De Geer was found to be responsible for the destruction of the timber roofs of many famous buildings in Europe (Essig, 1947). There are probably other species in the tropics which may cause similar damage to cultural property.

Ptinidae. The almost cosmopolitan species *Niptus hololeucus* F., *N. unicolor* P. (Bohatta, 1927), *Ptinus brunneus* D., *P. fur* and *Sphaericus gibboides* Boisd. have been recorded as attacking leather backs and glue in books. Ptinids are small sombre-coloured beetles with scarabaeoid-type larvae.

Bostrychidae. An important wood-borer family representing minute to large beetles of uniformly dark-brown, reddish-brown or blackish colour. They have light-coloured curved larvae.

The minute species *Rhizopertha dominica* F. is a common library pest (Hoffman, 1933). It has been distributed to all parts of the world by commerce (Fisher, 1950). Another small circumtropical species, *Dinoderus minutus* F. is sometimes found in museums attacking bamboo artefacts (Kalshoven, 1963). Pests of structural timber with a wide range in the tropics are *Sinoxylon anale* Lesn. (ibid. 1963) and *Heterobostrychus aequalis* Waterh. (Fig. 38). The latter often damages floor boards. Adult beetles emerging from a floor were reported to have perforated a valuable carpet in Indonesia (ibid.).

Lyctidae. Serious pests of structural seasoned timber. One of the best-known cosmopolitan species is *Lyctus brunneus* Steph. (Fig. 39). *Minthea rugicollis* W. causes severe damage to ethnographical specimens, such as wooden masks and carvings in Indonesia (ibid.).

Nitidulidae. A very small species, *Carpophilus dimidiatus* F. (Fig. 40), mainly a stored product pest, is sometimes found in museums damaging small insects.

Cucujidae. A minute species, *Ahasverus advena* W. is an occasional pest of plant specimens in herbariums.

Tenebrionidae. Tribolium castaneum H., a cosmopolitan storage pest, has been found damaging large mounted insects in the Philippines.

Cerambycidae. A very few species of the large family of the longicorn beetles attack seasoned timber. Such is the house borer, *Hylotrupes bajulus* L., which causes severe damage to softwood timber *(Plate 7)*. Some species of the tribe Clytini are borers in bamboo curtains.

Preventive methods and treatment

Dermestids and other beetles can be controlled in museums, herbaria and libraries by the same methods as are recommended in this chapter against cockroaches, book-lice and moths (naphthalene, paradichlorobenzene, British Museum Mixture, application of lacquers and repellents, and fumigation in case of heavy infestation). Control methods against termites (wood preservation, treatment with dieldrin and dichloroethyl ether) are also effective against most timber beetles. The following is a formula for the control of *Anobium punctatum:* 500 cm^3 dichloroethyl ether, 80 cm^3 chlordane, or 125 cm^3 dieldrin, or 160 cm^3 DDT; make up to 2.5 litres with lighting kerosene (Anon., 1964).

APPENDIX

FORMULAE FOR BOOK-INSECT REPELLENTS

Formula of the Library of the Botanical Garden, Singapore (by courtesy of Mr. H. M. Burkill); bottles should be labelled 'Poison'

Lindane (benzene hexachloride)	60 g
Paradichlorobenzene	30 g
Pentachlorphenol	30 g
Shirlan powder (sodium salicylanilide)	60 g
Mercuric chloride	20 g
Colophony	85 g
Shellac	3 kg
Methylated spirits as required to effect solution.	

Formulae of the HSPA book-insect repellent and HSPA Library lacquer (by courtesy of Messrs. F. E. Hance and C. Hopkins)

A. Book-insect repellent:

Dichlorodiethyl trichloroethane (DDT), granular	150 g
1. Aroclor resin No. 5460, granular (Monsanto Chemical Co.)	75 g

Isopropyl alcohol (99 per cent) to about 2.5 litres. Warm to effect solution. Avoid open flame or exposed electric heating elements

2. Lethane (an aliphatic concentrate of thiocyanates)	90 g

Refined kerosene (water-white). Warm with the DDT to effect solution. Avoid open flame or exposed electric heating elements.

Combine above two solutions when cold and add 40 cm^3 of an odour mask. Add 99 per cent isopropyl alcohol to the solution to make up 4 litres.

Odour mask:

Coumarin crystals	10 g
Musk ambrette crystals	10 g
Carbitol	400 cm^3

(Makes up approximately 0.5 litre: store in an amber bottle.)

B. Library-book lacquer:

Into a 1 litre wide-mouth bottle place:

Xylene	430 g
Methyl isobutyl ketone	80 g
Ethyl cellulose	72 g
Salicylanilide	6 g
Isopropyl alcohol	100 cm^3

Place in a warm place for a day or two in a slightly stoppered bottle. When in solution add enough isopropyl alcohol (99 per cent) to make up 1 litre.

Finally add 5 drops Alcoscent No. 2 (Givaudan-Delawanna), and shake.

C. Directions for applying book-insect repellent H and protective book lacquer H.

Materials needed:

1 soft paint brush, 2.5 cm; 2 soft paint brushes, 5 cm; 3 glass containers: 1 for lacquer, 1 for repellent, 1 for lacquer brush cleaner (Xylene).

To apply lacquer:

1. Place a small portion of the lacquer in one of the glasses.
2. Hold book in one hand. Open cover, dip brush in lacquer, and apply *sparingly* around inside edges of cover. Now repeat on the other inside cover.
3. Grasp the pages of the book and let the covers fall open. Now apply a thin, even coat over the entire outer surface of the book while it is standing on end.
4. With the covers still open, stand book on one end to dry.
5. Wash the brush with the cleaner.

To apply repellent:

1. Open one cover of book. Apply repellent *sparingly* on the inside edges of the front cover and the front page of book.
2. Repeat on the back cover and the back page.
3. Drop repellent into space between bindings and stitched back of pages.
4. Immediately close book tightly and apply the repellent on all three edges of the pages.
5. Return book to the shelf as usual. No drying out is necessary or desirable.

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Paul Coremans

Organization of a national service for the preservation of cultural property

5

INTRODUCTION

Since it was founded, Unesco has organized numerous missions of consultants to many different parts of the world with the object of advising Member States or institutions within them on the preservation of museum objects and of monumental and archaeological sites. If the general situation as it was only twenty years ago is compared with the situation today, the results can only be described as remarkable. Nearly all national authorities are now fully aware of the immense value of their cultural heritage and are endeavouring to ensure the preservation of whatever has resisted climate, wars and revolutions, and the rapid growth of urban, agricultural and industrial centres.

THE NEED FOR NATIONAL ORGANIZATION

All countries are aware that real unity must be rooted in a consistent cultural background and that their culture will be respected by others inasmuch as they respect it themselves. Responsibility for the preservation of that culture should therefore be situated at the highest possible national level and should be in the hands of a competent working group under the leadership of a man who knows what the difficulties are and how they are solved in other countries with more experience in this very specialized field.

EXAMPLES OF NATIONAL ORGANIZATIONS

Some countries have centred their national service in the national museum and have created what is called a Directorate-General of Antiquities[1] and Museums. In such cases, the tendency is to proceed gradually to the establishment of provincial museums in the various cultural or administrative regions of the country and, in more isolated areas where cultural relics may be less plentiful, to begin organizing field museums or repositories where objects of historical value can be assembled and given provisional safe shelter.

Starting from such a national service, a more complex organization can gradually develop. This is the case in India, for example, where museum work is now separated from the care of monumental and archaeological sites, the two sections each having many regional branches. In Brazil, another very large country, the Directoria do Patrimônio Historico e Artistico Nacional is composed of four large districts, each sufficiently independent of the central

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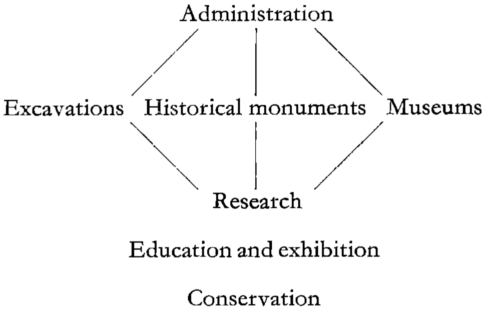
1. In many Western countries more attention is given to art than to archaeology; in other (including tropical) countries greater emphasis is placed on antiquities. Collections relating to science and technology, to the natural sciences and to traditional arts are sometimes initially included as part of the national museum to be separated later as distinct museums in their own rights. This also applies to collections of easel paintings.

office to carry on with its own routine work. Both of these principles, however, depend for their successful application on the availability of a large number of qualified specialists, and this is not the case in at least 90 per cent of the tropical countries. For such countries it may be useful to outline an organization scheme.

AIMS AND ORGANIZATION OF A NATIONAL SERVICE

This chapter, which is the fruit of many missions in different countries, offers a possible solution to the problem. Other solutions may equally well be envisaged, depending on existing social, political and administrative structures, the means available, the relative wealth in ancient relics and their geographical distribution, and a host of additional considerations. But for present purposes the subject will be discussed in terms of the following schema:



Central administration

The greatest difficulty in setting up a central administration is to find a suitable leader of high standing, qualifications and experience to carry out the very complex responsibility of running a working concern depending for its efficiency on the co-operation of specialists in widely different fields, such as archaeologists and art historians, physicists and chemists, architects and engineers, and technicians in excavation, conservation and photography. The person selected should be a national of the country, though the assistance of a foreign adviser may be required in the early stages. If this is so, the adviser should stay only for a limited period of time, and his responsibilities should be set out in a well-defined programme. All too often carelessness on both sides in this respect leads to an indefinite sojourn, restricting the development of responsibility.

An independent annual budget is also a necessity. It is essential that the director of the national service should have the full confidence of the higher administrative authorities and that he should be provided with the financial means to develop his service gradually over a long period of years. Another point that should be considered is that of collaboration, within the national service itself, of civil and religious authorities. In many countries the situation is such that the government is responsible for the national cultural heritage but this responsibility is not clearly defined for religious buildings—which constitute by far the majority of ancient monuments—whether they are still in use or have long been abandoned. Confusion on this point leads to difficulties of all kinds, usually insoluble, and the result is that ancient sites of possibly immense importance are just left as they are. A possible solution is the creation, within the national service, of an advisory committee on which both religious and civil authorities, at the highest possible level, can meet and review such problems quietly. This kind of arrangement has produced excellent results in more than one country.

Excavations, historical monuments, museums

Ancient materials requiring special care can be divided into three broad categories: those kept indoors in collections, those that are still buried in the ground, and those that form part of some ancient monument. In each case a different class of specialist is required and different professional aims are involved. The national service can thus be logically subdivided into three main sections: Excavations, Historical Monuments, and Museums. The most difficult to organize is certainly the Historical Monuments Section. Although a variety of solutions are possible, depending on the relative richness of the country in ancient architectural sites and the nature and state of preservation of the monuments themselves, it may be said that in general the following specialized staff will be required: an engineer (structural problems), architects (restoration) helped by modellers (care and reconstitution of decoration) and copyists (mural paintings), surveyors (inspection of monuments) and draughtsmen (plans, drawings, etc.). Special attention must be given to the appointment of a suitably qualified engineer (not easy to recruit in certain countries where more pressing national demands have priority) and to ensuring that he works in close co-operation with the architects—it is too often forgotten that structural problems of soils and foundations are by far the most important cause of degradation of ancient monuments. It is essential that the architect should have a thorough knowledge of structural problems; without this knowledge he can be no more than a capable foreman, simply knowing the tricks of the trade and using them expediently to the best of his ability. In addition, the architect must have a proper understanding of the principles of architectural restoration: this requires a degree of knowledge and sensitivity going far beyond the study of the technical history of architecture or an understanding of one or another theory of reconstruction or anastylosis.

Research, education and exhibition, conservation

Whether kept indoors or in the open air, whether they are part of ancient monuments or not, all ancient materials, theoretically at least, have to be studied and published, exhibited and used for mass education, and of course preserved for future generations. To these requirements correspond the three common services: Research, Education and Exhibition, and Conservation.

Research, its principal aims. The main aim of the research service should be the establishment of an inventory of the cultural heritage, covering its full geographical distribution throughout the national territory. This inventory should of course not be limited only to the important monuments, antiquities and works of art belonging to the distant past, but should also include the products of more recent periods, whether of national origin (traditional arts, etc.) or acquired from foreign sources (e.g., Western oil paintings in national collections). With such an inventory to work from it will be possible to formulate objective plans for the future extension of the national service, and to see more clearly which sections must be developed and in what respects.

The Research Section could also include small but highly specialized units for the study of such subjects as Islamic art, Buddhist epigraphy, Christian iconography, modern painting, ethnography, etc., depending on local needs and circumstances.

The results of research have to be made available. In other words they must be published, and this should be another main purpose of the research section. The section would thus have to assemble all the documentation and records required for this purpose, enlisting the services of the library and photographic workshop. It is now generally accepted that no national treasure of any importance should be restored until every available detail of its technical history is known (by reference to archival and literary sources for information on its origin, development and previous treatment). It is also a rule that any treatment undertaken should be fully documented by photographs (showing condition before, during and after treatment) and carefully written descriptive reports. The library and photographic workshop thus become an important part of the Research Section. In addition to the usual black-and-white photography, the advantages of colour photography should not be overlooked; nor should the equipment for microfilming and mechanical reproduction of documents. Since the photographers will frequently have to operate at considerable distances from their workshop, this equipment must be chosen accordingly (Unesco, 1960, pp. 117-118), and the national service will have to provide a small truck for use as a mobile dark room.

Educational and exhibition programmes. Citizens of all countries cherish their cultural past. But general standards of education may be such that a great effort of information is still required before whole communities can become aware of the real significance of the achievements of earlier generations. Close co-operation with schools thus assumes particular importance, and guided visits for both students and adults to museums and archaeological and monumental sites will often do much more than any amount of theoretical lecturing. These functions can only be carried out by a specially designed education unit.

The same unit may also be responsible for the arrangement of exhibitions or at least should collaborate with the museum to this end. Much can be achieved with very simple means, if it is clearly recognized that a museum object is not just a piece of historical evidence but that it may have a real artistic value of its own. Not too many objects should be exhibited at one time for the general public (organized repositories can be made available for specialists). There are many types of good and inexpensive showcases. The new plastics materials can greatly enhance the presentation of fine and delicate materials.

Conservation. Although we have placed it on the same administrative level as the Research Section and Education and Exhibition, the Conservation Section calls for much more detailed treatment. The responsibilities of such sections and the laboratory and workshop facilities required are discussed individually below under separate headings.

Scientific study, conservation and restoration

Responsibilities of the Conservation Section. Unesco, ICOM, the Rome Centre, IIC and practically all national organizations agree that scientific study must be the basis for all conservation and restoration work. This does not mean in the least that less importance is attached to the skill, the knowledge and the experience of the craftsmen in charge of repair, consolidation and restoration; it simply means that the ageing of cultural materials is fundamentally a scientific problem and that modern science (mainly chemistry and physics) and technology have made available new techniques for exploring the composition, structure and alteration of the cultural materials to be preserved. It also means that the craftsmen of the workshop (having acquired a general understanding of the various ageing processes) must work together with the scientists of the laboratory who in turn should not forget that real knowledge can always be expressed in simple words. It may take many years before real understanding grows out of the daily contact between scientist and 'conservator', but the final reward is worth every effort.

'Conservation Section' seems to be an acceptable term for the working unit which does the theoretical study and the practical work concerned with preservation of the cultural heritage, whether with respect to archaeological objects, works of art or the materials of monuments.[1]

First of all, the Conservation Section should be the technical adviser of the national service, for example in all problems concerning lighting, climate[2] and air-conditioning. It should assist the Excavations Section by drawing its attention to the consequences of a sudden change of physical environment, as when buried objects are brought into contact with the outside air, and its services can be invaluable in problems of packing and transporting such objects to the museum. Expert advice concerning climatic conditions is also needed by both the Historical Monuments and Museums Sections. Quite recently the plans for the preservation of the Maya site of Bonampak in Mexico had to be reviewed completely because proper attention had not been given to the detrimental action of atmospheric conditions. As regards the conservation of objects in museums, it is known but not always fully understood that simple remedies to counteract the effect of high humidity can often do more for the preservation of collections than complicated and expensive treatments. Proper technical counselling may thus offer the double advantage of efficiency and economy.

Scientific and technical laboratories. In addition to its advisory role, the Conservation Section is responsible for the technical or scientific examination of objects to be treated. Starting from a general understanding of causes and effects of the changes that take place in materials, the scientist must be aware of the specific tendencies of individual materials to decay, exploring each one as if it were a human body suffering from this or that disease. As an example: the treatment of a bronze object will be very different if there is a metallic core left, if mineralization has a chloride, a carbonate or a sulphate basis, if such corrosion has a structure of several layers, or has gradually invaded the whole depth, etc. This is one of the main differences between science and craftsmanship, between inductive knowledge and manual skill.

But craftsmanship and ability have as much importance as science and advanced techniques when it comes to actual conservation and restoration. Fortunately, craftsmen are easily found in the tropical countries, as in any part of the world that has not yet become too industrialized, and generally their sensitivity is good if not excellent. The most important thing then is to ensure that they understand the nature of ancient materials and how they have decayed as a result of natural ageing and human intervention. The problem is thus one of education in a new and very specialized field.

When we come to consider the organization of the Conservation Section on a national level, it should be said at the outset that, with the possible exception of a very few particularly large countries (India is one of them), no more than one central scientific or technical laboratory[3] should be set up. The two main reasons for this are that specialized scientists are not easy to find and that scientific and technical equipment is very expensive. The transition from the 'technical' to the 'scientific' stage of the laboratory should be gradual: it takes time

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1. In this classification, the study of changes that take place in the 'materials' of monuments and the conservation of such materials are the responsibility of the Conservation Section, but not the actual restoration of ancient monuments, for which the Historical Monuments Section is responsible.
2. See Chapter 2 of this manual: 'Climate and Microclimate', p. 27.
3. It is important to distinguish between scientific laboratories, technical laboratories and technical workshops for conservation. In general terms, it can be said that the head of a technical workshop has at his disposal the usual technical equipment for conservation, without real scientific apparatus; starting from a reasoned understanding of matter and its decay, he knows how his craftsmen can use the routine procedures for repair, consolidation and presentation. The head of a technical laboratory has a larger variety of scientific and technical equipment and can undertake tests and experiments in the fields of microscopy, microchemistry and ordinary physics (X-rays, ultra-violet, infra-red); he thus has open to him a wider range of possible

to pass from the stage of carrying out ordinary microscopic and microchemical tests to that of being able to provide acceptable interpretations of complex structural problems, and more than one university-trained scientist is needed when it comes to interpreting the results obtained by various physical methods in terms of their profound implications for conservation. A few years ago equipment worth some $500,000 was left covered with plastics sheets in a university faculty because there was nobody in the faculty capable of using it. This should never be allowed to happen. There are perhaps only three museum laboratories in the whole world with radiocarbon dating equipment of their own, so this may be the last piece of apparatus to acquire!

Conservation workshops. The establishment of conservation workshops is a completely different matter. The Conservation Section will normally begin by setting up a first workshop, for example in the national museum, under the aegis of the technical laboratory. Whether one or more subsections should be planned for eventually in the Conservation Workshop is a matter of local concern according to the types of objects most frequently handled. A distinction can be made between archaeological objects and works of art such as easel and mural paintings, or between ethnographical or traditional art objects (mass production requiring simple and inexpensive treatment) and others, or even between easel and mural paintings, organic materials, metals and siliceous materials and similar (ceramics, glass). After a while, the tendency will be to increase the number of workshops gradually and to establish them systematically in the various provincial museums or at important monumental sites. This would imply a system of regular contacts between the central workshop and laboratory and the provincial units, in order to ensure exchange of ideas on important new problems and to facilitate common access to special equipment (a small truck is needed to transport equipment from a central location to the spot where it is required). At a certain stage the need will be felt for conservation scientists and technicians to meet regularly to discuss general professional problems: such a need might well be met by annual meetings of a national museums association.[1]

TRAINING OF PERSONNEL

General discussion

In 1961, the ICOM International Committee for Scientific Museum Laboratories took the initiative of seeking contact with some seventy countries in the tropical zone to define the main causes and effects of degradation of the cultural heritage. Almost all the answers received stressed the lack of specialized personnel in the field of scientific study and conservation. It became only too evident that a serious effort had to be made in this field, that something of more lasting and practical value had to be undertaken. The resulting 1963 ICOM Report included a chapter on the shortage of specialists felt almost all over the world and a possible solution was put forward. It is worth nothing as well that an ICOM meeting held in 1962 at Neuchâtel also put the emphasis on the urgent need for specialists.

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procedures in conservation and restoration. The director of a scientific laboratory will be a university-trained scientist well versed in the language of modern science, having at his disposal costly physical equipment with which systematic scientific research on minute samples can be carried out (e.g., emission and absorption spectography at different wavelengths, X-ray diffraction, tracers, radiocarbon dating, etc.); through fundamental and applied scientific knowledge he will arrive at the best possible methods of conservation and restoration.

[1] In the early stages a solution may be found in a museums association covering more than one country. The Museums Association of Tropical Africa in Lagos (Nigeria) is an example of this.

For many years previously, Unesco and numerous governments and private foundations offered opportunities for trainees to study abroad. These trainees generally went to Western Europe or North America and stayed there for a few months or one or two years. Although the results were acceptable, it soon became evident that the young people concerned had considerable difficulties in settling down in a completely different environment, and that often they were not really prepared to assimilate the substance of what was taught them. From this it could only be concluded that the benefit would be much greater if the beginner could start by learning simple principles in an environment not too different from the one he usually lived in. This led to the idea of setting up regional basic training centres, in addition to the already-existing advanced training centres.

Regional training centres

It was suggested that the first regions to be covered by the basic training centres should be in the Pacific, in Latin America, South Asia, Central Africa and the Near or Middle East, the advanced centres being more likely to succeed in Europe, North America and India where the conservation network is more widely spread. It was also considered that the main teaching languages should be English and French, that training should normally last at least one year and comprise lectures on theory representing a quarter or one-third of the course and practical sessions on the examination and conservation of cultural property. The whole system should of course be organized in close collaboration with the international organizations concerned with conservation and the main museum laboratories in the world. The provision of subsistence and travelling expenses should not be overlooked, but it seems that sufficient possibilities are offered by national funds, the assistance of international organizations, of private foundations and cultural agreements between individual countries.

A further differentiation between the basic and advanced training centres could be based on following main principles:

Students

Basic centres: many beginners in the field, from nearby countries.

Advanced centres: limited number, with some prior knowledge and experience; also selected graduates from basic training centres.

Future career prospects

Basic centres: head of conservation workshop.

Advanced centres: head of national technical workshop or technical laboratory.

Basis of teaching

Basic centres: reasoned understanding of nature and degradation of matter with a view to applying craftsman's techniques of repair, consolidation and presentation.

Advanced centres: scientific knowledge of composition, structure and degradation of matter with a view to applying scientific methods of conservation and restoration.

Early experience gained at the Basic Training Centre in Tropical Africa since the beginning of 1964 has shown the real significance and the immense importance of the initiative taken by Unesco. Those who attended the Jos Seminar in August-September 1964 know that this excellent example will soon be followed for other regions of the world.

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Equipping the laboratory

6

A. Basic equipment and processes,
by H. W. M. Hodges.

B. An example of Unesco's programme to aid countries in the tropical regions of the world, by H. Daifuku.

H. W. M. Hodges

A Basic equipment and processes

INTRODUCTION

A minimal amount of equipment is required to establish a laboratory to carry out the work required for the conservation and, if necessary, the restoration of cultural property. Elaborate or costly items are not necessary at the beginning and it should be kept in mind that most objects coming to the laboratory of a museum for examination and treatment can be taken care of readily. It is the badly deteriorated or potentially unstable object which may require the use of more advanced tools required for careful analysis before treatment can begin.

Hence, more important than equipment is the knowledge and experience—gained over a course of years—of the technician in charge. Programmes for systematic training of specialists exist in several parts of the world (see preceding chapter, p. 71). As laboratories acquire larger staffs it is natural that objects presenting greater difficulties are dealt with and, with increased competence it is natural that the laboratory begins to acquire more expensive items of equipment to aid the technician in assessing damage, its causes, the best methods of treatment, etc. In some instances it is possible for the museum or the monuments service to have an adequate budget for the purchase of equipment. But for most of the tropical areas this would mean the importation of laboratory apparatus requiring (frequently) foreign exchange, and the payment of high import duties. In many instances, however, they may count upon the aid or assistance of bilateral programmes, foundations, and international programmes.

CONTAINERS

Everything in the laboratory should be in some kind of container. This is true not only of solutions and reagents but also of the objects undergoing treatment. Much damage can be done to an object left exposed on the workbench.

Stock solutions and solvents

It is normal to keep stock solutions in glass bottles, and if required in large quantities in a glass aspirator; but for many such solutions polythene containers are preferable since they are lighter and less prone to damage. Many polythene containers originally manufactured for other purposes (e.g., domestic or camping uses) are perfectly suitable. Thus, large polythene jerrycans may be used to hold many stock solutions commonly used in conservation work.

Dry stock

Here again, most chemicals and other materials, such as kaolin and plaster, can most conveniently be stored in polythene containers. For large quantities dustbins are ideal.

Working containers

For many purposes, glass vessels, especially beakers, are to be preferred. But glass is brittle and for some processes other materials may be superior. Thus, for processes to be carried out in the cold, polythene beakers, or even polythene domestic vessels are ideal; but they cannot, of course, be heated. Where a vessel must be heated, a suitable glass must be used, and it is often more economical when dealing with large volumes to buy domestic glass ovenware than large containers designed for laboratory use. An alternative may be aluminium or stainless steel vessels. Both types are easily made from the sheet metal but it must be remembered that aluminium is rapidly etched by alkaline solutions. Although it is customary to use glass or stoneware vessels for large-scale operations such as electrolysis, a wooden box lined with a heavy grade of polythene is just as durable and far less expensive. Many synthetic adhesives and consolidants are difficult to clean from their containers. Where such materials are being used, a supply of paper cups will be found useful.

Containers for objects

Small objects should be kept in boxes, ideally with a transparent lid. Many manufacturers now produce plastic boxes with hinged, transparent lids, and these are very suitable, although rather expensive. Larger objects are more difficult to box satisfactorily, but may be kept under glass or plastic covers designed to protect food.

Labels

No container should be without a label showing its contents. Toxic and poisonous materials, and all inflammable material, should be marked as such, preferably in red capital lettering. Labels on containers for solutions must state both the concentration of the solution and the solvent used. Unless the object itself bears a label, the container should at all times be labelled with at the very least, the object's number (see 'Administration' below).

MEASURES: WEIGHING AND SOLUTIONS

Scales and balances

Two types of weighing device are advisable. For weighing large quantities kitchen scales are ideal, although laboratory scales are generally more accurate. For smaller weighings a laboratory balance is essential. Weighing devices when not in use must be kept covered, and at all times they must be kept scrupulously clean. Great care should be taken in levelling and adjusting balances, after which they should not be moved. At no time should weights or pans be handled other than with forceps provided for this purpose. When weighing, the weights used to achieve the final point of balance should be checked twice before removal from the pan. With all chemical balances the manufacturer's instructions must be followed to the letter.

Volumetric measures

For measuring large quantities of fluids, kitchen glass graduated measures are usually suitable, or for really large quantities even graduated polyethylene buckets. For smaller quantities it is advisable to have available a variety of graduated cylinders (50, 100, 250 and 500 ml). For very small quantities burettes and pipettes are used and the reading taken from the bottom of the meniscus (the curved surface) of the fluid being measured.

Making solutions

From two or more fluids. Particular care is required when preparing dilute acid solutions. Concentrated sulphuric acid, in particular, will heat violently should water be added to it, to such an extent that it will 'spit' and the operator may well be sprayed with the concentrated acid. The following procedure should be used. The required volume of water should be placed in an open container, such as a polythene bucket (preferably not glass, and *never* a bottle) which should be stood in a sink. The acid should then be added little by little with constant stirring, using a glass or polythene stirrer. The oustside surface of the container should be felt from time to time to ensure that the solution is not overheating. Should it do so, add no further acid until it cools. Allow to cool before transferring to bottles.

From a fluid and a solid. Many solid materials will not easily go into solution, and instead may form either a cake or a gelatinous deposit at the bottom of the container. This can to some extent be averted by reducing the solid to a fine powder, adding it slowly while stirring continuously by hand or mechanically. Even so, many organic materials are still difficult to put into solution this way, and it will often be found more effective to suspend the solid in a nylon bag in the solvent. Discarded nylon stockings are ideal for this purpose.

Solution strength

Solution strengths are usually given as a percentage. Where the solute is normally a fluid, such as nitric acid, the percentage stated is volumetric. For example, a 10 per cent nitric acid solution means 1 volume of nitric acid in 9 volumes of water. Where the solute is commonly a solid, solution strength refers to weight per volume. For example, a 5 per cent caustic soda solution would be obtained by dissolving 5 g of sodium hydroxide in 100 ml of water. Solution strengths may also be quoted as M (molar) or N (normality), or multiples or fractions of M or N, as for example $5N$ (normality × 5) or $M/2$ (Molar : 2). The meaning of these terms, together with M and N solution strengths, will be found in any good practical manual of chemistry.

WATER

Tap water

The conservation laboratory must have a copious supply of tap water. Tap water varies enormously from area to area, depending upon its source, but it always contains some impurities. Before beginning operations the conservator must determine the principal impurities in the local water supply and plan accordingly.

Hard water, usually containing in solution the bicarbonates and sulphates of calcium and magnesium, will form a scum with soap, and will require treatment before it can be used for cleaning such materials as textiles. While, in principle, washing soda may be used to alleviate hardness, in practice it is advisable either to use distilled water or to install an ion-exchange water softener.

Nearly all city water supplies are now chlorinated to kill germs. Excellent as this is from the point of view of public health, it must be remembered that chlorides are extremely corrosive to most metals, and here again for washing metals only purified water should be used.

Drainage

A continuous water supply must be matched by an adequate drainage system, but this is often overlooked. Washings from the conservation laboratory usually contain both corrosive materials and a high proportion of sediment. The drainage system must, therefore, be resistant to corrosion and have sufficient 'traps' in which to collect and remove sediment. In practice, polyethylene fittings and a 'trap' to each sink, with a further main 'trap' for the whole laboratory effluent has been found the most effective system.

Some materials must never be allowed to enter the drainage system. Plaster of paris will set in time and block the piping. Solutions of cellulose or polyvinyl acetate will form gelatinous lumps in contact with water, with the same result. Corrosive materials should only be put down the drain when greatly diluted.

Pure water: distilled and de-ionized

Distilled water may be bought in large containers. This is normally most uneconomic, and it is preferable to install either a still or a de-ionizing column. Where the tap water contains a high proportion of impurities, a still is the obvious choice. An electrically heated still gives the least trouble in operation, but attention must be given to regular cleaning out of 'scale', the calcareous deposit in the heating chamber. Even under the most favourable conditions this must be removed at least once a year, and often more frequently. In many countries legal permission is required for the operation of a still.

De-ionizing columns of synthetic resin which remove impurities have certain advantages where the water supply is not heavily contaminated, but where the tap water is very impure, the resins have to be regenerated at such frequent intervals that their use is impractical. Before installing de-ionizing equipment the following points must be considered:

1. Initial expense—the outlay is often considerable.
2. Whether the resins will remove the impurities present (different resins will remove different ions; a correct choice must be made).
3. Ease and cost of regeneration. Some resins must be returned to the suppliers for regeneration. The supplier must guarantee adequate service. Other resins may be regenerated in the laboratory. The cost of materials for regeneration may be so great that distillation is more economic.

WASHING

The term 'washing' takes on a number of different meanings in the laboratory; it seldom, if ever, implies a rapid rinse with soap under the tap. Indeed, in the laboratory, soap should be kept for washing one's hands only.

Washing to remove dirt

Only warm (not hot) water of adequate purity should be used, but if a wetting agent is required a non-caustic detergent may be used. Prolonged washing must follow the use of a detergent.

Prolonged washing

This implies rinsing with water of adequate purity to remove water-soluble materials such as salts or detergents. The process may be carried out by making repeated changes of water, or by allowing water to run through the wash-tank continuously. Prolonged washings can be considered as finished only when the wash-water has been tested and shown to contain none, or an acceptably small quantity of the material to be removed.

Intensive hot washings

This is essentially prolonged washing in which the water is maintained at a relatively high temperature (see below under 'Basic equipment', p. 89).

HEATERS

External heaters

Although the bunsen burner is the traditional laboratory heating apparatus, it is often ineffective or wasteful, and the domestic gas-ring is often to be preferred for heating large containers. However, electric heaters may prove less smelly and more easily controlled. Domestic hot-plates with thermostatic temperature control[1] are very effective for maintaining steady temperatures. For heating glassware, asbestos muffs with a built-in heating element can be obtained from laboratory suppliers.

Internal heaters

The possibility of using immersion heaters should not be overlooked. A wide variety of immersion heaters can be obtained for domestic and photographic purposes, often thermostatically controlled, and these may be built in to equipment instead of using an external heat source. For example, if it is required to keep a volume of wax at a steady temperature it is often better to design a tank with immersion heaters than to apply an external source.

Ovens

Ovens may be required for a wide range of purposes, and it is always advisable to have a chemical oven with a wide temperature range ready for use. However, laboratory ovens are expensive and for certain purposes domestic ovens may be far cheaper to install and just as suitable. Food warming cabinets, for example, will maintain temperatures just below boiling-point and are suitable for intensive hot washing.

Furnaces (see below, 'Basic equipment', p. 89).

Blowers

A hot-air blower is ideal for many heating purposes. Although the hand-held, electric hair-drier can be used, such devices are not always very sturdy, and being largely constructed externally of plastics they may be damaged by contact with some organic solvents. Light industrial blowers are normally stronger and give more heat.

Infra-red lamps

Infra-red lamps which give a steady heat are very suitable for purposes such as drying or maintaining thermosoftening materials in a fluid state. On the other hand, infra-red lamps can be dangerous, and one should be careful not to work with one's hands under infra-red radiation for more than a very short time.

HEATING

Glassware

Chemical glassware. Although chemical glassware may be used either on a hot plate or in an open flame, it must never be put on a surface that is already hot, or plunged suddenly into the hottest part of the flame: inevitably the glass will crack. Fluids heated in small beakers and test-tubes may tend to spit when hot; this can be avoided to some degree by placing glass beads at the bottom of the vessels.

Domestic ovenware. Domestic ovenware should never be used on an open flame, or hot-plate. It should be placed in the oven when cool and brought up to top heat, rather than placed directly in a hot oven.

Other glassware. Other forms of glassware can only be used with heat when exceptional care is taken to raise the temperature slowly. There is a very great temptation to use, for example, old glass accumulator jars because of their size and shape. The thickness of the glass, however, can so easily result in cracking that the operation is never worth the hazard.

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[1] See 'Temperature control', p. 85.

Inflammable materials

Solids. Inflammable solids such as wax should never be heated over an open flame, but ideally should be warmed using a thermostatically controlled electric hot-plate or immersion heater. Even with these precautions, the molten material must never be left unattended, and a tight-fitting lid to the vessel should be at hand to cover it should the contents catch fire. If a hot-plate is used, it must be remembered that the material at the bottom will melt first, leaving a crust of solid material at the top. Injudicious prodding of this crust, particularly if it is not absolutely free of water, may cause the hot, molten material to splash over one's hand, with ensuing burns.

Liquids. Even greater care is required when inflammable fluids are to be heated. The work *must* be carried out in a fume cupboard, and any form of open flame is quite out of the question. It is always advisable to stand the vessel being heated in a water-bath.

TEMPERATURE CONTROL

There is a critical temperature for many operations. For most purposes the normal laboratory thermometer will suffice for checking the temperature. Today much equipment is provided with thermostatic controls, and in theory one has only to set the dial to obtain an even, steady temperature of one's choice. In practice, it is sometimes found that the calibration falls very far short of requirements, and with new equipment in particular it is advisable to check the calibration against a thermometer reading. Temperatures above the range of a thermometer call for the use of a thermocouple. For any specific piece of equipment, it is advisable to use the thermocouple recommended by the manufacturer.

DRYING

Heating

One is always tempted to dry objects by placing them in an oven. However, the oven must be adequately ventilated: a poorly ventilated oven can easily become a humidity chamber in which objects, although hot, remain moist. Small objects are often better dried using either an industrial hot-air blower or an infra-red lamp. In the latter case great care must be taken not to overheat and a thermometer should be left in contact with the object being dried.

Alcohol drying

Effective drying can be achieved by repeated changes of pure alcohol, followed by evaporation of the alcohol. The method is expensive and should be used only where complete elimination of all moisture is essential.

Drying agents

It may be necessary to store objects in the dry state before further treatment. Any airtight vessel will serve as a desiccator, although a glass vessel in which changes can be observed is to be preferred. Undoubtedly the most convenient drying agent for use in the desiccator is silica gel, especially the type with a coloured indicator that shows when the silica gel has become moisture-saturated. Should this be unobtainable, caustic soda pellets or dehydrated crystals of copper sulphate may be used to maintain a dry atmosphere.

HUMIDIFIERS

It is sometimes necessary to maintain an object at a high relative humidity for some time. Specially designed humidity chambers may be bought for this purpose, but they are apt to be expensive. The essential features of a humidity chamber are the air-tight container, sources of heat and moisture, and a hygrometer to show how it is functioning. At its simplest such a chamber may be no more than a thermostatically controlled oven in which are placed a dish of water and a direct-reading hygrometer. Such a device, however, lacks the easy control of relative humidity obtainable with the manufactured chamber.

FUMIGATION

The toxic agents found useful in fumigating objects contaminated by moulds and by insects are fully discussed in Chapters 3 and 4. Fumes from any of the agents should never be inhaled. This also applies to volatile solids which might be used as fumigants, such as paradichlorobenzene, thymols, etc. They may also be severely irritating to the mucous membranes, the eyes, or to the skin, particularly when the climate is moist and humid and one perspires.

Various types of containers may be used as fumigating cabinets for small objects. Yadon (1956) describes the construction in the museum metal shop of an air-tight chest which is 70 cm wide, 118 cm long and 88 cm high, equipped with rubber castors to permit mobility. The container is large enough to permit specimens to be kept inside their standard container during fumigation in the chest. Another convenient size is 2 metres long by 1 metre high and 1 metre wide. A museum workshop can build such a chest, which could be made of wood lined with sheet metal or made entirely of heavier gauge metal. It should be set above the floor and should be equipped with a stop cock and drainage pipe at the bottom, so that the fumes, which are heavier than air, can be led outside the building at a well-ventilated spot to ensure rapid dispersion of the gases. The cover should be gas-tight, using a gasket which will resist the corrosive effects of the fumigants. An effective fumigant would be a mixture of 3 parts by volume of ethylene dichloride with 1 part of carbon tetrachloride. Between 500 cm^3 and 1 litre of this mixture is placed in pans to volatilize within the container (Burns, 1941). Another effective fumigant, not unduly toxic, is methyl bromide.

Larger museums may install a gas chamber to treat many objects at once.

Following fumigation, the treated objects should be kept in quarantine apart from the collections for about a month before further cleaning and treatment.

VISION

Lighting

It is to be hoped that the days have gone when the curators of museums imagined that the laboratory should be housed in the darkest recess of the building. There is no substitute for daylight, and windows should be placed in such a manner that there is a good, even light throughout the room. The windows, furthermore, should have adequate shuttering against excessive direct sunlight. Even when these ideal conditions have been achieved, however, some artificial lighting will be essential. Here we must consider two sources: (a) general over-all lighting, and (b) individual lighting for close work.

General over-all lighting should give, as far as possible, values similar to natural daylight. Fluorescent tube lighting is probably the best solution. Care must be taken, however, neither to under- nor over-illuminate the room, and a qualified lighting engineer should be consulted to ensure the correct number and placing of lights.

For individual lighting a number of adjustable stand lamps will be required. Ideally these should be of a type that will allow rapid change of the light source from one position to another, while directing the light in a fairly narrow beam. The normal desk reading lamp is not really suitable, although better than nothing at all.

Magnification

Many operations demand a considerable magnification, as, too, does the preliminary examination of most objects. Many people can manage quite comfortably with a watch-maker's eye glass, others cannot, in which case either a stand magnifying glass or head-band binocular magnifiers must be provided. These pieces of equipment are absolutely essential, and many would maintain that a binocular microscope is equally indispensable. Binocular microscopes are now obtainable with built-in illumination and a long arm to allow clearance at reasonably low cost, and no single piece of equipment can justify the money spent on it more than such a microscope. The magnification of many microscopes may be varied by changing eye-pieces or objectives, but if it is decided to buy a binocular microscope with fixed magnification, 20 times would be most suitable.

SAFETY PRECAUTIONS

Ventilation: fume cupboards

Obviously the laboratory must be well ventilated, but even good normal ventilation is inadequate when one is dealing with toxic and inflammable materials, so that a fume cupboard will be essential. Furthermore, a fume cupboard is quite useless if the extractor fan does not function correctly, or if the cover is closed so tightly that a good through draught is prevented. These are important matters and not always appreciated by the tyro in the laboratory.

Inflammable solvents

Most organic solvents are highly inflammable and should not be kept in bulk in the laboratory. For preference a shed, detached from the main building, should be provided for bulk-storage, or failing this a space open to the weather. Smoking should not be allowed near the store. The solvents in use in the laboratory should be kept in small bottles with screw tops. On a hot day a cork or stopper may easily be displaced from a bottle of ether, and a naked flame may then cause a fire.

Gas installation

The gas installation should be checked regularly to ensure that there are no leaks. Equipment that is found consistently to 'burn back', that is to say burn at the jet before the gas has been mixed with air, should be examined and, if faulty, adjusted correctly.

Electrical installation

Electrical installations should also be examined regularly. Frayed cables must be replaced, as too must plugs and switches that tend to arc. At all times care should be taken not to overload circuits. There is always a temptation to increase the number of socket outputs by using adaptors, but the point is soon reached where the circuit is overloaded and this may cause a fire. The correct procedure is to ensure that sufficient plug-sockets are provided for the work undertaken.

Poisons

Even if none but the staff have access to the laboratory it is always advisable to keep poisonous materials under lock and key. Poisons left on an open shelf may be spilt or used in error.

Fire-fighting equipment

Every person in the laboratory should know what fire-fighting equipment is available, where it is kept, and where and when to use it. The following points are worth keeping in mind:

1. A fire in a container is most easily quenched by covering the container.
2. A fire on a table or bench is most easily quenched by covering with an asbestos blanket.
3. A person whose clothing has caught on fire should be wrapped in an asbestos blanket.
4. A jet of water directed against burning organic solvents is more likely to spread the fire than to put it out.
5. Widespread fire can be quenched with 'foam'.
6. If a fire is not quickly quenched, ring the alarm.

From this it will be seen that an asbestos blanket and a 'foam' fire extinguisher are the essentials for rapidly containing a fire: after that it becomes a job for an expert.

First aid

Every person in the laboratory should know the fundamentals of first aid, and every laboratory should be equipped with an adequate first-aid outfit. Most standard first-aid boxes contain sufficient materials for dealing with burns, cuts and abrasions, but in two features they are often lamentably lacking: (a) an eye-bath and a bottle of eye-wash must be included, made up to the correct concentration for immediate use; (b) a supply of self-adhesive dressings will be needed for dealing with small cuts and scratches. Regular inspection will be required to ensure that the stock of dressings has not been exhausted.

PERSONAL EQUIPMENT

All the equipment so far discussed has been of a general nature, allowing nothing to personal idiosyncrasy. In the choice and use of tools, however, individual tastes vary greatly and, within reason, one must allow everyone to make his or her own choice of tools and how to use them. What follows is a list of processes and the tools that may be found suitable by various workers. It is suggested that each worker should maintain his own kit of tools for his use alone.

Handling

Forceps will undoubtedly be required for handling small or delicate objects. For some operations a pair of forceps may be needed in each hand.

Cutting

A wide variety of scalpels and knives will be needed. The type of scalpel with replaceable blades is most suitable for delicate work, but sturdier scalpels with heavy, fixed blades may also be needed. There is an almost limitless choice of knives: two or three knives of various shapes and sizes may well be needed. A heavy and a fine pair of scissors will also be required. A hone will be needed for sharpening. A piercing saw may be required.

Brushing

Every worker should have a number of small and large brushes of natural hair or bristle. Glass-bristle brushes will also be needed.

Spatulating

Since many adhesives and filling materials require spatulating, palette knives, spatulae and tiles will have to be provided.

Mechanical cleaning

For the removal of corrosion products and concretions from the surface of objects, the worker may choose to make his own chisel-ended tools from lengths of steel rod, although it is simpler to mount steel needles in a pin-chuck for this kind of work.

Machine aids for this process include rotary burrs and engraving tools. Rotary burrs may be mounted either in a drill with a flexible arm, as used by dentists, or in a smaller hand-held motor. For the beginner, the latter being less powerful is to be preferred, although unless used with great care both types of burr tend to burnish the corroded or concreted surface rather than remove it.

Engraving tools with a vibrating arm, when fitted with a fine needle point, can be used for this work. As with hand-held tools, the point should always be held at right angles to the surface being removed, and never obliquely to it, as should the tool slip the underlying surface will become scarred.

Chemical cleaning

For the local application of chemical reagents short lengths of glass rod and pipettes will be needed. These can easily be made from laboratory glass rod and tubing.

INITIAL EXAMINATION

Some initial examination of objects under treatment will be essential, although the precise nature of such examination must depend upon the knowledge of the worker and the complexity of the antiquities under treatment. The following is the bare minimum of equipment required: (a) magnet; (b) Mohs' scale; (c) litmus and pH papers; (d) platinum wires mounted in glass rod and borax; (e) test tubes, test-tube brushes, test-tube holders, racks, funnels and filter papers; (f) reagent bottles and reagents.

BASIC EQUIPMENT

Specialized equipment has been described in the appropriate chapters. The following is a list of equipment of fairly universal application that will probably be required.

Equipment for soldering

Soldering is required for the repair and maintenance of laboratory equipment and during the making of electrotypes: its application to antiquities should be severely limited. Solder, flux, a soldering iron and a small jet blow-lamp will be needed.

Equipment for intensive hot-wash

Apart from an oven (see above, p. 84) a conductivity bridge and dip-cell will be required. Care should be taken when ordering a conductivity bridge to ensure that the suppliers can guarantee adequate servicing.

Furnaces

Either gas or electric furnaces may be used, although electric furnaces are normally cleaner and simpler to operate. When ordering, it is essential to ascertain that the capacity and temperature range and control are adequate for the work to be done. Great care should be taken over installation and, for preference, furnaces should be sited either outside the main laboratory or in such a position that their operation will not present a fire hazard.

Sources of direct current

Since most electricity mains supply alternating current (A.C.) at a fairly high voltage (usually 110 or 250 volts) a source of direct current (D.C.) of low voltage will be needed for electrolysis, electroplating and small power tools. A single source may be used for all these purposes, but on the whole it will be found simpler in operation to have separate sources for each group of equipment. Each source must comprise a transformer, a rectifier and some means of controlling output, either a variac or variable resistance. A qualified electrician should always be consulted to supervise the design, building and installation of such sources.

Impregnation equipment

Where large quantities of very friable materials are being dealt with, equipment may be needed for impregnation. A small but effective unit has been described by Burgess (1954), and a more elaborate unit by Rees-Jones (1963).

Carpenter's and metal-worker's equipment

It will be found convenient to have at hand a number of wood and metal-working tools. The following are of general application: a vice, tenon and hack-saws, chisels, small planes or smoothers, sandpaper and emery paper of different grades, hand-operated and electric drills with various bits, files, pliers, pinchers, and tin-snips, screwdrivers (carpenter's and insulated).

SEATING AND BENCHES

Considerable thought should be given to the subject of bench space and seating. It is advisable that every person in the laboratory should have his own seat and work bench as well as a locker or cupboard in which to keep personal equipment. Ideally, bench height and seating should be adjusted to suit the individual, for no one can be expected to do good work when cramped or otherwise uncomfortable. Other benches will be required for specific purposes, and on the whole laboratory benching and stools of standard height will be found suitable. In planning a laboratory, however, care should be taken not to so fill the space with benching that it becomes cluttered, leaving no room for movement or equipment. It is on the whole advisable to leave plenty of open floor space in which temporary benching can be placed as and when required.

ADMINISTRATION

Records

A day-by-day record must be kept of all work undertaken. Records should be filled in as the work is done. It is an advantage to maintain a standard system for recording, each object being given its own record sheet or card. Every process carried out, complete with all the essential data (materials used, temperatures, readings and so on) should be entered. Failure to keep adequate records will result in chaos.

Cleaning

A laboratory will not keep clean and tidy of its own accord, and a dirty laboratory is usually an indication of poor organization and poor workmanship. Cleaners may be employed to attend to the floors and windows, but they must be told where their duties begin and end. It is totally wrong to ask cleaners to attend to things that they do not fully understand: equipment, shelves and benches must be left alone by the cleaners and dealt with by the laboratory staff. Any member of the laboratory staff who adopts the attitude that keeping his own laboratory clean is beneath his dignity is a parasite without whose services the museum would do much better.

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H. Daifuku

An example of Unesco's programme to aid countries in the tropical regions of the world

INTRODUCTION

Over the course of years Unesco has aided a number of countries in the tropical regions of the world to train technicians and to establish laboratories for the conservation of cultural property. It has had the occasion to consult the 'Rome Centre' and the Institut Royal du Patrimoine Artistique in Brussels with regard to training programmes and the choice of equipment considered desirable. Inevitably the equipment chosen reflects the level of skills of the personnel, the type of objects which are to be conserved or restored, and the amount which the country is willing to budget towards such projects.

THE LABORATORY OF THE NATIONAL MUSEUM IN BANGKOK

As an example, Coremans has suggested that the following areas be covered in a technical laboratory to be built in the National Museum in Bangkok (Thailand):

Technical laboratory: (a) microchemical laboratory; (b) physical laboratory; (c) biological laboratory.

Conservation workshop: (a) archaeological workshop (metals); (b) organic materials (wood, textile, paper, palm leaf, bone, etc.); (c) ceramics and stone; (d) art workshop.

Photographic workshop, including studio, two darkrooms, rooms to carry out enlargements, repository for negatives, photostats and microfilms.

At its inception, Coremans had suggested that the laboratory include microscopy, microchemistry, routine application of ultra-violet, infra-red and X-ray studies. Later, expansion should take place in physics. On the basis of analogous programmes which had been worked out either with Coremans or with Plenderleith as Unesco experts, the following types of basic equipment have been furnished to Member States by Unesco. It should be noted that the list below represents a synthesis dependent upon the level of training received by the specialist in charge and the type of objects he would most likely have to handle. In the case of rare itemswhich are in a poor state of preservation and where local techniques may be inadequate, it is of course understood that advice is sought either through correspondence or the object in question is shipped to one of the important laboratories which have had longer experience and better facilities.

TYPICAL EQUIPMENT FURNISHED BY UNESCO[1]

Microscopes

Stereoscopic microscope with table stand (free-swinging arm which can also be

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[1] Laboratory glassware and utensils, frequently unobtainable in the tropics, are also given as well as the specialized items listed below. Equipment makes up an important element in international programmes in which aid is granted at the request of the government concerned.

adapted to other types of support). Usually equipped with 10 × and 15 × eyepieces giving 8 to 60 diameters magnification. Detachable microscope lamp and transformer.

Trinocular microscope (permitting the attachment of photo-micrographic equipment) with 5 ×, 10 × and 15 × eyepieces, 4 × (metallographic), 20 ×, 40 × and 100 × objectives. Microscope adaptable for examination of opaque or metallographic specimens. Microscope lamp and transformer.

Specialized equipment

Metallographic specimen grinder with mounting press for specimens.

Electric drill equipped with a flexible drive shaft with variable speed control and wide assortment of grinders, drills, etc.

Humidity cabinet.

Vacuum desiccator.

Electric vacuum pump (because of variable water pressure in many countries, the inexpensive type attached to a tap is not practical).

Air compressor and paint sprayer.

Vacuum hot table (if easel paintings form part of the collections of the museums of the country).

Drying ovens, small crucible oven.

Ultra-violet and infra-red lamps.

Flood lamps.

Laboratory glass ware, thermometers, hot plates (with variable controls), specialized burners (usually to be used with butane gas), etc.

Water distillation apparatus.

Industrial, portable X-ray equipment ranging between 20-30 kV and 100-150 kV

Softer X-ray machines tend to be more expensive.

Photographic supplies and equipment

35 mm single-lens camera equipped with 35 mm wide angle, 50 mm and 105 or 135 mm lens. Lens shades, filters, microscopic adaptor, close-up copying devices, etc.

6 × 6 cm twin lens reflex with parallax correction either incorporated in the camera or special device, with interchangeable or modifiable lenses for wide angle, standard and long focus (e.g., 65 mm, 105 mm, and 180 mm lenses), equipped with lens shades, filters, etc.

9 × 12 cm studio-type camera with 90 and 127 mm lenses, lens shades, filters, special cable release, and other accessories.

Tripods.

Light meter.

Dark-room equipment, 9 × 12 cm enlarger with negative carriers for smaller films, easel, dark-room lights, developing tanks, for roll and for cut film, film hangers, washer, glazer, dryer for prints, etc.

Contact printer.

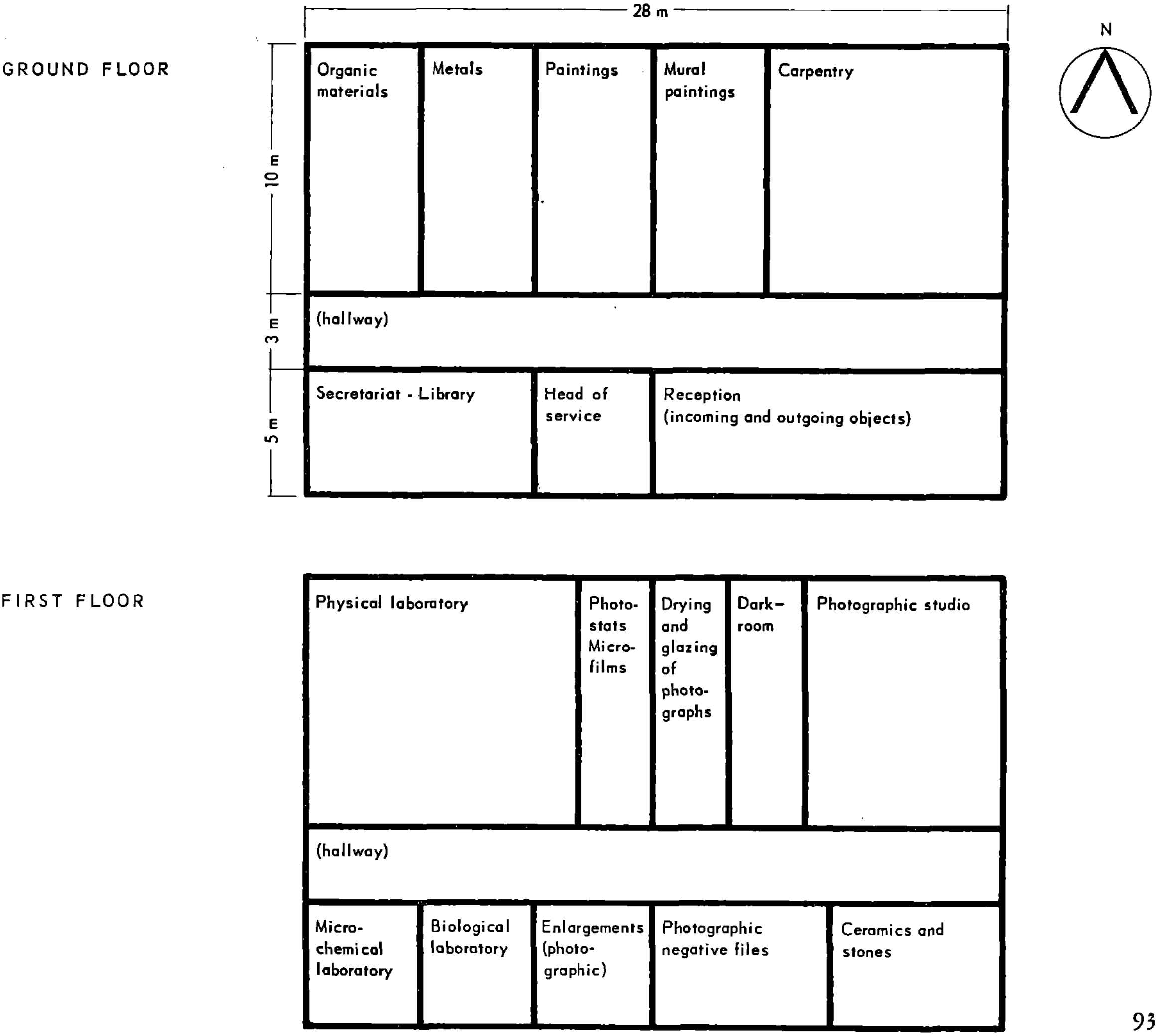
Dry-mounting press and electrically heated spatula.

In most instances museum laboratories find the 9 × 12 cm camera to be the largest format required. New fine-grained films and high-quality enlargers tend to favour the use of the smaller formats, e.g. 35 mm and 6 × 6 cm, which are easy to work with and usually give all the resolution desired. Moreover, films, enlargers, filing cabinets for negatives and print storage, and a host of other accessories are obtainable from a wide range of manufacturers at reasonable prices up to the 9 × 12 cm formats. As production of larger formats is more limited, their accessories are obviously more costly. From time to time, however, for specialized purposes, larger format cameras have also been provided.

As Unesco does not contribute towards building costs, the local institution is under the obligation to build suitable quarters. The buildings should have, of course, run-

Fig. 41.

Proposed layout of the laboratory for the National Museum in Bangkok (Thailand) (Coremans).



ning water, sinks, electricity . . . provision has to be made for north lighting if paintings are to be treated . . . suitable cabinets for the storage of chemicals, etc. A hood over a counter and sink with exhaust fan may be required. If a fumigation chest or room is to be planned for, the specialized requirements for ventilation have to be taken into account. Carpentry tools for the shop must also be planned for. If the country is characterized by extreme temperature or humidity conditions it may be necessary to have some of the rooms air-conditioned as well.

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B. A. F. Nimmo and A. G. Prescott

Moulding, casting and electrotyping

7

INTRODUCTION

When an object has to be moulded the first thing to do is to examine the condition of the surface. Even if it is in good condition it is always advisable to apply a thin coat of a protecting medium (lacquer) so as to reduce to a minimum any risk of damage during the moulding process. On other occasions one may have to deal with surfaces that are porous, crumbling or decayed when, even after protective treatment, the use of certain moulding materials would be unwise. The choice of the medium to be used must be left to the discretion of the operator.

One old and tried method of protecting the surface is to apply by brush or spray, french polish (shellac) diluted with methylated spirits (alcohol). A number of thin coats are recommended, allowing each to dry before application of the next, finally allowing the whole to harden before proceeding with moulding. The big disadvantage with this method is the tendency to darken the surface. Should it be of importance to avoid this discoloration a transparent type of medium with a cellulose base can be used. A solution of nitrocellulose diluted with one part acetone and one part amyl acetate, or a lacquer such as Ercalene have been found to be satisfactory. One must still be prepared, however, for a slight darkening of the surface of the object, but this can normally be rectified by using the appropriate solvent on completion of the moulding.

In the case of worm-eaten or decayed wood, ivory, etc., modern epoxy resins have been found to be very useful. Araldite, for instance, made up in varying viscosities can be injected into the bore holes with a small hypodermic syringe. Alternatively the object can be immersed in a diluted mixture, or a number of coats can be brushed on to the surface. Araldite CY 219 can be recommended, used with varying proportions of the hardener HY 219 and accelerator DY 219 to obtain the required viscosity. There is a whole range of Araldite resins available. Advice and particulars in regard to their use are gladly given by the manufacturers on request.[1]

MOULDING MATERIALS

Moulding in clay

If a reproduction of an original object is needed an impression must be made of the surface for subsequent casting. Materials for procuring such an impression are many and various. Undoubtedly the cheapest and one of the oldest types of moulding material is clay, and this can be safely used today with certain reservations. Where financial considerations prohibit the use of more expensive materials clay may be used, always provided that the surface to be moulded is found to be suited to this material. Stone work that is in

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[1] CIBA, A. G. Klybeckstrasse, 141, Basle, Switzerland, or: 96 Piccadilly, London W.1.

good condition is no doubt the best material to practise on. All that is necessary is to dust lightly the surface of the original object with talc; take a section of clay about 10-15 mm thick, smooth it on a flat wood or glass surface which has been previously dusted with talc, and then firmly press the clay all over the area to be moulded. If the surface area to be covered is more than, say, 25 cm² it is advisable to make a series of undercuts in the back or outer surface of the clay (this can be done by stabbing the butt of a brush handle into the clay, thus providing a locking surface) and the surface so prepared is then covered with a layer of plaster of paris. Once the plaster has set no distortion can take place when the clay mould is removed from the original. Before casting takes place it is necessary to apply french polish by spraying as opposed to brushing which might damage the clay impression, and, when the surface has been lightly but thoroughly covered, allow an hour to elapse before proceeding further. Now treat the mould with a releasing agent such as olive oil or a grease made of tallow and rape-seed oil. To take the plaster cast, mix plaster to a thin creamy consistency, stipple this on to the mould surface with a brush to avoid the risk of air pockets being trapped between the mould surface and the plaster, and as the plaster mix begins to thicken build up to the required thickness of the mould. If the mould is larger than about 1,000 cm² in area it is advisable to introduce a strengthening frame into the plaster cast in the form of a thick wire or a piece of iron. This should be previously coated with thick french polish to prevent rusting which might eventually come to the surface of the casting. Wooden laths may be used, but they should be thoroughly soaked with water first, since dry laths would absorb water from the plaster mix and cause the cast to crack on the surface. To make a plaster cast with a framework inside, first introduce into the mould a layer of plaster about 6 mm thick. When this begins to thicken place the iron, wire or lath on the plaster, taking care to see that there is enough plaster to prevent the framework from sinking through to the mould surface. Mix a second lot of plaster, immerse a piece of scrim into this, then apply the scrim to the back of the casting, entirely covering the framework and press down lightly with the hands. This will enable a light but very strong casting to be made. The cast may safely be removed from the mould in an hour from the commencement of this operation.

It will be noted that the technique outlined here refers to a flat one-piece moulding. To mould an object in the round or with any degree of undercutting will obviously necessitate more than a one-piece mould, and a considerable amount of tooling-up of the cast will subsequently be necessary. Satisfactory casts can be made from clay moulds, if the work is carried out carefully, but there is always the possibility of imperfections when compared to the results obtainable with other moulding materials.

Moulding in plasticine

Plasticine may also be used as a moulding material, employing essentially the same technique as for clay; but plasticine, being a tougher material, must be applied with greater pressure to produce a good impression and care must be taken to see that the object to be moulded is in sufficiently good condition to withstand such pressure. Plasticine, like clay, is fairly cheap, and can be reclaimed for further use almost indefinitely. This is an advantage where regular casts are required, but it must be appreciated that first-class reproductions are not possible from either clay or plasticine moulds.

Moulding in plaster of paris

Plaster of paris as a moulding material is much superior to clay and plasticine, and still comparatively cheap. It has been used for this purpose for a considerable time and was the only practical material available in the year 1802 when the moulding of the pediment figures and reliefs was carried out on the Parthenon at Athens. The thought of moulding these intricate carvings must have been enough to daunt all but the most accomplished of moulders. This work necessitated the making of a plaster piece-mould in literally hundreds of sections and was a monumental task. Piece-moulds made at this time are still in use at the British Museum. Fortunately for the successors of these artist moulders, master casts (i.e., the first casts taken from the moulds) were made and retained in good condition, so that subsequent moulds can be taken from them, thus sparing the original casts which, in their way, are veritable works of art. This point illustrates the importance and advisability of retaining a master copy from which another mould can be taken if the first becomes badly worn.

Obviously, when a plaster of paris mould is to be made, a releasing agent must be applied to the surface of the original object. If the object is of granite or an allied stone it can quite safely be lightly greased or oiled before the plaster mix is applied and the mould can easily be removed when the work is complete. But this technique cannot be employed when the original object is a white marble or alabaster since oils can stain the surface, and any subsequent attempt to remove such stains by chemical action is undesirable. If one wishes to use plaster on a white marble it has been found that a dilute solution of white curd soap and water applied with a brush before moulding gives quite satisfactory results. The plaster is released without difficulty once it has set and the thin film of soap can easily be removed later with warm water applied with soft brushes or sponges. Finally, the surface should be dried with a fine white cloth.

Now that the mould has been removed from the original object something must be done to counteract the porosity of the plaster, otherwise it will be impossible to separate any cast made in this mould from the mould itself. A simple solution of soft soap and water should be brushed on to the plaster surface (remove excess soap by mopping with a brush) and allowed to soak in for two hours. This will provide a non-porous surface. A little olive oil may be added to the soap solution. The casting process may now be undertaken.

Another and perhaps a more secure method of mould-surface treatment is to apply, by brushing, successive coats of french polish until a definite and permanent shine is obtained. Allow a day for the surface to harden, then oil or grease the mould lightly and proceed to make a casting. It will be appreciated that a subject such as a bust or figure will require a piece-mould of a considerable number of pieces owing to the undercuts in the ears, nose, hair, etc. Good plaster piece-moulds of such subjects can only be made after a long experience in this particular field, and the less-skilled would be well advised to consider the use of an alternative medium. The answer is the flexible mould.

Flexible moulding materials

Flexible moulding materials are available in the form of cold-setting latex, Revertex and silicone rubber, as well as in hot-melt compounds.

Hot-melt moulding material. An outstanding example of hot-melt moulding materials is the Vinamold range. These Vinamolds can be obtained with a melting scale of between 120° and 170°C. They are completely flexible, strong, and have the advantage of being reclaimable, i.e., when a mould of this material is no longer required it may be remelted and used almost indefinitely. Plaster, cement and the whole group of epoxy and phenol-formaldehyde resins may be used to obtain reproductions from a flexible Vinamold. However, great care must be taken in deciding whether an original object can be safely subjected to moulding in this particular medium. It would be courting disaster, for instance, to attempt to mould a delicate or porous ivory, wood or bronze object in Vinamold without first impregnating or treating the surface with a protective coating of cellulose lacquer which has a higher melting point than the moulding material. If any doubt is present in the mind of the moulder in a situation of this kind, and it is still desired to obtain a copy of a delicate object, the safest material to use would be a cold-setting moulding medium, and the best in this field is silicone rubber.

Silicone rubber. While silicone rubber is the best of the cold-setting moulding mediums it is also the most expensive, costing about the equivalent of 25 shillings sterling a pound. There are a number of grades of this material and undoubtedly the easiest to use is the fluid grade. A catalyst is added to the silicone rubber to promote a setting action—2 per cent of the catalyst will be found to be satisfactory. The two ingredients must be thoroughly mixed together and (ideally) put under vacuum to eliminate trapped air in the mix. If this is not possible the container should be tapped on the bench for a few minutes so as to allow the air bubbles to come to the surface and disperse. Pouring on to the object may now commence, even although all the trapped air may not be disposed of. If the pouring is done slowly none of the trapped air will come in contact with the surface of the object. After pouring is completed allow the mix twenty-four hours to set, after which it can be removed from the object under mould. Care must be taken during this operation as, if the mould is subjected to excessive flexing, the silicone will split. Once the silicone rubber mould has been obtained, the whole range of casting resins can be used to make very accurate reproductions.

A point to be borne in mind when using silicone rubber to mould a metal object is the following. Should there be any corrosion on the surface of the metal this must be treated with a coating of cellulose lacquer. If this is not done the silicone rubber in contact with this area may not set, thus ruining the mould and leaving a deposit of the rubber on the affected surface. This tacky deposit will be difficult to remove, doubly so if the corrosion has caused any pitting in the metal.

Moulding in Vinagel 118

Before the advent of this polyvinyl chloride-based material, the making of a positive casting of a cylinder seal was a most laborious process. It was necessary first to smooth a suitable piece of plasticine on a working surface, then to roll the cylinder seal over this with the correct, even pressure. This gave a flat positive copy, but one too soft and too easily damaged. To get a copy in a more durable material it was necessary to make a plaster of paris casting. This meant that the plasticine cast would have to be oiled and the plaster of paris poured on to this, left to set and then removed from the plasticine. But this would give a negative copy. To obtain a positive copy it was necessary to make a further casting from the plaster of paris negative. The plaster of paris had to be thoroughly dried, then brushed with a dilute solution of french polish or cellulose lacquer to nullify the porosity of the plaster, then brushed with oil to effect a releasing action before casting again with plaster of paris. This would produce a positive copy but after this series of operations it will be appreciated that much of the detail would be lost.

Now, with the use of Vinagel 118, the process of casting a cylinder seal is much simpler and the results much more satisfactory. Nevertheless, considerable practice is necessary before one becomes proficient in the use of this material. The brand of Vinagel used for the above purpose is V.G. 118 museum terracotta, type 060. To obtain a flat impression of a cylinder seal the following instructions should be carefully observed. The working surface should be a piece of thick glass kept scrupulously clean and made moist by passing a wet sponge or cloth over it to prevent the material adhering. Some Vinagel 118 is then kneaded in the hands until it becomes pliable; the hands must be clean as the material is very easily stained. Now place the Vinagel on a piece of smooth hardboard, turn over and press down firmly on to the moist glass surface until the thickness of the Vinagel is approximately 5-6 mm: remove from the glass and, after ensuring that the material is smooth, lightly dust with talc using a soft brush, camel hair if possible. The cylinder seal should also be dusted with talc. Next place the seal on the extreme right end of the flattened Vinagel, press lightly into it, then commence rolling the seal over the moulding surface until the full-length impression is obtained. The pressure should be applied with a piece of flat wood with a layer of rubber on one side, so that it will be applied evenly without risk of damage to the seal itself. Trim off unwanted edges with a palette knife, then put the cast in an oven at 140°C for 25 minutes. Remove from the oven and allow to cool for 15 minutes, then, using the knife, lever the impression off the hardboard. Any smoothing of the edges which may still be necessary can be done by careful filing.

Moulding in sealing wax

At this point two other mediums come to mind, sealing wax and gutta percha. Both of these, unfortunately, are of more limited value in the higher temperatures of the tropics, but they are so generally useful that they must take their place in this review of moulding materials.

Sealing wax, preferably Red Seal Engravers' Wax, gives first-rate results and with care can be used many times over, thus compensating for the initial higher cost. This wax has been used successfully for many years in the British Museum for making impressions of coins, medals, seals, tokens and many smaller pieces of a flattish nature.

Requirements for the use of this material are comparatively simple: a small methylated spirit lamp or bunsen burner, a piece of plate glass or flat slate, talc (french chalk), small camel-hair mop, a sharp short-bladed knife and a small saucepan or bowl for melting down the wax.

Wax impressions are used for the making of casts in plaster of paris or for electrotype reproductions, enabling both sides of a coin or medallion to be exhibited at the same time. If desired, the original can be shown alongside an electrotype of the other side, or both sides can be shown as electrotypes, thus enabling the original to be on hand for study purposes.

Making the wax impression. The method of use is to break up some sealing wax into small pieces and melt down in the saucepan, using a small flame and stirring continuously. Stirring is essential to prevent burning. (If the wax is allowed to overheat it becomes rubbery and is of no further use.) When the wax reaches a semi-fluid pourable stage make some discs of wax (blanks) by pouring steadily on to the piece of plate glass that has been previously dusted with talc. Allow the blanks to cool off completely before attempting to remove by prising with the knife.

To make an impression of a coin, select a wax blank of a suitable size. Should the coin be 4 cm in diameter the blank should be approximately 6 cm. Holding the extreme edge of the blank between thumb and forefinger of one hand pass it fairly quickly to and fro over a small flame, softening it slightly. With the other hand take a stick of wax and warm it over the flame, keeping it revolving all the time to prevent the wax dropping into and around the flame. When it is pliable spread in a circular motion over the warmed blank until it is evenly covered with a thin layer of fresh wax. The stick of wax can now be put aside and the blank passed backwards and forwards once more over the flame. (Change from one hand to the other during this operation as the wax becomes warmer). When the new surface of the blank is smooth and pliable and free of air bubbles, place the blank, new wax uppermost, on the prepared glass. The object to be impressed must also be slightly warmed by passing to and fro across the flame and then well dusted with talc to reduce to a minimum the possibility of surface damage and to assist in its removal from the sealing wax. It is important to warm the coin slightly, otherwise it will chill the warm wax on contact and so produce an inferior impression. Now press the coin well into the wax, using both thumbs, and sustain pressure for a few seconds; then with moistened fingers press the surplus wax around the edges of the coin and so build up the side of the impression to the depth of the object. The coin must be removed while the wax is still slightly warm and pliable. Passing the whole over the flame again at this point will be beneficial. The edge of the impression must first be gently eased away from the coin and then placed back into position all round. Tapping on the back of the blank will release the coin. Replace the wax on the glass, impression uppermost, and lightly press the edges down to ensure that the base is flat. Leave to cool off completely.

Making a plaster cast from the impression. Should a plaster cast be required, the edges of the wax impression may have to be trimmed back with a sharp knife to remove any undercut. Failure to do this would mean trapping the plaster within the impression at the edges and so spoiling the cast. A light film of oil (olive oil has been found suitable) should be brushed on to the impression with a small hog-hair fitch (brush), and any surplus oil removed with a small pad of cotton wool or fluffless cloth. Only a slight trace of oil is necessary to act as a releasing agent; too much may cause blow holes on the surface. The plaster of paris can now be prepared. Add the plaster to water, pour off surplus water and mix well. The mixture is now stippled into the impression, again using a hog-hair fitch or similar type of brush. Stippling is important as it minimizes the formation of blow holes. When the plaster reaches a creamy consistency it can be built up in the impression, with a small spoon, to the required thickness, perhaps 5-6 mm. Allow the plaster to set, but while it is still damp (allow 60 minutes) remove the cast from the mould by gently prising round the edges with a knife blade or spatula. At this stage the surplus plaster around the edges can be carefully trimmed to the correct contour of the object; when dry the back can be levelled down with a coarse file. Finally, dusting the front surface with talc removes oddments of loose plaster. Pairs of casts can be mounted on a card with a touch of glue for photographic purposes.

As an alternative to using blanks the sealing wax can be warmed as previously described and spread evenly to the required size on a piece of cardboard. Build up the wax to a thickness sufficient to accommodate the object. Pass to and fro over the flame until the wax is even and pliable, then make the impression as detailed above. Should the impression be required for electrotyping the cardboard backing must be removed. It must be removed in any case before the wax is remelted for further use.

Gutta percha as a moulding material

Gutta percha is the coagulated latex from a tropical tree, and being unvulcanized

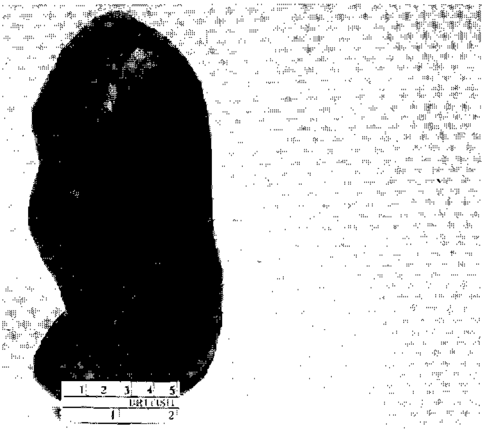

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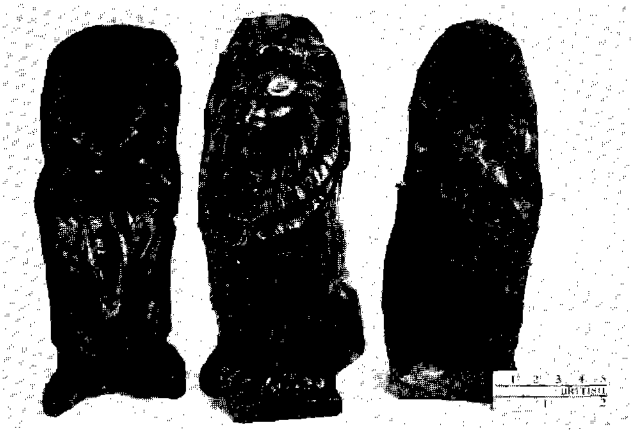
Plate 8

A gutta percha mould, in three pieces, of a bronze lion (British Museum Research Laboratory).

a The three pieces of the mould in place.
b Two of the pieces of the mould removed showing the bronze lion, details of under-cutting, etc.
c Three pieces of the mould removed and the bronze lion.



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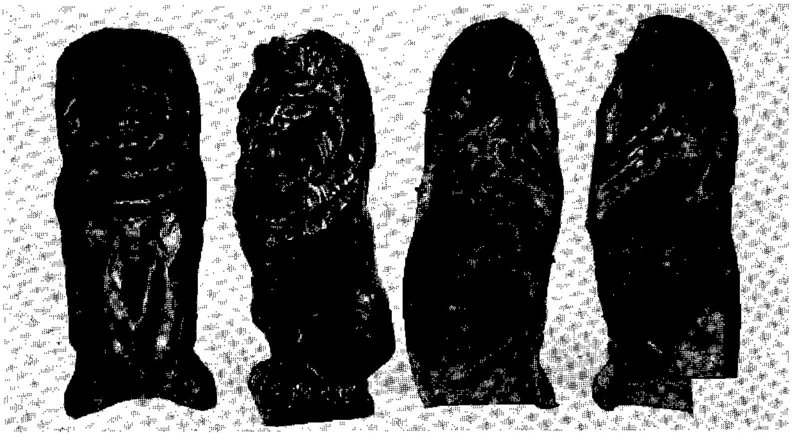

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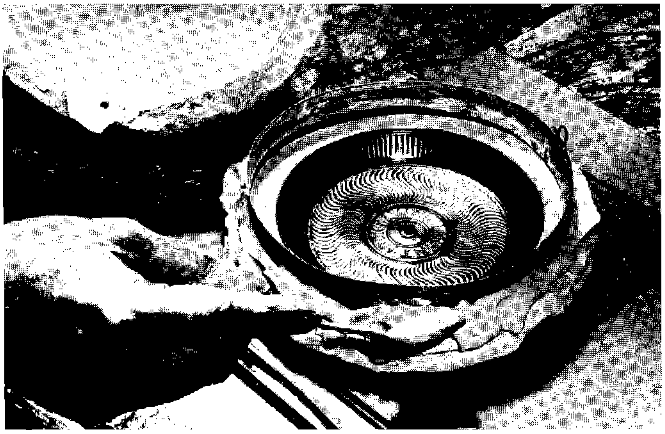

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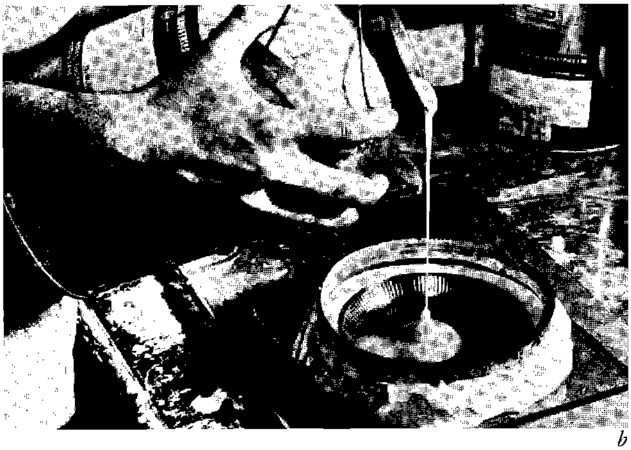

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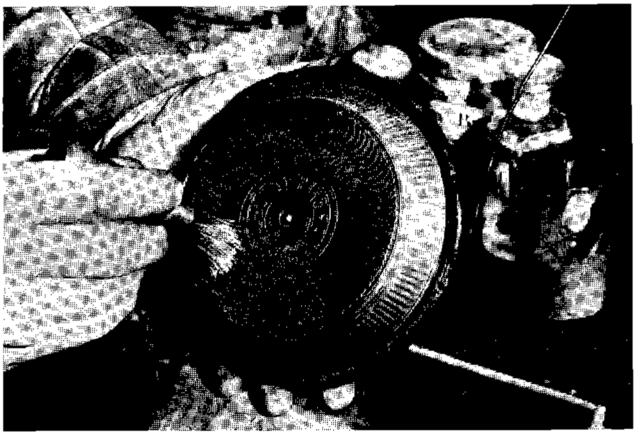

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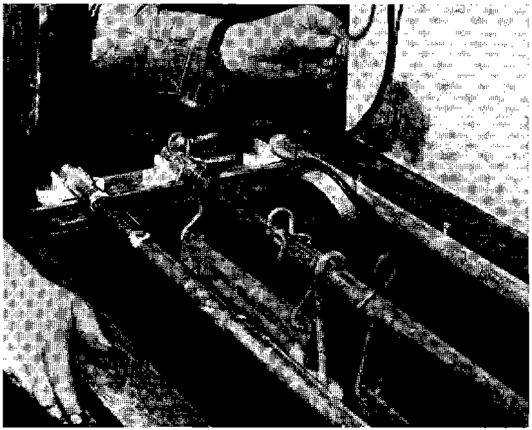
Plate 9

Making an electrotype reproduction (British Museum Research Laboratory).

a Preparing the original for a mould using either polyvinyl-chloride or a cold cure silicone rubber.
b Pouring in the liquid moulding material.
c Applying powdered graphite to the mould for the electroplating bath.
d Immersing the mould in an acid copper bath for electro-deposit of metal.
e Removing the electro-deposit reproduction from the mould.
f Trimming the sections prior to fitting.



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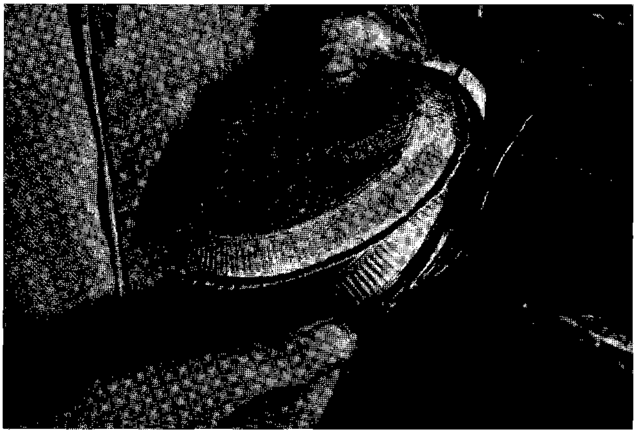

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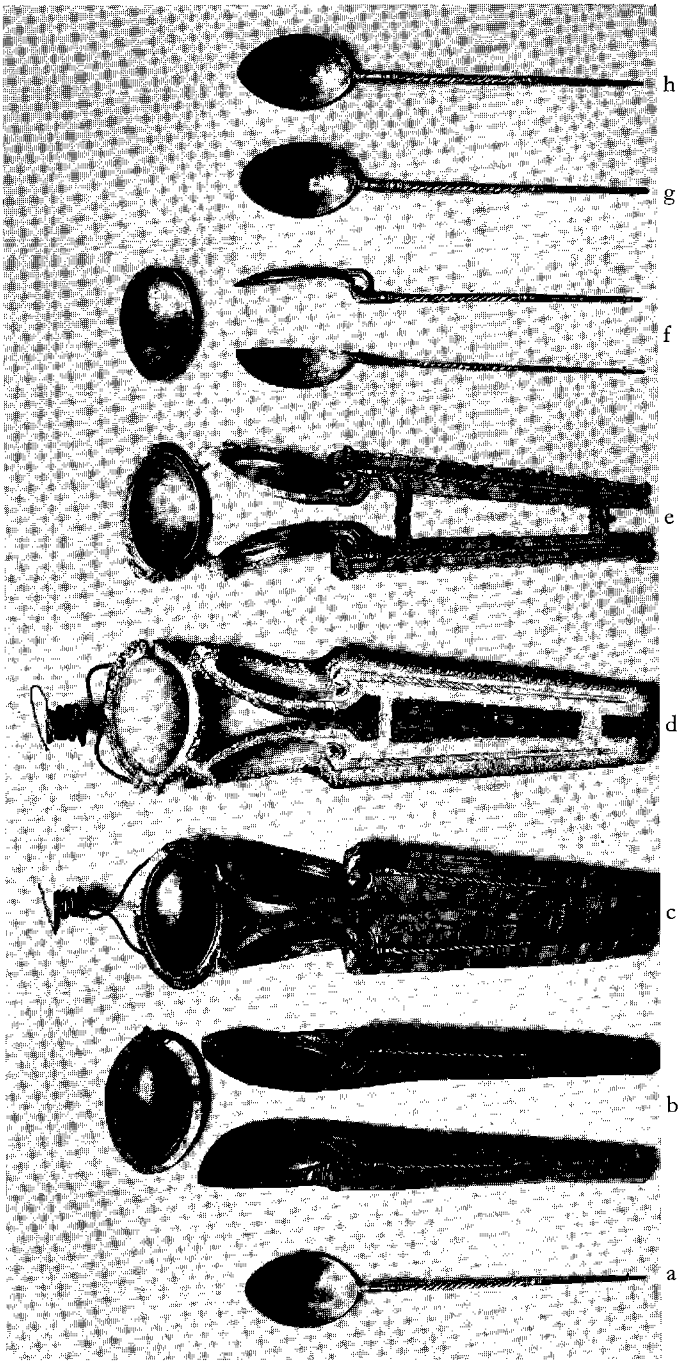
Plate 10
Illustrations showing successive steps in making an electrotype reproduction of a Roman spoon. The copper reproduction is assembled and silver-plated (British Museum Research Laboratory).

- *a* Spoon (facsimile of fourth century Roman spoon found at Mildenhall, Suffolk).
- *b* Moulds of spoon in gutta percha.
- *c* Electrically conducting surface of graphite applied to the mould and this surface connected to a conducting wire prior to connexion to the negative electrode of a low-voltage charging plant; the mould is hung in an acid copper sulphate solution together with an anode of pure copper and current is passed between the two electrodes. The result of this treatment is that a layer of copper is deposited on the mould and faithfully reproduces all the details of its surface.
- *d* The mould and layer of copper where the required thickness has been deposited.
- *e* Copper reproduction of surface after stripping from the mould.
- *f* Parts of spoon after trimming, backed with soft solder and ready for assembly by pressing the soldered surfaces together and heating.
- *g* Assembled spoon.
- *h* Reproduction after silver plating.



remains thermoplastic so making it usable for a number of moulding purposes. It has one disadvantage. If it is being used in temperatures above 20°C some form of refrigeration is essential. Normally, owing to the limited quantity of gutta percha one is able to handle at a time, a small domestic refrigerator will be all that is required, except for moulding very large objects. Gutta percha is usually purchased in 5 mm thickness. Strangely enough, the best results are obtained with the inferior grades as they break down more readily to the required consistency.

The requirements for using this material are comparatively simple, with the exception of refrigeration, and there is an advantage in the fact that it can be reclaimed for use over and over again. To make casts from gutta percha the following items are required: a piece of plate glass or slate, a useful size being around 40 × 30 cm, a 1-litre (minimum) bowl or saucepan, talc, camel-hair mop (brush), a form of rolling pin, preferably a piece of smooth brass or copper tubing about 4 to 5 cm in diameter and 30 to 35 cm long, a pair of scissors, a sharp short-bladed knife, and a heater for the boiling water that is necessary to get the gutta percha into a manipulative condition.

First prepare the working surface by liberally dusting the plate glass with talc. Cut up the gutta percha into pieces about 10 to 15 cm square. Bring water to the boil in the saucepan, remove from the source of heat, and pause a moment before immersing the pieces. Allow to stand for 3-5 minutes, ensuring that all the pieces are beneath the surface of the water. (Do not place them in the water and leave it boiling.) Cold water is then added to the saucepan to make the gutta percha bearable to the touch. Remove the gutta percha from the water. It is then kneaded, with wet hands, to remove as much surplus water as possible and to make it all of an even consistency. Place it on the prepared glass plate and pat with the fingers into a flattish lump; brush more talc over the surface and, using the rolling pin in a similar manner to making pastry, level the material to the desired smooth thickness necessary to accommodate the object to be moulded. It will help if the surface is again dusted with talc and smoothed over with the fingers. The object should also be dusted lightly with talc and gently pressed into the gutta percha. It is essential to avoid excessive pressure: steady, even pressure is required to prevent the deeper sections of the object breaking through the bottom of the moulding material.

Moulds of flat objects and sectional moulding. If, for instance, twenty coin impressions are being made at one time, first press all the coins into the gutta percha, then return to number one and give each of the coins in turn a further light pressure. It will considerably speed up the setting time if the gutta percha with its coins and plate glass is put for a time into the refrigerator.

Gutta percha can also be used for sectional moulding *(Plate 8)* and likewise for 'wrapping over' the more highly modelled single-sided objects. The method of preparation is similar to that already described, but this time, after removing from the heating container, the material is smoothed and rolled out considerably thicker, not less than 1 cm thick. Dust with talc all over and dust the plate-glass surface as well. Also dust the fingers and the edges of the scissors. Then cut the gutta percha to the size required, or in a number of pieces of suitable dimensions if a series of objects is to be moulded.

When the gutta percha has attained the consistency of soft warm plasticine it can be applied to the object, or the first section can be applied in the case of piece moulding. Manipulate with light finger pressure to ensure good contact all over. Such finger pressure may have to be maintained for as long as 10 minutes. Now allow this section to harden whilst in position on the object.

When set the first section can be gently eased away and trimmed to the requisite shape with a very sharp knife. Small V-notches are cut in the edges of each section so that the adjacent sections will key on to it. The trimmed section is now placed back on to the object and the remaining sections moulded in the same manner, remembering all the time to dust the sections and joints with talc. In effect, this amounts to the equivalent of making plaster sectional moulds in a more pliable material.

Moulds of cylindrical objects. A mould of a cylindrical object in this material would need to be made in five or six sections: three or four sections of equal size for the sides and one piece each for the top and the bottom. A small pouring hole for the plaster can be cut in the bottom section, or alternatively the plaster can be poured in before the bottom is closed, the last section being squeezed into position just before the plaster sets.

It must be pointed out that gutta percha is normally only suitable for plaster casting or for making electrotype reproductions. It is as well to experiment with objects of no value when learning to use this material: only with perseverance can one hope to attain the satisfactory results of which gutta percha is capable.

Three of the secrets of success with gutta percha are: avoid using it too warm and soft, use light, gentle pressure when moulding the object, and make liberal use of talc throughout the whole moulding operation.

COLOURING PLASTER CASTS

Before colouring plaster casts it is necessary to apply two thin coats of french polish to the raw plaster surface to eliminate porosity. The polish should be in the proportion of one part french polish to three parts methylated spirits. Hog-hair brushes should be used as these are considerably cheaper and better suited to this type of work than finer and more expensive ones. After application of the polish allow half an hour to elapse before proceeding to the next stage. To colour the plaster casts first prepare equal parts of french polish and methylated spirits and add powder-colour pigments to it, thoroughly integrating these by stirring and mixing with a paint brush until an approximate match of the colour required is achieved. Apply this to the surface of the plaster cast, using a brushing technique with oblique strokes and then a light stippling action. If a uniform colour has not been obtained, stipple lightly again with a second coating of the colour medium. As the french polish dries rapidly the second stage may be started 15 minutes later. Assuming that there is no varied patina to be copied and the operator is satisfied with the colour, the surface can now be polished. A light coating of a soft clear wax, similar to shoe polish, is brushed over the entire surface, allowed to harden for a few minutes, then rubbed lightly with a soft cloth to give a subtle polished finish.

Sometimes it is necessary to imitate the broken patina surface of the original object. In this case proceed with the first two stages as detailed above, i.e., apply the two thin coats of french polish to the cast to eliminate porosity,* then apply the coating of the basic colour medium. Now mix together powder-pigments to match the tones of the patina, adding water in which a small amount of glue has been incorporated to act as a fixative. Combine these by stirring vigorously until a thin, creamy consistency is obtained. This is brushed on with a stippling action either over the whole surface to match the original or in sections as appropriate. The colour medium will dry quickly, and will match the tone that the powders had when they were first mixed dry. Allow 10 minutes for the coloured surface to harden, then brush the wax film over the whole area and polish lightly with the soft rag.

With practice it will be found that pleasing results can be obtained by these methods, which are quick to use and give lasting and stable results. Another point in favour of this form of colouring is that the second and third coats may be removed easily if the finished tone is not satisfactory. The wax can be cleaned off by brushing over lightly with turpentine, and the water colour can be dispersed with warm water. The initial base colour mixed with french polish will remain intact and a new attempt can be made to imitate the patina surface.

Marble and ivory finishes can also be achieved by these methods, but for such light-coloured finishes it is essential to use *white* french polish. Terra-cotta finishes are also easily obtained, but in which case of course the coloured surfaces should not be waxed as this would impart a gloss incompatible with the usual mat appearance of this material. Plaster copies of originals can also be coloured with oil colours, but oil colours require a longer drying time and the results are not necessarily any better indeed, often not so satisfactory.

ELECTROTYPING

For electrotype reproduction *(Plate 9)*, moulds in sealing wax, gutta percha and silicone rubber are particularly suitable; silicone rubber gives the best results as regards perfection of detail, but sealing wax and gutta percha can also be used with considerable success. (The mould is made as described under the appropriate sections above.) Very briefly, to make an electrotype reproduction, the surface of the mould must be brushed lightly but thoroughly with graphite to make it electrically conductive, using once again a round hog-hair fitch for preference. After the necessary wiring has been done to provide a point of contact to the graphite, the edge and back of the mould must be coated with a stopping-off lacquer (Lacomit). It should be carried to within 5 mm of the actual part of the mould required to be reproduced. This is to prevent the copper deposition creeping over areas where it is unwanted. Do not paint over the wire so as to insulate the points of contact! The prepared mould is now placed in the acid copper solution (1 kg copper sulphate crystals, USP standard, dissolved in distilled water to which is added *slowly* 10 cm^3 of concentrated sulphuric acid) so as to make electrical contact with the negative pole. A copper anode is attached to the positive pole. The electric current is switched on at approximately 3/4 volt D.C. A copper deposit will now form over the whole of the conducting surface of the mould, i.e., the graphite reproducing faithfully all details. When a suitable thickness of copper has been built up it can be removed from the mould. A 'backing-up' layer of tinning solder is then applied to the back to give added strength and if necessary to enable a number of sections to be joined together by soldering. Silvering, gilding or chemical colouring to simulate various bronze tones can then be undertaken, so completing the electrotype reproduction *(Plate 10)*.

CASTING AND REPAIR RESINS

Modern polyester resins have proved their value in the reproduction and restoration of antiquities. By incorporating a metal filler of the desired colour, and, in addition when necessary, fibre glass for reinforcement, extremely good casts can be taken from silicone rubber, and to a lesser degree from prepared plaster piece-moulds. Satisfactory repairs and consolidation can be achieved by using these resins on a variety of materials, bronze, wood, ivory, pottery, etc. They are specially useful in the case of corroded bronze where a normal soft soldering repair is impossible owing to the mineralization of the metal. In preparing a joint prior to repair, it is essential to remove all loose surface particles and, where considered necessary, to consolidate by using one of the impregnating media previously recommended. Added strength can be given by backing up with fibre glass saturated in resin, especially at the rear of a joint. Araldite epoxy-resin high-stress adhesive can be recommended as a powerful jointing medium for repair work, especially in the repair of metals as an alternative to soldering. Araldite is supplied commercially in tube form, in two containers, the adhesive and the hardener respectively. When mixed in equal proportions, applied to the fractures and then assembled, it provides, on setting, a very satisfactory bond.

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Ione Gedye

Pottery and glass

8

INTRODUCTION

At their best pottery and glass are among the most stable of materials. However, inferior wares occur widely in all categories and examples coming from primitive kilns, provincial imitations of well-known types, even 'wastes' (which may have as much interest for the ethnographer or museum curator as perfect examples), form an important part of collections.

When pottery requires emergency treatment for its preservation this is generally concerned with the removal of salts and other contaminants and subsequent consolidation of the ware and its decoration. Glass may require similar attention, although probably to a lesser degree as it is much less porous. Each material, in its own way, presents problems calling for the application of special techniques for consolidation and repair which are briefly described in this chapter.

POTTERY

WASHING

Pottery must never be separated from the labels recording its provenance until it has been marked; it is washed piece by piece, put on a perforated tray to drain and then transferred to a dry tray. A number of sherds should not all be put at once into the water; a sherd may stand washing but not soaking, and there is a risk that small sherds may be thrown away with the sediment.

Well-fired pottery can be scrubbed with a nail brush or tooth brush. Edges should be brushed as well as the inside and outside, but care must be taken not to remove traces of food or paint. A neutral soapless detergent may be used and the water should be changed frequently; muddy water leaves a film on the pottery.

Fragile badly-fired pottery should be brushed carefully while dry to remove as much dirt as possible, without damaging the surface, and then impregnated with a suitable consolidant such as polyvinylacetate or soluble modified nylon C 109/P grade DY 55. When set, the remaining dirt can be removed with a brush dipped in the solvent or with a scalpel.

Painted pottery should be tested for colour fastness before washing; if the colour is fast, the pottery may be washed with a brush soft enough to avoid damaging the surface, but not soaked.

SALTS AS A CONTAMINANT

Pottery coming from a country with a restricted rainfall is often impregnated with salts which may be soluble or insoluble in water.

Soluble salts

If the relative humidity is variable, soluble salts will dissolve and crystallize repeatedly, working their way to the surface of the pot where greatest evaporation takes place. There, as a mass of needle-like crystals, they will hide all detail. The repeated crystallization and dissolving will cause the surface to disintegrate and the internal stresses set up will eventually break up the pot. Pottery in this state must be soaked in running water or in repeated changes of water until free of salts. Various soluble salts may be present: chlorides from the soil, phosphates from any site where there is much ash from kilns or hearths, or nitrates following on treatment of insoluble salts with nitric acid. Although other tests may be carried out to determine the presence of these ions, it is preferable to do a conductivity test. The pot, or one large sherd from a group, having been washed in tap water, is placed in a known quantity of distilled water, the conductivity of which has already been taken. Conductivity readings are taken at 2-minute intervals over a period of 16-30 minutes. These readings are noted and recorded on a graph. The procedure is repeated daily, always using the same volume of water. The graphs are compared and when they show a repeatedly similar gradient the washing is considered to be completed.

Insoluble salts

Calcium carbonate. Before lime deposits are removed from the surface of pottery it is vital to determine that the ceramic body itself does not contain appreciable quantities of lime or calcium carbonate, such as marble, chalk or shell. In such instances soaking in acid solutions would cause solution of the lime particles and leave the pottery porous—and ruined.

Only when it is known that the body contains no carbonates may the pottery be immersed in a diluted solution of nitric or hydrochloric acid—diluted to not more than 20 per cent by volume—the pottery first having been well soaked in clean water. The pottery remains in the acid until effervescence ceases, but under observation so that it is removed as soon as the incrustation is dissolved. Where the body is shown to contain lime, very great care should be taken if acid treatment is to be used. The pot or sherds are soaked in clean water, after which the dilute acid is applied drop by drop to the *surface* only, each area treated in this way being washed in running water immediately. Particles of body lime at the surface of the pottery should be scrutinized regularly to ensure that they are not being dissolved. Even so, in such cases mechanical removal of lime incrustation is often preferable to chemical treatment. Painted or glazed wares should be held in tongs thoughout treatment so that they can be removed immediately if it appears that damage may be done to the surface.

In the case of ancient lead-glazed pottery, a white film often appears on the surface. This may be a carbonate deposit resulting from devitrification of the glaze surface and the exposure of metallic lead to corrosion. In cleaning glazed wares it is preferable to use concentrated hydrochloric acid applied drop by drop to the wetted pot, washing off immediately until all the incrustation has been removed. The pot should then be boiled in water to remove the white film of lead chloride resulting from the combination of the acid with any free lead present.

Calcium sulphate. If the incrustation is heavy, the worst of it should be removed mechanically before acid treatment. The pot is then immersed in clean water for a few minutes and concentrated nitric or hydrochloric acid is dropped on to the incrustation.

All acid treatments must be followed by prolonged washing, and conductivity tests should be applied to determine the efficacy of the treatment.

Silicates. Siliceous deposits on the surface of pottery must be removed mechanically, since they are not soluble in the common mineral acids. The conservator may read elsewhere, or be advised, to remove such incrustations with hydrofluoric acid; this acid, however, can be extremely dangerous to both operator and object and should be used only by the most highly qualified chemists who are fully aware of the dangers involved. Even these will, however, prefer to try mechanical methods rather than to take the risks involved in using hydrofluoric acid.

MARKING POTTERY

Porous pottery does not 'take' ink neatly. The area to be marked should be painted with one or two coats of dilute lacquer (cellulose nitrate will do) and the ink should then 'take' over the dry lacquer. All markings should be painted over with two coats of lacquer to make the marking resistant to washing and handling.

MENDING POTTERY

Adhesives

The choice of a suitable adhesive is important. Cellulose nitrate is probably the most convenient to use, but since certain commercial varieties favoured by archaeologists are deficient in plasticizer, care must be taken in selection. From the point of view of speed, Balsa cement is good; otherwise, if a cheap brand is desired, H.M.G. obtainable from Marcel Guest, Collyhurst, Manchester 9, is perfectly adequate and sets in from a half to one hour according to the thickness of the joint. Cellulose nitrate cuttings may be dissolved to the required consistency in equal quantities of amyl acetate and acetone. A plasticizer such as castor oil or camphor may be added. If the pottery is very thick, it is preferable to use an impact glue such as Evostick, a rubber-resin mixture soluble in toluene, benzene or carbon tetrachloride. The edges of the sherds must be absolutely clean and any hollows cleaned out with a pin so that the tightest possible join will result. If a tube of adhesive is not used it is preferable to use a stick as a spreader. A thin coat of adhesive is spread along both edges which are then pressed well together, any surplus adhesive being wiped off. One sherd is then stood in a tray of sand so that the other will balance on it and adhere to it by its own weight. Plasticine 'splints' along the joins should be avoided as they clog the join and prevent setting at the correct angle. Joins should be balanced clear of the sand and if pieces fall they must be cleaned before being restuck. If possible, pots should be mended from the base upwards and only one piece should be stuck at a time so that errors can be adjusted as the work proceeds. If a white hazing appears on the surface near the joints it can be removed with amyl acetate.

Friable pottery may be difficult to mend owing to its breaking away on either side of the joint; such sherds should be impregnated with a suitable consolidant before sticking.

Filling gaps with plaster of paris

Missing portions of the pot can be filled with finest grade dental plaster. First, plasticine is rolled to the required size and thickness on a smooth, clean surface (rolling pin and surface being dusted with french chalk to prevent sticking), trimmed to shape, and an impression is taken of the inside of an existing section of the pot. The plasticine mould is then shifted inside the pot and held in place close to the broken edge so that the missing fragment can be built up with plaster on the outside surface. The plasticine mould should be dampened or dusted so as to be easily removed. The edges of the pottery are well wetted before plastering, otherwise the dry pottery will rob the water from the plaster and leave it soft and crumbly when set. Fine-grade dental plaster is mixed in a china or rubber bowl, and should not be stirred until all plaster necessary has been added to the water. In this way the strength of a 'set' can be gauged and repeated. A normal set is when all free water has been taken up by the plaster; an extra strong set when a little more plaster is added above the water line; a less strong if a little free water is left. The missing fragment is built up with plaster using a spoon or spatula, taking care to press it against the edges at the joints so that it will adhere well. Plaster runs should be removed immediately as they are difficult to remove later. The surface is smoothed with a wet spatula as it sets, leaving it a little 'proud', since it is easier to work down a slight surplus than to add. When set, plaster can be worked with steel tools, small rasps or rifflers and sandpaper, taking care not to scratch the pot and keeping the work as clean as possible.

Filling gaps with Alvar-jute-kaolin dough

This plastic dough is a great improvement on plaster for gap filling and is prepared as follows.

Alvar-jute-kaolin dough (AJK dough)	*Parts by weight*
800 g Alvar 770 (polyvinyl acetal)	100
1260 ml acetone	120
504 ml industrial methylated spirits	50
370 ml amyl acetate	40
Stir and leave for 24 hours in covered container.	
Add:	
928 ml xylene (benzene or toluene)	100
Stir well. Add:	
480 ml water	60

Stir till well emulsified, then stir in with a wooden spoon jute flock and dry kaolin in the proportion of two dry measures of jute to one of kaolin, until too stiff to stir. Turn out into a large tray or slab and knead in more jute and kaolin in the same proportions until the mixture does not stick to the hands. Good kneading is essential.

Alvar may be obtained from Shawinigan, Marlow House, Lloyd's Avenue, London E.C.3, and jute flock from Gullaflox Ltd., Fibril Works, Dartford, Kent, United Kingdom.

This so-called 'AJK dough' can be modelled when soft; there is no waste and the surface of the pot is not damaged as in other circumstances it might well be by plaster dust. The dough can be used rolled into flat ribbons as a potter would coil-build a pot, each 'ribbon' being well pressed on to the edges of the pot and on to the ribbon below; or it may be rolled, cut and pre-formed round a suitably sized mould to the shape of missing necks and rims. These strips can then be attached to the pot forming an open network that can be filled in with dough. The shape can be easily modified when set by painting on a little acetone so that the dough will again become plastic. For small gaps a plasticine mould covered with thin polythene sheet can be used as in plaster work. Too thick a section should not be made up at a time, as the solvent will evaporate from the surfaces only, leaving the inside 'unset', and a final application of surfacing dough should be made to compensate for shrinkage on the evaporation of the solvent.

Decoration can be impressed or moulded. For thin-walled pots the dough is rolled into thin strips which are allowed to harden by evaporation; the strips are then cut to the desired size and warmed on a thermostatically controlled hot plate. When they become pliable (in a few seconds) they are pre-formed to the exact curve on a drawing or mould, and when set on cooling they are inserted to span the gaps, using adhesive to fix the ends to the pot. The gaps between the strips are filled in with dough. This method enables thin-walled bowls to be built up without difficulty and the strips need no extra shaping when *in situ*. If the surface of the pot is very smooth the dough can be built up to just below the surface and surfaced with hardened plaster.

PAINTING POTTERY

The choice of paint used must depend upon the final surface required. For matt surfaces poster, distemper and powder paints are all suitable. For glossy surfaces oil-bound paints and those based upon acrylic emulsions are ideal.

Before colouring, it is advisable to determine exactly what is required by way of matching reconstructed parts to the original. As a general guide, the new work should not be noticeable at a distance, say 2 metres, but should be clearly discernible at close quarters, say 50 cm. Curators, however, hold widely disparate views on this topic, some liking reconstructed areas to be virtually undetectable, others preferring the made-up parts to be left uncoloured.

GLASS

PRESERVATION

Ancient glasses were composed of silica (silicon oxide) fluxes or glass modifiers (oxides of sodium, potassium and calcium) and glass colorants. If an excess of fluxes were used, as was often the case, they remained uncombined or only weakly combined with the silica. At relative humidities above 40 per cent these fluxes were converted into soluble hydroxides and beads of moisture appeared on the surface of the glass and these reacted with carbon dioxide from the air to form carbonates. Potassium carbonate will absorb moisture from the air unless the relative humidity is very low and so one comes across what is known as 'sweating glass'. The only treatment possible is to keep such glass in a relative humidity of below 40 per cent (Organ, 1956-57). The sweating condition is only made worse by the application of surface lacquers. None is impervious to water vapour, and the glass will continue to disintegrate beneath the lacquer until it is completely decayed.

The condition known as devitrification should not be confused with 'sweating'. Here the surface of the glass becomes partly crystalline, often flaking from the body, and normally shows a play of colour. In these cases a surface consolidant may be used, such as a dilute solution of polyvinyl acetate or polyvinyl alcohol. But nearly all lacquers yellow with age, and one must decide which is the less objectionable, the flaking of the untreated surface or the slight discoloration.

JOINING AND FILLING GAPS

The procedure for joining broken glass is the same as that for pottery, just described, save that adhesives based upon cellulose are not really suitable, epoxy-resins on the whole giving the most satisfactory performance.

Adequate gap-filling is exceptionally difficult, and unless one is prepared to sacrifice both time and money perfecting techniques, it is not really worth attempting. Broadly speaking, there are two approaches to the problem: to cut suitable areas from pre-formed plastics sheeting; and to cast a clear plastic material into the spaces left by missing fragments. In the first instance Perspex sheeting may be cut, heated gently and bent into shape, and set into position with adhesive. In the latter case it is normal to use casting acrylates manufactured for the dental profession. A concise account of this technique has been given by Wihr (1963).

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Preservation of entomological materials in the tropics

9

INTRODUCTION

Maintaining insect collections in good condition in the tropics is usually more difficult than in temperate regions. There are many obstacles in the way, particularly when it is desirable to keep the material pinned and spread. The high relative humidities and temperatures in most tropical regions make it quite difficult to keep dried collections free from mould and safe from insect pests and for this reason it is often more convenient to preserve specimens in liquids than to store them in the dry state.

For collections that are to remain in the tropics, serious thought must be given to choosing methods of preservation appropriate to the main objective, whether it is to prepare specimens for study, for display or for exchange. When, on the other hand, specimens have a long distance to travel, it is essential that they should be safely packed, and this may well be a determining factor in the choice of the particular method to be adopted for their preservation.

But in all cases, whatever subsequent precautions may be adopted, a great deal depends on the initial treatment of specimens at the time of their collection in the field. This aspect of preservation will therefore be discussed in some detail in the pages which follow.

TREATMENT OF MATERIAL IN THE FIELD

Specimens for transmission to temperate regions

Expeditions or research personnel from temperate areas working in the tropics may often have to take special precautions. Some materials may be sent out of the tropics by air mail immediately after collecting; in other cases, for one reason or another, there may be unavoidable delays and steps must be taken to avoid the speedy deterioration of materials which is apt to take place. Essentially, for dry collections, this involves protection from mould and pests and, for liquid collections, prevention of evaporation, spilling and contamination. In both cases, adequate precautions must be taken to prevent crushing, jarring and other types of damage. It may come as a surprise to learn that, even when adequately labelled, a parcel sent by air mail may be thrown and even kicked around; and heavy boxes, bags or trunks may be stowed on top of it despite warnings to the effect that the contents are fragile and must be kept 'this side up'. Material shipped by freight must also be packed with this in mind. In unloading freight from ships loads have been known to be dropped from cranes for the last metre or two on to concrete piers and even more serious accidents may occur which serve to emphasize the importance of careful packing.

For the shipment of dry, unmounted insect collections (often the most convenient form for shipment), the smaller boxes, cartons or tins containing the specimens should be packed in larger cartons or wrapped in paper to prevent rattling. These packages should then be assembled in very strong cartons or wooden boxes padded with a moderate amount of shock-absorbing material. This may be wood-wool ('excelsior'), cotton waste ('cellucotton') or even shredded or crumpled newspapers (unprocessed plant material such as rice-straw or grass should never be used, as they soon lose their resiliency).

For the shipment of wet specimens in alcohol (70-75 per cent), formalin or other fluids, each vial should be properly stoppered and wrapped both in cellucotton and paper. Groups of vials of the same size can then be wrapped together in the same manner and placed in tins of appropriate size. These tins should then be soldered, or placed in larger soldered containers to prevent evaporation. The containers are eventually packed in cartons and placed in wooden boxes thickly lined with corrugated paper or the like to reduce jarring in shipment. Such shipments should be opened promptly on arrival, particularly when shipped long distances by sea freight, for if tins have become rusted or punctured some evaporation is certain to have taken place. When unpacking such collections, the labels should be checked for rubbing, fading or other damage, and replaced if necessary. To prevent evaporation vials should be put into jars containing an appropriate fluid. At the same time it is advisable to replace rubber or cork stoppers with cotton as cork tends to become blackened and to deteriorate in double containers and rubber becomes soft, but cotton survives in good condition.

Specimens to remain in the tropics

When collections are to remain in the tropics, their transfer from the field to the museum may require precautions similar to those for shipment further afield, especially if the collections are not transported under the care of the collector. Because of the important factors of temperature and humidity in the tropics, new collections require special and constant care until they are finally housed in circumstances designed to reduce or prevent losses due to mould growths, insect pests or other adverse factors. For dry collections, suitable containers will be required and a copious supply of repellents or fumigants must be used. Failing these, constant drying by artificial heat or by air-conditioning is essential. The chances of loss by mould growths, etc., are lessened by putting as many types of specimen as possible in fluid preservatives, but this has its disadvantages in that specimens so preserved are less adaptable and convenient for study and sorting, whether for arrangement or display, and, as the jars of liquid will certainly take up more space, the collection will be more expensive to maintain than a dry collection. Moreover, unless considerably more space is allotted per specimen, the label data of liquid collections tends to be decidedly less accessible.

METHODS OF PRESERVATION

Dry mounting

In general, miscellaneous insects collected by net, by sweeping or by hand are placed in killing bottles using a poisonous vapour such as hydrocyanic acid gas produced from potassium or sodium cyanide placed in the bottom of the jar or tube. The moisture necessary to produce the gas is provided by the bodies of the insects themselves, although a drop of water may be necessary at the start. Ethyl acetate (acetic ester) is another poison which has been found to have many advantages over cyanide and a small amount of this liquid dropped onto cellucotton or paper in the bottom of a tube rapidly evaporates, killing the insects. When the liquid has evaporated another drop or two should be added. One advantage of ethyl acetate is that it leaves the specimens more relaxed than does cyanide, thus diminishing the chances of breakage during transport or in the preparation of the collections. It also gives the specimens a certain resistance to mould growth over a considerable period of time. Since it is a liquid, dipterists and lepidopterists tend to avoid its use, but if care is taken to keep the jar or tube dry by using sufficient cellucotton paper flies and moths can be killed without being wetted. Whatever type of killing bottle is used, excessive exposure to warmth will be likely to damage the contents owing, particularly, to the action of condensed moisture. This may not be detrimental to Coleoptera or other heavy-bodied insects, but the container must be emptied frequently and overcrowding avoided when fragile or delicate-winged forms are killed in ethyl acetate.

Collections should be prepared in the field whilst the specimens are fresh. Time should be given to this, since it takes much more time to mount insects than to collect them. Where possible, insects to be dry-mounted should be pinned out immediately, otherwise a body may be crushed or appendages broken off. The process of relaxing with damp sand (containing fungicide) in a close container or with steam or warm water never gives quite such sure results. There is the same urgency in respect of mounting Lepidoptera and other insects requiring the wings to be spread. Mounting should be carried out promptly and specimens should be sufficiently dried by artificial means during spreading to prevent later relaxation which might be caused by the atmospheric humidity.

Dry specimens to be packed for mounting elsewhere should be placed carefully between layers of cellucotton or cardboard boxes. It is not advisable to mix insects of different size and weight in the same box. Nor should many specimens be put together in one layer; layers should preferably be composed of insects of similar size and type. Thus, one would not mix beetles and moths, or beetles and lacewings. Similarly, material with different ecological data should not be put in the same box. The collector should have a supply of all sizes of boxes and pill-boxes, so that small or large collections can be packed separately. Fungicides are of course very important. Each container should be supplied with a fungicide, flakes or crystals of naphthalene or similar material. In general, the combination of killing with ethyl acetate, artificial drying, and use of sufficient amounts of naphthalene should prevent the growth of moulds. There are more effective fungicides than naphthalene, however, and some of these may be mentioned. Paradichlorobenzene is excellent, but it dissipates more rapidly and cannot be relied on for long periods of storage. Paradichlorobenzene should not be mixed with naphthalene for in a humid climate the mixture is deliquescent. A good general preservative for dry specimens is chlorocresol and this is fairly satisfactory as a mould inhibitor. Beechwood creosote, a liquid, is also very good both as fungicide and pest repellent but it must be used sparingly with pinned specimens (on inside of cover of box) as it tends to rust or corrode pins.

Finally, a word must be said about traps. Collections from light traps, Malaise traps and the like (Gressitt and Gressitt, 1962; Oldroyd, 1950; Peterson, 1934) are usually kept dry, but such traps may catch many different types and sizes of insect at one time, and even spiders and caterpillars, which will require sorting. Some of the specimens will need to be preserved in fluid, while others, the more delicate, will have to be either pinned or carefully separated and layered. A light trap may be fitted for the direct preservation of the specimen in alcohol. This can be useful for minute flies but is not advisable for moths. Some light traps are designed to separate moths from other insects and in these, too, killing agents may be employed. Berlese funnel collections are usually channelled directly into alcohol, but ethyl acetate, water or even empty jars may be used.

Preservation in liquids

Living insects or mites that are to be preserved in liquid are best placed immediately into 70 per cent ethyl alcohol for killing. For some types it is necessary to add certain liquids to the alcohol, such as chloroform, acetic acid, glycerin, etc. The primary purpose of these additives is to prevent blackening or straining, shrinkage and distortion. A commonly-used larval fixative goes by the name of K.A.A.D. It is a mixture of kerosene (1 part), 95 per cent ethyl alcohol (7-10 parts), glacial acetic acid (2 parts) and dioxane (1 part) (Peterson, 1951). Larvae, depending on their size, should be retained in the fixative for a half-hour to four hours and then transferred to alcohol. Because K.A.A.D. and similar fixatives are corrosive, they should never be used or stored in containers with exposed metal parts. It is advisable to consult specialists regarding the best media for different types of insects. For some minute forms like Collembola it may be necessary to add, for example, 1 part ether to every 3 parts alcohol in order to lower the surface tension so that the specimens may sink into the preservative. An excellent collecting fluid, Isopropyl-Carnoy, developed by Ueshima, is prepared as follows: 98 per cent isopropyl alcohol (3 parts), and glacial acetic acid (1 part). This preservative has the advantage that it does not harden specimens as much as does ethyl alcohol. It is an excellent fixative for chromosomes and, unlike standard Carnoy's fixative, may be prepared up to three months before use. In an emergency, 70 per cent isopropyl alcohol which is widely sold as a rubbing alcohol may be used alone, and has most of the advantages of the complete mixture.

After a certain time the preservative fluid should be renewed as it may have become stained, diluted and less effective. It is important to check the labels both at this stage and again when the specimens are sorted into groups and put into permanent containers or separated for study. If various kinds of insect have been preserved together in the fluid, precautions are necessary to see that there has not been damage in storage or transport. Sorting should be done as soon as possible and in any case before the specimens have hardened, changed colour, or been damaged by pressure or friction; this applies especially to specimens taken in a Berlese funnel as they may be mixed with sand or other harmful debris.

When the vials of specimens are eventually put into museum jars with preservative, it is advisable to use neoprene gaskets rather than rubber ones, to reduce loss by evaporation.

Slide mounting

Material to be slide-mounted may have to be preserved in special fluids and the slide-mounts should be made without too much delay after the specimens are preserved. Mites and certain insects, for example, can be cleaned in warm lacto-phenol (phenol 20 ml, lactic acid 20 ml, glycerine 60 ml and water 20 ml) or other suitable medium prior to examination or to mounting on slides.

Specialists have their own preferences regarding the best media to use for slide-mounting. Canada balsam and euparal are common, Hoyer's or Gater's media are often used for mites or minute flies, but all of these have drawbacks. A critical matter is the depth of the mount. If very deep, there may be enough darkening of the medium with age to cause opacity. Thick balsam mounts may with age become difficult to examine. Euparal and Hoyer's (distilled water 50 ml, chloral hydrate 200 g, glycerol 20 ml, and gum arabic 30 g) are useful for temporary mounts. In some humid climates Gater's may become completely opaque. This appears to apply particularly to regions experiencing great changes in seasonal humidity and temperature. The use of paper rings to build up the support of the cover-slip to the top level of the specimen in addition to an outer seal helps to give long-term protection and reduce changes. It is important to dry the slides thoroughly after mounting (in an oven at approximately 55°C for several days) and to seal the cover-glass with sealing fluid ('zut slide ringing compound'). Otherwise, if slides are not kept horizontally, the cover-slips may slide off in transit or in storage.

Some authors (Grandjean, Balogh and Sengbusch) emphasize that oribatid mites should not be kept in permanent closed mounts, but are better stored in vials in alcohol or other suitable media.

SPECIAL COLLECTIONS

For most groups it is advisable to document specimens with pertinent ecological data, in particular, host data. This may include vertebrate hosts such as mammals, birds, reptiles or amphibians; insect hosts of various groups; nests; plants or plant products. Where appropriate, insects should be kept in the same containers as their hosts; if kept separately, the two should be associated by field numbers. A notebook must also be kept indicating quantity, type of insects, type of host, locality and related information, niche of host, measurements and all other pertinent data (Fig. 42).

In the case of mammal hosts the specimens must be prepared—skinned, labelled, and the skulls dried and given individual reference numbers. Certain small mammals, such as bats, may be preserved in alcohol or formalin in their entirety. This permits re-examination for parasites that may have been overlooked in the first instance and later examination for internal parasites. Care should be taken to pierce the abdominal cavity at more than one point, so that the internal organs will be adequately preserved. This method may also be used for birds, although it may render later study more difficult. Small birds may be preserved in fluid, taking the same precautions mentioned above for mammals. Bird hosts should be measured, labelled and skinned, retaining the skull, feet and outer wing bones. Even when it is proposed to preserve the entire host in fluid, however, it should first be examined for ectoparasites because parasites may become dislodged in the fluid in transit, making it impossible later to determine what part of the body of the host was attacked by a particular parasite. This information may have an important bearing on the comparative ecology of different parasites and the diseases they transmit.

Reptiles and amphibians are usually preserved in alcohol or formalin, but in such cases a good part of the body is removed and the remainder is preserved. Of course the best ectoparasite material is to be found by a thorough search of the body of the host immediately after killing.

TRAPS

Spring-door cage traps in which animals are taken alive are preferred for ectoparasitic work. Snap-traps which kill the animals are less desirable, because many parasites leave the host after death and in the lowlands ants attack the corpse. However, some animals will not enter cage traps, and snap-traps will catch specimens otherwise missed. Also, in the highlands (2,000 m and higher) where ants are not a problem and decomposition of the body is not so rapid, snap-traps can be used. Traps are normally baited and set in the evening and specimens gathered early in the morning. The traps are placed where animals are most likely to be found, near burrows or nests, at the base of trees, on or near fallen logs, etc.; for arboreal mammals, some should be attached to horizontal limbs. When a large

Host Animals

B. P. Bishop Museum, Honolulu, Hawaii

BBM-No.	Locality	Host	Date	Collector	Sex	Total length (mm)	Tail (mm)	Hind foot (mm)	Ear (mm)	Tragus (mm)	Forearm (mm)	Notes

Ectoparasites

B. P. Bishop Museum, Honolulu, Hawaii

BBM-No.	Locality	Host	Date	Collector	Mites				Ticks			Fleas	Lice	Flies	Others/Notes
					N	B	E	U	H	E	B				

Fig. 42. Example of registry card for collection of insect specimens.

number of traps are used, they are placed more or less at random without searching for runways and nests.

KILLING SMALL ANIMALS

The best method of killing small animals for ectoparasite examination is with an organic liquid such as ethyl acetate, chloroform or diethyl ether. Cyanide gas should be avoided. One or more animals, each in a clean cloth bag, are placed in a large, heavy plastics bag with a piece of cotton soaked in the killing agent. This kills the host and kills or anaesthetizes the parasites.

Small animals can be killed by squeezing the chest over the heart for a half-minute or more after the animal has been transferred from the trap to a cloth bag.

It is essential that only one animal be put in each cloth bag and care taken that parasites do not move from one host to another. It is emphasized that the cloth bags should be clean and never re-used until after thorough washing and drying. Always tie the top of the bag tightly so that neither the mammal nor parasites can escape.

COLLECTING AND KILLING ECTOPARASITES

If the animal is killed by chloroform, the ectoparasites are immobilized, but in using the 'finger' method of killing mentioned above, all the ectoparasites are left alive when the host is killed. The host is then immediately rubbed thoroughly (preferably kept inside the bag) with ether or chloroform-soaked cotton to anaesthetize its ectoparasites. Parasites can be recovered by beating, shaking, and combing the host body, and examining the ears, nasal cavities, etc., and the bag (or other container). For fleas, hippoboscids, streblids, gamasoid mites and other agile ectoparasites, every preventive measure against escape should be taken. While pulling out ticks from the host skin, care has to be taken not to damage their mouth parts which are of great importance in systematic studies. Turpentine or other essential oils, or tincture of iodine, nicotine solutions, etc., may be applied, causing them to loosen their jaws within a few minutes. Alternatively, a small piece of host skin together with the attached ticks may be cut off and dropped into weak alcohol solution. The usual method is to hold fast the neck of the host and then slowly and gently pull the parasite out. The success of these and other methods depends on experience and patience. For biting and sucking lice one must thoroughly and carefully examine a host skin that is concealed by hairs or feathers. Colonies of ear and nasal mites are best left attached to the corpse and pieces of the body harbouring the mites are cut off and preserved in alcohol. Indeed, in all cases where there is a concentration of mites, a piece of the skin with the colony may be cut off and preserved. This not only saves time in the field, but also keeps the mites in perfect condition. All material thus collected may be put directly into 70 per cent alcohol to kill and preserve the anaesthetized or active parasites.

For nests and similar material, it is very important to identify the animal concerned. An unattended nest should be revisited when the owner is at home.

HOST MATERIAL

In collecting host material, it is important to have full knowledge of the local conservation situation—regulations, protected species, seasons or, if there are no regulations in force, knowledge of the present situation, for an avid collector might endanger a very rare species without realizing it. It is possible to collect most of the ectoparasites from a live mammal or bird and then release it. Material can also be removed from most nests for Berlese-funnelling and a similar material substituted, without upsetting the situation.

For precise identification of the host plant of an insect, the plant should be collected and treated as a full-pressed herbarium specimen. The specimen must be numbered and the appropriate number attached also to the insect specimens. Data bearing on the plants collected should be recorded. In areas which are little-studied botanically, several sheets should be made of each plant species, in case it should be new, rare or difficult to identify.

LABELLING

It is essential that all material collected should be adequately labelled. Incompletely or inaccurately labelled specimens are worthless or dangerous. Data should include country or island, district, general and precise locality, distance from nearest city if not a well-known place, altitude in metres, environment, niche or host, and in some cases the collecting method, date, the name of the collector. For certain groups, the complete host specimen with its data may be required. In regard to specimens taken on plants, it is very desirable to separate those that have been actually observed to be feeding on the plant from those merely found on the plant.

In museums in the tropics great care must be taken with all types of labels. They should be neatly written or printed in india ink or other permanent ink on 100 per cent rag paper, and special care should be taken to dry thoroughly all labels which are to be placed in fluids, before they are immersed. It is not safe to paste, tie or wrap labels around the outside of a jar or vial for they may become separated in transit or be eaten by pests. Furthermore, those exposed on jars, trays or boxes are subject to damage from silverfish, cockroaches or other pests, particularly after handling when perspiration has come into contact with them. And, even in the absence of pests, perspiration may cause the labels to fade.

In the tropics, trays for insect cases should be kept inside a vitrine with plenty of naphthalene and, if possible, the rooms should be air-conditioned. Vials must always be in outer jars containing fluid.

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Monuments

10

A. Problems in the preservation of monuments, by H. J. Plenderleith
B. Examples of problems encountered in the field, by Paul Coremans
C. Examples of the preservation of monuments in India, by T. R. Gairola

H. J. Plenderleith

A Problems in the preservation of monuments

INTRODUCTION

In the strict sense of the word a monument may be defined as a structure intended to commemorate something. It may or may not be a work of art. It may be of stone or other material and it may be set up indoors or in the open. Indoor monuments are dealt with in other chapters under their appropriate headings of stone, wood, etc. In the present chapter we take account only of the structure or monument exposed out of doors to all the rigours of a tropical environment, considering what steps can be taken to delay or prevent its deterioration and to ensure, as far as possible, its permanent preservation.

Evaluation

In evaluating cultural property, it is necessary to select and assort it, to list the authentic and interesting pieces and to arrange the material in some form of chronological order. Items may be widely spread geographically, but their location should be known and a permanent record maintained so that it will be possible to ensure their physical protection by law. Thus, by scholarly study, a select nucleus of *chefs d'œuvre* or 'type specimens' come to be recognized, scheduled and photographically documented. This is the first stage. The actual treatment that may be required to effect material preservation is the second and this, of course, may vary from none at all or merely surveillance, to complicated major operations of salvage and repair. The aim is thus in the first place to establish a nucleus—the cream of the collection—to protect it, if necessary, by legal means, and after this to take measures to ensure its material preservation.

Principles of treatment

The conservation of cultural property requires a knowledge of materials and structures and of how these are affected by the various environmental factors that individually, or in consort, tend to bring about their destruction. Chemistry and physics come into this, engineering and the study of architecture, and also a sympathetic appreciation of artistic and archaeological values. Such considerations form an essential background. But today it is seldom essential to invoke the pure sciences in the task of conserving cultural property. This has already been done very thoroughly and in large measure in the museum laboratories and by architects throughout the world and, as a result, a special new form of applied science has come into existence. Techniques have been perfected to cover most requirements and a very worthy profession has developed out of all this, securely based as a matter of course on science and offering the services of personnel trained in conservation and expert to a degree determined by their knowledge, skill and experience. Beyond this, the main characteristic of a professional restorer is his integrity, that is, his honesty of purpose in aiming to conserve all that is authentic without introducing materials or using processes that might in future lead to possible confusion with the genuine work of art or antiquity with which he is mainly concerned. This is as true of the major monuments that are our present concern as it is of paintings and museum objects.

New ground has been opened up by Unesco (Daifuku, 1963)[1] in extending conservation to meet the requirements of tropical countries, for conditions here are highly specialized and the issues complicated. Torrential rains may characterize the monsoon climates, a prodigious growth of vegetation may be typical elsewhere, monuments may become engulfed in ever-changing sand dunes or crushed by falling timbers or masonry. Yet the basic requirements for conservation remain unchallenged, though they may have to be adapted to meet these new and more extreme conditions.

The dangers of exposure

Monuments may be classified according to their degree of exposure to the elements; exposed monuments, sheltered monuments, and monuments protected in museums. And before we go on to the question of actual repair and restoration it is as well to remember that the exposed monument's most urgent need, as a first-aid measure, may be for protection, either by some form of natural screen or artificial shelter, or even by its transfer to a position of greater security. This principle is a fundamental one for all those concerned with preservation work.

Outdoor monuments may be simple and free-standing (steles, carved boulders, figures, columns) or built-up structures (lanterns, gateways, arches) or even complex buildings (pagodas, stupas, temples). But whatever their nature, the foundations are of the first importance and care should be taken to see that they are consolidated and protected as far as possible from the infiltration of water. Water is a major cause of damage, not only to the foundations, but to the superstructure as well. All stones suffer slow deterioration on continued exposure whether it be to capillary moisture from the ground or to occasional heavy rainstorms. Water dissolves soluble matter from stones and by collecting in cracks breaks them up. During thunderstorms the rain becomes acidified with nitric acid and this dissolves carbonates. The lower forms of plant life grow on broken-up rock, die in dry weather and then proliferate again, forming humus on which higher plants grow. Animals feed on plants and thus man himself may cause destruction by his thoughtlessness in allowing the spread of vegetation. The common factor in all these causes of deterioration, however, is the presence and action of water.

The exposed monument, then, must be protected as far as possible from damp. How can this be accomplished? It will be convenient to consider first what can be done to protect a pavement, then a typical complex such as a wall, and from this the procedure for dealing with more complex forms still may be deduced.

FOUNDATIONS AND PAVEMENTS

The first consideration in preserving a monument *in situ* in the tropics is to examine the foundations. Study the lie of the land, the subsurface geology, the line of drainage, and ensure that flood waters can easily leave the structure. If the monument is a building that is floored—if, indeed, it is simply a mosaic or tesselated pavement—tramping

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[1] See also, in *Museum*, Vol. III, No. 1, 1950, the full text of the Unesco monograph *Sites and Monuments* containing the recommendations of a Committee of Experts convened in Paris (October 1948) to consider problems relating to this subject.

over it will be sufficient to indicate the existence of any lacunae beneath. Cracks in the mosaic or floor should be investigated. Loose tesserae tell their own tale. The only cure in such cases may be to lift the mosaic and make good the foundation. If the basis is uncertain and settling seems likely, the ground should be rammed with broken stone and concrete before replacing the mosaic. The suggestion to reset such things in a clay mortar is ill counsel, for when the rains come this type of foundation will move and cracks will soon appear again in the pavement.

The process that is adopted for lifting a mosaic pavement may be here presented in outline:

1. Clean the surface of the mosaic to reveal the design by using a metal scratch-brush and, if necessary, a wallpaper scraper from which the sharp corners have been removed.
2. Areas of 2,000 to 3,000 cm^2 of pavement are generally enough to remove at one operation. Cut along straight lines suitably chosen in regard to the decoration and delimit a selected area by removing a line of tesserae and cut through the mortar below.
3. Attach jute hessian (open-weave) to the surface of the cleaned mosaic by a coating of strong hide glue, to which some flour may be added if it is likely that the mosaic may have to be rolled. It is best, however, to avoid rolling if possible.
4. Insert 60-cm long blades between the bedding mortar and the rammed stone foundation (not between the tesserae and the mortar!) and by levering sideways gradually work the required area loose.
5. Invert on a flat board so that the surface of the mosaic is encouraged to lie in one plane.
6. Clean the back and set in a strong lime sand mortar or, if the ground is liable to become damp, in Portland cement, 30 parts to 70 of sharp sand.

It should be noted that when the floor at ground level is paved or tiled over-all, or otherwise made impervious to moisture, damp will tend to rise in any boundary walls unless a breathing space is left in the floor where it meets the walls. This may take the form of a narrow strip trench rammed with aggregate and finished with a porous surface.

WALLS

Damp-proof course

Second only in importance to the security of the foundations is the waterproofing of walls. To do this it is often of great value to introduce a concealed damp-proof course near the base, using materials that will form a water barrier and so counteract the effects of the capillary action whereby porous materials conduct water up to higher levels. Suitable water-barrier materials that will serve well may be available locally. A bricklayer normally thinks of these in terms of slate, tar, pitch, bitumen or asphalt, or lead or copper sheeting set in Portland cement. But if the ground is salty and lead is used, it should be thoroughly coated on each side with shellac before being placed in position. And obviously, the surrounding earth must not be allowed to pile up against the walls above the level of the damp-proof course, or its effect will be vitiated.

Tops of walls, roofs and eaves

Waterproofing from above is equally important but it is useless to try to do this by covering, say, the top of a wall with cement mortar. This just cracks in time and peels off, leaving the joints further exposed. If some tiles are available and can be inserted unobtrusively or if the wall can be capped with a cement aggregate incorporating perhaps some carefully placed pieces of slate, the result is likely to be much more satisfactory. If a building is in question, arrangements should be made for its regular inspection to ensure that gutters and gullies and drains never become clogged. Care should be taken to remove leaves, the remains of bird or insect nests, etc., and attention should be paid particularly to joints between roofs and walls and to the condition of metal flashing and such-like.

Resistance to water of the wall itself

There remains the condition of the wall itself. Is the surface reasonably impervious and the mortar, if present, in sound condition? The latter may be susceptible to improvement by pointing (see p. 131) but one should remember that mortar should be left with the same degree of porosity as the stone itself, for if it is made much harder and less porous it is likely that the stone will be exposed to even greater wear. It is well, therefore, to be interested in the various formulae available for mortar and in the technique that allows one to remove and replace a stone or brick that has for any reason failed and become frail or emaciated.

Retaining walls

Where a massive wall is built to buttress higher ground, draining from this ground may tend to expose the inner face of the wall to much greater humidity than the external face and in such cases provision should be made, e.g., by the introduction of water channels or ventilation bricks, to prevent accumulation of water behind the wall.

Similar phenomena are common in excavation work where a town site is in question and in some cases it may be prudent to dig away the higher ground or at least to cut it down in such a manner that the levels on either side are not too discordant. This is a really important matter where there is much soluble salt in the soil because, if the precaution is not taken, the wall will become heavily coated with saline efflorescences that will greatly accelerate its destruction.

DAMAGE BY ACCUMULATIONS OF SOLUBLE SALTS

When present in quantity in the ground, soluble salts can do more damage to a monument than perhaps any other natural agency.

The salts arise from the decomposition of rocks such as feldspars and gypsum and may be accumulated locally as a result of the relative permeability of the soil, flooding or perhaps the heavy irrigation needed for rice growing in the vicinity. In any case the result will be gradually to raise the water-table and bring the salts to the foundations of the monument after which, by capillarity, they will get into the structure itself.

The capillary fringe at the base of a monument so affected is not difficult to distinguish, the surface being emaciated and probably discoloured and the stone soft and powdery, ready to flake away at a touch. Where there is a high diurnal change in relative humidity, hygroscopic salts are lifted much higher than the capillary fringe and the constant movements and recrystallizations work havoc with porous stone and bricks. A classical example is to be found at Mohenjo Daro in Pakistan where the salts actually saturate the bricks some 13 metres above the capillary fringe and poorly fired specimens of brick have lost all cohesion so that sometimes they remain merely as patterns in the dust. The over-burnt (darker coloured) bricks are more permanent.

Suggested procedures for desalinization

If the monument is in such a condition that its conservation is still worth-while or economically possible, the following procedures will require consideration:

1. Taking all measures possible to lower the water-table, e.g., by introducing tube wells, shallow drains or land drains (as used by farmers). This involves

making a careful survey of soil permeability in order to discover the most effective drainage areas. Rice-growing should be prohibited in the vicinity of the monument. On the other hand, depending on the nature of the soil, fruit cropping may be permitted as it promotes drainage.

2. Washing out the salts by a carefully prepared programme of spraying, using a fine mist of fresh water, the wash waters being conveyed to drainage areas away from the site.

The success of such operations will naturally depend on many factors and not least on a thorough pre-investigation and assessment of the problem; for this purpose air-photographs can be invaluable as indicating, *inter alia*, the main trends of drainage.

Precautions to be observed

Where expert advice is not available, practical steps can still be taken to alleviate the damage by regularly sweeping away saline deposits from the foundations so that the diurnal cycle of solution and crystallization is broken, or by capping the walls with mud bricks. In the latter case the mud is washed down the wall by rain and although this mud may be rather unsightly, the soluble salts crystallize in the mud and to this extent the underlying bricks are protected from the recurrent forces that cause their disintegration. Nevertheless, this in itself is not sufficient and must be followed by a regular routine of sweeping the ground clear of salt-impregnated mud.

All extraneous causes of damage should, as far as possible, be eliminated and in this connexion it may be noted that in early excavation work spoil-heaps may have been left too near the main area of interest. These may contain much salt and should be gradually removed to a safe distance where the soluble salts can be drained away without danger to the structures which it is desired to protect.

VALUE OF EXTERNAL SCREENING

External screening may take a number of forms, depending on the site, the conformation of the ground, the nature of the monument and, above all, on the direction of the prevailing storms. A row of trees may suffice set at an angle and at such a distance as to obviate the possibility of the monument being undermined by root growths. If gardens surround the monument, a pergola for climbing plants may be designed to act as a screen, but this is not without danger for, unless it is kept within bounds, the creepers may extend their territory to the monument itself and considerable damage may then result from the action of suckers, tendrils or root-like excrescences penetrating the weakest parts. Finally, and again depending on the monument, it is sometimes possible to set in a course of tiles near the top so that dripping rain will fall clear of the wall, or to extend the eaves so that they will afford greater protection.

Successful attempts at overhead screening have been carried out in the field, particularly to shelter large areas of fine mosaic. These have taken the form of a skeleton structure carrying a light tiled or plastics roof or a cloister-like enclave covered with transparent synthetic material, such as green-tinted corrugated perspex reinforced with glass fibre. As a more temporary measure, polythene sheeting may be used; if exposure to bright sunshine is inevitable, the black opaque variety of plastics is to be preferred. Good examples of the application of various forms of shelter are to be seen at Constanza in Romania, at Piazza Armerina in Sicily and in the Roman forum. When a monumental slab has fallen or has been discovered in the undergrowth, care must be taken to set it up at such an angle that rain-water will be readily drained from the decorated surface.

CONSOLIDATION

The security of the monument is a prime consideration and to effect this it may be necessary to arrange for temporary buttresses of baulk timber, light railway lines, etc., to scaffold the structure in order to give local parts essential support. The inspector will always be on the look-out for the appearance of new cracks and if doubt exists as to the movement of the structure, information can be supplied by applying plaster 'tell-tales' across the joints or cracks and observing them over a period of time. Increased cracking in the plaster may be taken as a sign that settling is taking place. For permanent reinforcement tie-bolts or steel splinting or both may be required. If so these appendages should be as inconspicuous as possible. The splinting should be hidden within the structure and the metal preferably buried in waterproof cement.

It should be noted that if not applied properly, the long-term effect of using ferrous metal may be precisely the reverse of that desired, because when the irons are left exposed to rain and salt action, they become black, rusting ensues, staining results and in such circumstances considerable expansion in volume takes place as the iron oxidizes and this often causes the stone to burst asunder. It is therefore very desirable to introduce some form of waterproofing when iron or rolled-steel joists are used in exposed masonry. Bronze and brass also require protection as their corrosion products can cause serious staining. Stainless-steel dowelling is free from these objections and is to be preferred where sculpture is concerned.

Reinforcement may be given to a structure by replacing deteriorated members—odd stones in walls, the occasional faulty brick—or even by cutting out bad areas and making good with sound material.

Where any repair or reconstruction of an extensive nature is made, care should be taken, as a general principle, not to attempt to reproduce the old surface exactly in new materials. Let the finish be in keeping with the old, unobtrusive but sufficiently varied in colour and preferably in texture to be discernible as a repair, and where a group of structures is concerned let there be a standard convention in this matter applicable to the whole group. Naturally, such work will be accompanied by detailed documentation which, in community groups, may conveniently be preserved in an adjacent antiquarium.

ANASTYLOSIS

Definition

In cases where a monument has disintegrated in such a manner that substantial fragments survive, it may be possible by measurement and detailed study to recover the form and establish its dimensions with exactitude; in which case reconstruction can be contemplated. The rebuilding of a fragmented monument from its elements is known as anastylosis.

The contribution of anastylosis to the conservation of monuments is fundamental and it involves very important considerations. There may be every reason, for example, to reconstruct a composite column when the drums are found lying on the ground in disorder. It may even be justifiable to remake part of the shaft when the height is known with certainty and the capital or entablature can be reset in its correct relation to the structure as a whole, but in this event the new must be discernible from the old. Clearly it would be as wrong to create a facsimile column with a view to its being taken to be genuine as it would be to attempt to re-erect a building without information regarding the ground plans. Such 'restorations', though entirely outmoded, can still be seen today. We need, therefore, have no compunction in emphasizing once again that the key word to all good modern restoration is 'integrity', and this signifies that in appraising the success of a restoration there should never be any doubt, at least to the discerning eye, as to what is authentic and what is to be taken as a justifiable expedient essential for the realization of the anastylosis.

Justification

A daring anastylosis from small fragments may be considered to be justified under the following circumstances:

1. When irrefutable evidence can be adduced as to the original plans and decoration of the monument and its site. This means, incidentally, that it is known exactly where each residual fragment fits in the reconstruction.
2. When the anastylosis is acceptable as part of the landscape. A monument may fit perfectly into the landscape when seen from a distance of 200 metres, but in the interest of accuracy, when viewed from 50 metres it should be clearly apparent that it is largely a modern reproduction of lost elements.
3. When, in a position reasonably near at hand for consultation, there is a centre of documentation providing the means of verifying what is authentic and ancient and checking what has been added to take the place of missing parts.

Distinguishing new parts from the original

When a wall is remade, it may be desirable to work to a horizontal line for the sake of waterproofing, applying a coping, etc. In this case materials or textures will be used in such a manner as to indicate new work; this is probably to be preferred to the incorporation of a line of white stones to mark the boundary between new and old as is sometimes done. The latter expedient has been advocated by the purists but, in practice, the white line effect tends to be irritating and unnecessarily fussy.

New work can be sympathetically differentiated in a number of ways. The great blocks of white marble or travertine originally incorporated in arches and still often surviving at the base, may be simulated in the reconstruction by conglomerate masses of strata made up of marble or travertine slabs taking the over-all shape of the missing blocks.

Bricks may be made in similar sizes to the old but of a slightly different colour; tiles may be dealt with likewise, or they may have their exposed edges chipped to give a sense of maturity in conformity with the old, yet sufficiently differentiated from it.

Large lacunae in a coloured marble veneer may reasonably be made good to the original level surface by packing with a cement of mottled texture and non-uniform colour, and when it is desired to restore ruined walls, the rebuilding may include modern bricks set askew to introduce a difference in texture. But it should be emphasized that the unpardonable error in all restoration work is to attempt to go too far.

A great deal could be said, also, about the use and abuse of mortar, but it may suffice to remark that in new building it should be of the same thickness as the old, and if some old crushed brick powder or chips can be incorporated the colours will be more likely to be in harmony. Lastly, new mortar should never be left, a staringly obtrusive white, protruding from the bricks. This is the height of vulgarity, for mortar is the subsidiary element in the wall and should remain as such. It should be finished to just below the surface level and thus the old structure will be preserved. If the pointing has been crudely done, the old stones will have less chance of draining and in the presence of excess water decay will be intensified.

Circumstances must sometimes be allowed to determine the issue as when an older monument (carved stone) is found to be an integral part of a more recent structure. Before any decision is made to interfere with the structure and recover the old stone, the implications must be carefully weighed from every angle as irreparable damage can easily be caused by precipitate action. This kind of problem is presented when successive civilizations have built over ancient monumental sites and in such cases there is always an interesting field for discussion as to what should be the most desirable procedure in restoring the site as the integral setting for the monument. The fact must be accepted, regretfully, that great and important monuments exist, especially in the tropical zones, that are so decayed as to be apparently irrecoverable. Shapeless mounds in the rain forests of Mexico are often all that now mark what were once a series of pyramids and temples. Yet if these can never be recovered, at least they may be made to yield important information as to structure and contents by the modern methods of archaeological excavation.

MORTARS

Lime/sand mortars

All sorts of plastic materials have been used as mortars for bedding and jointing stones —mud, clay, lime mixed with water and sand, gypsum plasters and cements—but the most satisfactory are those in the lime/sand category. The quality of the lime is often the determining factor as regards the properties of the mortar. Lime burned from a pure limestone and well slaked (hydrated) constitutes the standard product. If the limestone contains magnesium (dolomite), the burnt product is unsatisfactory because magnesium oxide requires a long time for efficient slaking. A clay limestone on burning yields a kind of lime that eventually gives rise to mortar that has hydraulic properties—it may even set under water, which is of no little significance in countries having a heavy rainfall. Indeed some authorities advocate using nothing but hydraulic mortars for preservation work in public buildings.

In the raw state, ordinary mortar is a wet plastic mixture of slaked lime and sand undergoing chemical action. It is used to fill the joints between stones where it eventually sets, the lime combining with carbon dioxide in the atmosphere to form calcium carbonate and with sand to form calcium silicates.

The repair and replacement of decayed mortar by the addition of fresh material is known as 'pointing'. This is done in four stages: (a) scraping out the old mortar joint to a depth of 1 cm or so; (b) brushing the freshly exposed surface vigorously to remove dust; (c) wetting the residual mortar thoroughly with a brush; and (d) pressing the fresh mortar firmly into the joint space, taking care that the material is so under control that it does not run down the front and stain the surface. The aspect of the pointing should be uniform throughout.

It is rather important to choose a specially soft mortar for soft stones while a good standard mix can be used for all others. Two well-tried recipes are, therefore, given below, one for standard and the other for soft stones.

Standard lime/sand mortar for normal pointing. The following recipe yields a mortar that is hard and resistant though somewhat crumbly to apply. Mix 6 parts of clean washed sharp gritty sand with 1 part of slaked hydraulic lime and let stand till ready for use. When required take 6 parts of the above, well-mixed, add one half part of Portland cement and mix up thoroughly again with the minimum of water. Use immediately and reject after 3 hours. The colour, strength and texture depends on the sand.

Special lime/sand mortar for soft stone or brickwork. Mix 3 parts of clean sand, washed and gritty as above, with 1 part of slaked hydraulic lime and use immediately.

Replacing damaged brick or stone

Mortar is used in the common operation of replacing a damaged brick or stone. This is carried out as follows. Cut away the faulty member, clean out the hole, remove all dust and wet the fabric all around using a brush. Choose the new brick or stone which should fit easily into the hole, leaving plenty of room for mortar behind and around it. Remove and trim the brick or stone with hammer and chisel until it becomes somewhat wedge-shaped and then, after spreading all the joint faces with mortar, replace it and drive it well home with a hammer, using a wooden stake as intermediary to spread the forces and soften the blows. Cut away the excess mortar as it oozes out and before it hardens to prevent staining, but latterly press the semi-stiffened mortar back to consolidate the joint. Stone-work is treated similarly.

PORTLAND CEMENT AND CONCRETE

Portland cement is for the most part a mixture in the same category of materials as hydraulic mortar, but it is much harder and stronger and is manufactured by calcining standard quantities of calcareous and clayey materials at very high temperature. While it is too recalcitrant for use alone as a mortar—it sets too quickly—it can be a valuable ingredient of a mortar recipe.

In commerce it is available in waterproof bags in powder form. The cement must be kept dry till required for use. It is then mixed with sharp sand in the ratio of 1 part to 3 or more and sufficient water is incorporated to form a uniform, stiff paste. This sets by chemical action in a short time, forming eventually a mass of rock-like consistency. If free from iron, the product is pure white; generally, however, it is slightly coloured, depending on the quality of the sand as well as the cement. Hydraulic properties are conferred by adding lime.

When a graded aggregate of gravel, clinker or crushed stones is incorporated, the material is known as concrete, a typical formula for concrete being: cement, 1 part; sand, 2 parts; aggregate, 4 parts. Concrete is able to withstand great compressive stresses and it therefore forms the ideal material for consolidating foundations, underpinning, etc. Where, in addition, tensile strength is required, the concrete may be reinforced by steel rods. Building components that are transportable and very strong may be pre-cast in reinforced concrete. A modern development is to maintain the steel rods under stress until the cement has hardened, thus producing what is known as prestressed concrete, vitually a new type of building material with great possibilities for the architect.

Ferroconcrete is the material, *par excellence*, for consolidating tottering buildings. Employed with cement grout and the rolled steel joist (RSJ), it offers the architect-restorationist the means of saving structures that would collapse in the absence of artificial buttressing. In general practice such artificial reinforcement is employed to carry the weight of the structure so that the old stones can last longer. As far as possible, it is concealed from view so that the monument will preserve its true character.

ORGANIC GROWTHS

The simplest forms of organic growth occurring on stone and visible to the naked eye are usually coloured green, russet or grey and are in the category of bryophyta (algae, moss, lichens), but at certain periods of the year and in the case of certain stones, such growths may be little more than a disfiguring black stain. It is then that they may be most economically removed by brushing the stone with a 2 per cent aqueous solution of zinc silicofluoride. Alternatively, solutions of 1 to 0.5 per cent strength of either zinc or magnesium chloride may be used for this purpose. [1]

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[1] See also the discussion on pp. 44 and 51.

It must be admitted that there are cases where little or no damage seems to result from the proliferation of such growths, others in which the deterioration is more in superficial appearance than of fundamental character, but in the case of porous sandstones and limestones it is quite safe to assume that all kinds of organic growth are detrimental, however attractive they may appear to be.

SALVAGE AND TRANSPORT

No general statement on the care of monuments in the tropics would be complete without reference to the mechanics of rescue operations, such as, for example, the salvage of a heavy stone that is submerged amidst tangled undergrowth.

It may be no solution merely to clear the forest because the foundations of the monument will certainly have been invaded by root formations and in any case the tropical vegetation will soon regain its mastery. When it is decided to remove a monument into a sheltered position, equipment must be assembled to drag the specimen to safety and it may also be necessary to place it in some form of crate for convenience in handling.

A most interesting practical account of such operations has been published by Willcox (1954), who, working at Caracol (British Honduras), successfully dealt with carved Mayan steles and altars up to a weight of 20 tons net and delivered them safely to the Philadelphia Museum without mishap. He describes equipment that reminds one of that used in the old 'windjammer' sailing days: block and tackle, jacks and makeshift skids made from greased wooden rails, chain hoists and an obviously potent instrument called a 'lug all' of 1.5 - ton lifting capacity that can be carried in one hand. It is described as a wire-rope operated by a lever and ratchet. The crates were made by first jacking the heavy stone on to four wooden blocks, then encasing it in what he describes as a 'pressure crate' made from felt-padded baulk timbers forming two floors and bolted together across the stone with 0.5-inch (12 mm) threaded iron rods, so that no matter which side was turned upwards, the stones were firmly braced and could not move. These crates could then be slid out on greased wooden runners, the final touch being to lift them on to a heavy transport wagon, using a borrowed bull-dozer improvised to act as a crane: a truck axle (as boom) was substituted for the blade and a heavy chain provided a means of attachment.

In cases where manpower is no problem and experienced bearers are available under a trained leader, great monoliths can be handled with a series of loose rope slings, the bearers being spread out evenly on each side of the monolith and working as a team. Setting the object up in the vertical position need be no problem if it is carried out according to the well-known ancient techniques making full use of the inclined plane and exploiting the force of gravity.

THE MUSEUM AND THE ANTIQUARIUM

Rescue operations of this kind involving the salvage of monuments require also the preparation of a reception area which is normally chosen to afford a reasonable measure of shelter. If a monument can be brought indoors its protection is doubly ensured. A museum has the advantage that related types of exhibit can be readily compared, but under such conditions what has been called the monumental value of the object is generally lost. This disadvantage can sometimes be overcome to some extent by establishing an informal site-museum or antiquarium.

Excellent examples of antiquaria are to be seen in most countries where archaeology and conservation are taken seriously, and, be it stated, the most successful are by no means necessarily the most imposing. A garden can be used with great advantage as a background for those lesser monuments which, while being unsuitable for a site indoors, need to have screened protection; and the value of such structures as cloisters and loggias and even of farmsteadings in this connexion will be obvious.

MAJOR PROBLEMS CONCERNING TROPICAL MONUMENTS

The action by which rocks are decomposed by weathering to form soils (sand, clay, loam) is well understood but in tropical areas the decomposition (e.g., of granites and basalts in India) is intensified by the action of heat and heavy rains and a particular type of weathering takes place, resulting in the material called laterite, from its red-brown colour resembling brick. In the course of laterite formation the silica content of the parent stone is largely washed away and the residual hydrated oxides of iron and aluminium remain. These oxides may actually compose 90-100 per cent of the laterite, when the substance is dense and solid, or correspondingly less when clays are present. Certain periods of dryness seem to be essential to laterite formation. Clay, not laterite, is found beneath rain-forests and jungle vegetation. Lateritic decomposition poses a very serious problem for the conservator and is unfortunately to be observed in some of our finest tropical monuments.

It is not easy to lay down ways and means for preserving great monumental structures exposed to severe conditions of weathering. Such work is, primarily, a task for the architect, but in the tropics and where laterite is in question there can be no easy solution, whatever facilities may be available. The two sections which conclude this chapter give an outline of the conservation problems of a number of important monuments in South Asia, the Middle East and Latin America, and in India (Fig. 43).

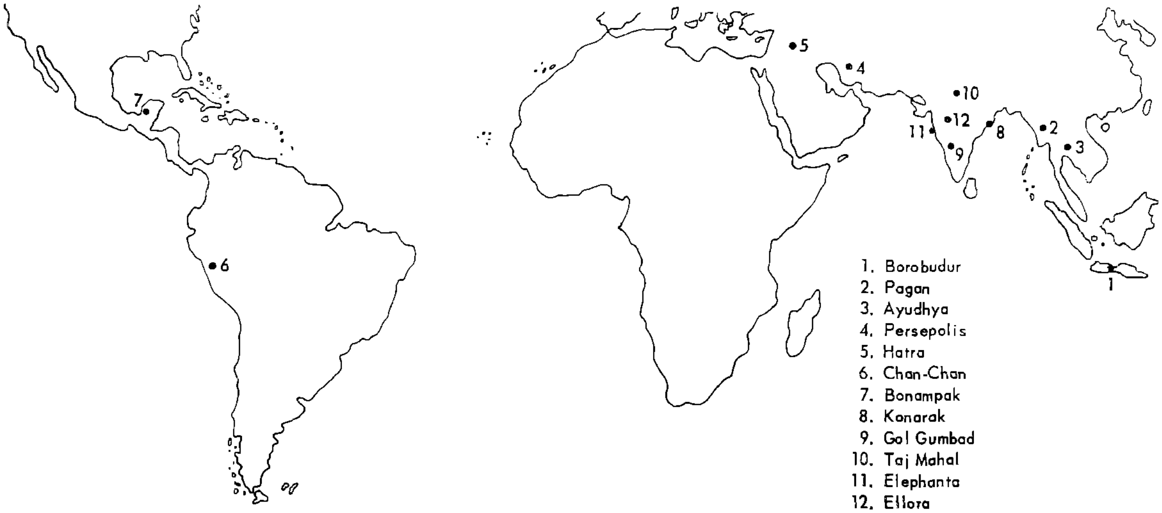

Fig. 43

Sketch map locating important monuments in the tropical zone discussed in the text.

Paul Coremans

Examples of problems encountered in the field

B

The following data concerning seven important monuments in or near the tropics, based upon observations made in the course of field studies, were contributed by the late Dr. Paul Coremans.

INDONESIA: THE BOROBUDUR SANCTUARY

Site. Buddhist sanctuary (*circa* ninth century A.D.) about 40 km north-west of Jogjakarta, Java (Indonesia). Abandoned at the beginning of the sixteenth century and soon completely covered by earth and vegetation. Gradually uncovered by the nineteenth century and restored (anastylosis), 1907-11. Unesco mission in 1956: active degradation was detected. Training of an Indonesian technician in Brussels, 1957-59. Present condition of sanctuary unknown.

Conditions. Wet Equatorial climate (Koeppe): mean annual temperature 25.5° C; relative humidity 80 per cent; mean annual rainfall 1,525 mm; extremes of temperature measured in 1956 on surface of stone from 25° to 45° C in four hours.

Material structures. Andesite, a darkish, rather soft and porous volcanic stone; originally plastered.

Degradation. Mechanical decay of stone by alternate heating (sun) and cooling (rain-water); extensive chemical and biological degradation of stone by rain-water and cryptogamic growth, with ultimate formation of limonite, kaolin and silica.

Protective measures. Simple measures such as repair of joints between stones and quick disposal of rain-water (gutters, etc.); spraying with suitable herbicide instead of mechanical removal of cryptogamic growth. Original plaster layer (sand and lime) covering whole of sanctuary is now lost: it was, no doubt, while it lasted, an excellent protection for the stone against rain and sun and prevented cryptogamic growth.

BURMA: THE PAGAN SITE

Site. Pagan, the former capital of Burma, about 400 km north of Rangoon, is the most important ancient site in Burma. The ruins of Pagan cover an area of about 40 km^2 with monuments (mainly Buddhist pagodas) essentially from the eleventh to the thirteenth centuries A.D. After the fall of the Pagan dynasty thousands of buildings were mutilated and left to decay until the beginning of the twentieth century and are now mostly in ruins; 800 to 1,000 have been inventoried, but only about fifty of them are under the care of the Archaeological Survey of Burma. Thousands of square metres of old mural paintings of great artistic value and very important for Buddhist epigraphy and iconography. Unesco mission in 1961. Training of an archaeologist and of an archaeological chemist in Brussels in 1962-63 and 1963-64.

Conditions. Wet and Dry Equatorial climate (Koeppe): temperature 21°-40.5°C; relative humidity 25-80 per cent; mean annual rainfall 760 mm.

Material structure. Mainly brick structures originally covered by plaster.

Degradation. Many decayed buildings. High temperature and heavy rains in monsoon period are largely responsible for the systematic destruction of the tempera mural paintings inside where there is condensation and cryptogamic growth during the wet season. Some religious buildings, still used, are in better condition.

Protective measures. The preservation of Pagan will only be possible when the Archaeological Survey has the means to cope, first, with the structural problems of the ancient buildings, and then with the preservation of the mural paintings within them. Protection against rain and heat by plastering the outside of buildings has been recommended.

THAILAND: THE AYUDHYA SITE

Site. Ayudhya, some 80 km to the north of Bangkok, is the former capital of Thailand (fourteenth century to 1767) and perhaps the country's most important ancient site. Most buildings are in ruins, only a very few being in an acceptable condition; recent attempts at restoration by the Ministry of Works. The most ancient mural paintings have been lost. Unesco mission in 1961. Training of a Thai technician in Brussels in 1962-64.

Conditions. Trade Wind Littoral climate (Koeppe): mean annual temperature 28.5°C; relative humidity 80 per cent; mean annual rainfall 1,400 mm.

Material structure. Mainly bricks, originally plastered.

Degradation. Wats and other ancient buildings abandoned for too long a time and exposed to unfavourable climatic conditions: considerable structural damage mainly by heat, rain and cryptogamic growth, and capillary action.

Protective measures. No hope of real preservation work at Ayudhya and other sites unless a specialized technical division is set up within the Department of Fine Arts. An engineering section (structural problems and restoration of buildings) and a technical laboratory are urgently needed.

IRAN: PERSEPOLIS

Site. On the plateau, some 80 km north-east of Shiraz. The most important ancient site in Iran: Achaemenian capital founded about 500 B.C. and destroyed in 330 B.C. Excavations started in 1931. Beautiful and extensive architectural and sculptural remains. Unesco mission in 1960.

Conditions. Semi-arid Continental climate: mean monthly temperatures 5°-30°C; mean relative humidities 15-55 per cent; mean annual rainfall 450 mm; range of temperature measured on stone in six hours: 2°-34°C.

Material structure. Mainly schistoid, fine granular limestone.

Degradation. In 1960, thirty-nine years after the first excavations, the uncovered sculptures had lost much of the sharper details, mainly through erosion (sandstorms) and wide variations of temperature; exfoliation of the limestone.

Protective measures. Conservation and restoration interesting but difficult work: general consolidation (joints) and repair; overhead and side screening especially for sculptures and fine reliefs; irreplaceable works of art housed in the local museum.

IRAQ: THE HATRA SITE

Site. Monumental ruins in the middle of the desert at some 60 km as the crow flies to the south-west of Mosul: unique example of Parthian art (full development during the second century A.D.) with Mesopotamian and Greek influence. Most important ancient site in Iraq. Unesco mission in 1960. Restorer trained in Brussels, 1961.

Conditions. Semi-arid Continental climate: annual ranges of temperature below freezing point to above 50°C; wide annual variations of relative humidity; annual precipitation of some 400 mm, half of it during the full winter season.

Material structure. Sandy limestone or pure limestone, originally plastered.

Degradation. Main degradation by large variations of temperature, frost and earthquakes (the last two: late nineteenth century and 1945).

Protection measures. Basic engineering work to check condition of substructures and walls must precede restoration proper. Work started in 1963 with assistance from a private foundation.

PERU: THE CHAN-CHAN SITE

Site. Important archaeological ruins of the former capital of the Chimu Kingdom (*circa* A.D. 1300-1440) covering many square kilometres; in the neighbourhood of Trujillo, on the Pacific coast, some 560 kilometres north of Lima. Chan-Chan is composed of ten units, some as large as 350 × 450 metres, each surrounded by high walls and with systematic divisions including streets, houses, pyramids, cemeteries and reservoirs. Unesco mission, 1964.

Conditions. Hot and Dry climate; mean annual temperature about 21°C; humidity is always high; mean annual precipitation of 50 mm or a little more: heavy showers very rare; persistent mist in winter-time.

Material structure. Adobe, a sun-dried clay used for the structures themselves and their decoration; originally plastered.

Degradation. Mainly mechanical decay caused by heat.

Protective measures. The establishment of a national laboratory and a national historical monuments service is considered essential: preservation of monuments and sites is a matter for organization at national level.

MEXICO: THE BONAMPAK SITE AND MURALS

Site. Bonampak is in the State of Chiapas, the south-east part of Mexico, in the middle of the tropical forest near the Guatemalan border. Important Maya religious centre with one temple decorated with mural paintings dating from the seventh century A.D. Site abandoned some ten centuries ago and rediscovered in 1946. Under the care of the Instituto Nacional de Antropología e Historia. Unesco missions in 1961, 1962 and 1964 for the safeguarding of the murals.

Conditions. Wet and Dry Tropical climate (Koeppe): mean annual temperature around 25°C, and relative humidity 80 per cent or more; annual precipitation possibly as much as 2,500 mm.

Material structure. Temple of limestone originally plastered; murals painted on a ground of lime burnt from local limestone; pigments earth colours, carbon black and Maya blue; painting technique not yet defined.

Degradation. Considerable damage to temples and murals through rain-water, migration of salts and efflorescences (mainly magnesium carbonate and some calcium carbonate). Cryptogamic growths are endangering the mural paintings.

Protective measures. Repairs made to vault and walls and corrugated iron screen erected to give protection against rainwater. Proposal to make this unique monument into an air-conditioned local museum is under consideration.

It is instructive to note that, in such widely dispersed monuments as those described above, with what at first sight seem to be insoluble problems of preservation, common factors of deterioration can be discerned and that these factors lend themselves to control by simple protective measures concerned, generally, with screening, consolidation and the improvement of drainage.

T. R. Gairola

Examples of the preservation of monuments in India[1]

C

INTRODUCTION

The monuments in India are situated between latitudes 8° and 35° N. and longitudes 68° and 97° E., a vast area including humid sea coasts, the high Himalayan altitudes and the dry regions in the interior of the country. Not only do temperatures fluctuate greatly in these places, but differences in humidity are also wide. Within this extensive area are found a variety of climatic conditions, but the dominant feature is the tropical monsoon.

The monuments comprise prehistoric burial sites, early stupas, temples, mosques, forts, rock carvings and sculptures and the various forms and figures which adorn them. The stone in use is mostly sandstone, granite, quartzite, marble, limestone and its local varieties, and basalt. Under tropical conditions of temperature, rainfall and varying high and low humidities, alterations in the composition of the original material take place at an accelerated rate.

CAUSES OF DECAY

The agencies that cause deterioration of monuments in this region are: (a) lichens, algae and fungi; (b) higher vegetation; (c) sea salts carried by winds in coastal areas; (d) salinity absorbed by the structure through capillary action from the soil; (e) leaching-out of the soluble ingredients of the stone by rain-water; (f) attrition caused by winds carrying sand and dust; and (g) foreign accretions of various kinds of greasy matter, soot, smoke, paint and the excreta of animals and birds. These agencies, singly or in combination, bring about the deterioration of the structure, depending on location and environmental factors. The damage sometimes becomes so alarming that it causes or threatens to cause the destruction or obliteration of vital parts of a monument and some kind of chemical preservation and architectural restoration work becomes necessary.

In coastal areas where there is heavy rainfall and the atmosphere is charged with sea salts, the monuments suffer mostly from: (a) organic growths of various kinds which, if overlooked, may cover the entire structure and even send roots deep into foundations; (b) absorption of sea salts by monuments; and (c) leaching by rain-water and consequent weakening. In the mountainous areas and regions of heavy rainfall, the monuments suffer from factors (a) and (c) above. In dry places, sand and dust-laden winds produce abrasive effects on building materials. Other factors which contribute

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[1] In a rather special category come the great monuments of tropical India, exposed to the monsoons and widely scattered and varied in character. These are the subject of systematic study by the Department of Archaeology (Dehra Dun) and by the laboratory of the National Museum (New Delhi).

Specific reference is made to a few of the major structures in this subcontinent and to the rather unique monuments exemplified by the Elephanta and Ellora Caves—H. J. P.

to disfigurement and sometimes to decay are stains of various kinds, deposits, destruction by animals and even, unfortunately, at times, by man. Faulty drainage is a frequent source of deterioration as then the structure remains wet and capillary action takes its toll.

The monuments of India are exposed in the open and generally remote and their treatment is often fraught with difficulty, but the methods are fairly standard and may be briefly described.

METHODS OF TREATMENT

Eradicating lichens, algae and mosses. The treatment for the eradication of these growths consists in swabbing the affected surface with dilute (3-5 per cent) ammonia solution and gently brushing. The cleaned surface is then treated with 1-2 per cent aqueous zinc-silico-fluoride solution. This fungicidal treatment is repeated after an interval of about a week. Finally the porous surface is coated with a protective coating of vinyl acetate or methyl-methacrylate *(Plate 12)*. When plants and trees are found growing on the monuments *(Plate 11)* deep roots are cut off and the stumps injected with sodium arsenite solution or sulphuric acid by means of a syringe.

Removal of salts brought by sea winds and deposited on monuments in coastal regions can be effected either by prolonged washing with fresh water or by repeated applications of moist paper-pulp, allowing time for drying between each application. The porous surface left after the removal of salts is consolidated with solutions of either vinyl acetate or methyl-methacrylate.

Protection against leaching by rain-water can be provided only by screening, for example, by providing overhead shelters, but these are considered objectionable from the aesthetic point of view. In such monuments movable sculptures are often better taken indoors. Surface coating is not very effective protection. Even a paraffin wax coating does not give satisfactory results in hot and humid climates.

Checking alkalinity. The rising alkalinity in monuments can be retarded by using damp-proof courses round the foundations of walls.

Removal of surface deposits. Extraneous accretions are removed by organic solvents if they consist of greasy matter, paint or smoke deposits, otherwise by such detergents as will not damage the material of which the monuments are composed.

Portland cement grouting. Gaps in the structure are filled by a cement grouting, i.e., Portland cement mixed to a creamy consistency.

Stabilization. Monuments rendered unstable by decay are given support by making replacement restorations, which not only reinforces the weakened structures but also restores their aesthetic appeal.

Screening. Protection against sea erosion and sea salts can sometimes be provided by planting trees in strategic positions, sometimes by erecting a screen of concrete blocks, and usually by washing the monuments periodically with water, though this is not always practicable.

CHARACTERISTIC EXAMPLES OF INDIAN MONUMENTS

The Sun Temple at Konarak

Site. The temple is situated in Orissa State (19° 8′ N. and 85° 8′ E.), a little over a kilometre from the sea-shore. It was constructed some time between A.D. 1238 and 1264 by King Narasimha Deva I and was dedicated to the Sun-God. It resembles the famous Jagannath Temple of Puri with a high Jagmohan (congregation hall) and

Viman (sanctum). This Konarak temple not only marks the culmination of the Kalinga style in architecture and sculpture, but is a high point in the history of Indian art, being characterized by an exuberance of carving throughout *(Plate 13a)*.

Material structure. The temple is built of a highly ferruginous khondalite stone, which is a garneti-ferrous sillimanite schist. The khondalite is not particularly durable. It weathers into a sandy rock having characteristically red and brown streaks and patches in a buff ground mass. The sculptures have become considerably eroded and alkalis have been leached out, rendering the surface irregular. The deities and the door posts and windows are carved out of chlorite schist. The beautiful greenish colour imparted by ferrous iron is getting patchy with reddish stains here and there due to the oxidation of ferrous into ferric iron. Being near the sea, soluble salts are carried by the winds and deposited on the stone. At one time the temple was filled with sand and heavy coastal rains penetrated the structure. Accumulated water seeped out slowly through the carved figures and there were parts of the interior which remained covered with moss and lichen throughout the year. The original iron dowels and cramps used to hold the huge stone blocks together rusted and were no longer able to carry the weight.

Protective measures. For conservation, the platform of the temple was grouted with liquid cement mixed with sand and an inert waterproofing material called 'ironite', obtained locally, applied through hundreds of holes drilled for the purpose. Terracing at the top of the Viman was re-done in places with a fresh lime-concrete mixed with cement and ironite. Rusted iron cramps were replaced by copper ones. Moss and lichen were removed with an aqueous solution of ammonia followed by two applications of 1-2 per cent zinc silicofluoride solution. Salts that had accumulated on the surface from sea winds were removed by repeated applications of paper pulp. The effect of leaching out the soluble ingredients of the stone by rain-water and the attrition effect can be seen from *(Plate 13b)*. The porous surface was coated twice with 5 per cent vinyl acetate solution. Extensive plantations of cashew-nut and casuarina trees have been put in around the temple to screen the monument and shield it from attrition by sand. Steps were taken to prevent the accumulation of stagnant water in the foundations and elsewhere by studying the slopes and reversing these where necessary.

The Gol Gumbad in Bijapur

The site. Bijapur (17° N., 75° 8′ E.) is in Maharashtra State. The Gol Gumbad is the Tomb of Adil Shah, a contemporary of the Mughal Emperor Shah Jahan and was constructed between the years 1627 and 1656. This great mausoleum has the biggest dome roof in the world and its height from the base of the building is 60.5 metres. The outside diameter of the dome is 44 metres and the inside is 37.9 metres. It is thus about 3 metres thick. The dome rests on a structure consisting of a square hall enclosed by four lofty walls and buttressed by octagonal towers at the four corners. At the base of the dome inside is a gallery 3.35 metres wide which projects into the interior of the building 33.37 metres above the floor and is called the whispering gallery. The dome has excellent acoustic properties.

Material structure. The monument, about 300 years old, began to show signs of deterioration. Salt-infected plaster started falling off. The iron dowels had become rusty and the mortar, which bound the bricks forming the core of the dome, had become weakened. Cracks developed in the plaster which became uneven and this resulted in weakening of the structure and, incidentally, in deterioration of the acoustic properties.

Protective measures. In 1937 the exterior of the dome was rendered watertight by a thin shell of a special cement called Gunite 6.5 cm thick, after grouting the cracks. The Gunite mixture was composed of 1 part of Portland cement and 3.5 parts of sand. Between the years 1949 and 1951, after stripping the dome of the salt-infected plaster *(Plate 14)* a Gunite shell was applied to the interior (23 cm thick for the first 60 cm height and tapering to 11.5 cm higher up). This shell was covered with a new plaster, quite smooth and uniform, and matching the colour of the existing dome. In place of rusted iron hooks, stainless steel hooks and dowels have been used in repairs.

The Taj Mahal

The site. The Taj is in Agra (27° 2′ N., 78° E.), Uttar Pradesh. It is one of the finest tombs in the world, a veritable model of perfection, and was built at the order of the Mughal Emperor Shah Jahan (1627-58) in memory of his wife Mumtaj Mahal; it took 20,000 workers seventeen years (1631-48) to complete it. It is set within a vast series of gardens, embellished with many fountains, and stands upon a terrace overlooking the river Jumna.

Material structure. The foundations of the Taj were laid in the subsoil at water level. The masonry below ground is stone in lime and the platform above ground is of brick in mortar and faced with marble veneer. The white marble used in the monument came from Makrana and Raiwala in Jaipur State, the red sandstone from Fatehpur Sikri and the neighbourhood of Agra, and the jewels and precious stones from Persia and elsewhere. Some leakage of rain-water into the tomb had been observed due to age and natural weathering. Certain stones had bulged outwards and cracked and joints had opened. Marble slabs had become fractured by the rusting of the iron clamps and dowels that were fixed in them. Efflorescence of salts was noticed on the plaster inside the dome. Some of the pillars had been badly split and their constituent stones broken.

Protective measures. To make the dome watertight all the stones that had bulged out or cracked were either reset or replaced by new ones in hydraulic lime mortar. The materials selected were of the full height and thickness of the original pieces and care was taken to avoid unsightly patchwork as far as possible. The joints were filled with special lime mortar consisting of marble lime, marble dust, rumi mastagi (gum), batasha (sugar) and belgiri (fruit of Aegle Marmelos), together with water in the proper proportions. The cement mixture used in repairs consisted of 1 part cement and 4 parts of hydraulic lime, or 1 part cement and 2 parts of lime *(Plate 15)*.

The old plaster to a height of 20 m was removed from the interior of the upper dome and the entire surface replastered with a weak mixture of cement mortar (1 part cement to 10 parts sand) in order to draw out the salts. The final plastering was done with hydraulic lime. The marble facing of the structure and the inlay work on it were repaired by replacing the cracked and broken stones and inlay pieces. Iron cramps have been replaced by copper cramps. The decayed concrete from the top of the inner dome was removed and then it was treated with Kankar lime concrete to a depth of 7.5 cm. Over this was laid another layer of cement concrete 1 : 2 : 4 (cement, sand and concrete). The load over the inner dome was thus reduced from a thickness of about 36 cm to 11 cm. The deteriorated pillars and other damaged members were replaced in such a way as not to cause any changes that would depreciate the value of the structure from the aesthetic point of view.

Elephanta caves and sculptures

The site. The rock-cut Elephanta Caves (19° N., 73° E.) are situated on an island off the western coast of India, 11 km north-east of Bombay. The caves and the sculptures are of post-Gupta period from the early seventh century A.D. There is one very large cave consisting of a great central hall supported by cylindrical pillars which rest upon a high cubical base and are surmounted by a support for the entablature. Inside the cave are large sculptures carved out of the solid rock.

The caves and the sculptures were disintegrating, the two main causes being the action of injurious sea salts absorbed by the porous rock and the seepage of water into the structure. The sculptures, pillars and the ceiling rock were flaking and pieces were falling off. Large cracks had developed. For the greater part of the year there was continuous seepage of water into the caves coming from the hillock above which had been saturated during the monsoon season.

Protective measures. All the earth, vegetation and the disintegrated rock were removed from the top of the cave. A number of suitably spaced holes were drilled above the cave to varying depths and cement grouting of fissures under pressure was carried out. A number of holes were bored in the rock at the back of the cave in some cases to 20 metres in depth and cement grouting was carried out here under pressure in order to seal up the fissures and cracks at the back by which the water had been finding its way into the cave. The concentration of salts on the sculptures was reduced by repeated applications of paper pulp. In Some cases as many as seven applications had to be made. The rate of reduction of the concentration of sodium chloride on one panel by the application of paper pulp is given below.

No. of applications	*Grammes of NaCl extracted by 1 sq. ft (1,000 cm²) of paper pulp of $^{1}/_{2}$ inch (12 mm) thickness*
1	2
2	0.7095
3	0.528
4	0.2
5	0.2

The surface, after paper pulp treatment, was given one or two coatings of 5 per cent vinyl acetate solution. The deteriorated columns were replaced by plain ashlar masonry to hold up the roof. The loose or cracked parts of all sculptures have now been internally secured with non-rusting metal dowels, and cracks in the panels have been neatly filled up with suitably coloured mortar.

Ellora

The site. Ellora (20° N., 75° E.) is about 30 km from Aurangabad in Maharashtra State. There are thirty-four rock-cut caves at the foot of the hill, the largest being the Kailash (Cave 16) built in the eighth century. The earliest caves there date back to A.D. 500. These caves were occupied contemporaneously by Buddhist, Brahmanical and Jain monks. Almost all the caves have a courtyard in front of them.

The rock out of which the caves are hewn and the sculptures carved is Deccan trap-basalt. Characteristically this stone exfoliates gradually when exposed to the atmosphere and is reduced to brown, red or black clay. The sculptures, pillars, ceilings and walls all show signs of disintegration. Seepage of water through the ceilings and walls has been responsible for increasing the rate of decay of both the caves and the sculptures. Drainage is imperfect; water accumulates and since the caves are at the foot of the hillock it seeps into the roof and walls.

Protective measures. For conservation, the steps that have been undertaken are as follows:

1. Provision of surface drains over the caves to direct the rain-water harmlessly away.
2. Cement-grouting of cracks.
3. Erecting masonry supports wherever necessary, cement concrete reinforcement being preferred to ashlar masonry.
4. Fixing the loose parts of sculptures to walls by inserting copper dowels.
5. Restoration, to the bare minimum, of the missing portions of sculptures and pillars by cement concrete in order to stabilize the precariously hanging portions *(Plate 16 a, b)*.
6. Provision of doors to the shrine to stop bat and bird nuisance.

APPENDIX

A SERVICE FOR THE PROTECTION OF MONUMENTS

H. J. Plenderleith

As a final coment it may be stated that any service that is devoted to the protection and maintenance of monuments in the tropics must be fully provided with:

1. Documentation, such as maps, regional and local, on which the position of monuments is recorded.
2. Card-index histories of individual monuments.
3. Files of photographs (including aerial photographs, or at least access thereto for consultation).
4. The necessary surveying equipment, apparatus for the measurement of humidity, etc., and photographic apparatus to maintain this documentation.
5. Plant for emergency work and for repair operations, located in a central repository and/or in convenient regional repositories.
6. Basic equipment to enable the service to effect permanent consolidation work at opportune times and in the most convenient seasons of the year.
7. An adequate system of surveillance, as monuments need protection from many potential enemies, and perhaps not least from man himself!

It is recommended that individuals responsible for the care of monuments should be internationally minded and should maintain contacts with the leading exponents of their cultures and of similar cultures both at home and abroad. They should not hesitate to seek advice, when required, from the International Centre for the Study of the Preservation and the Restoration of Cultural Property in Rome.

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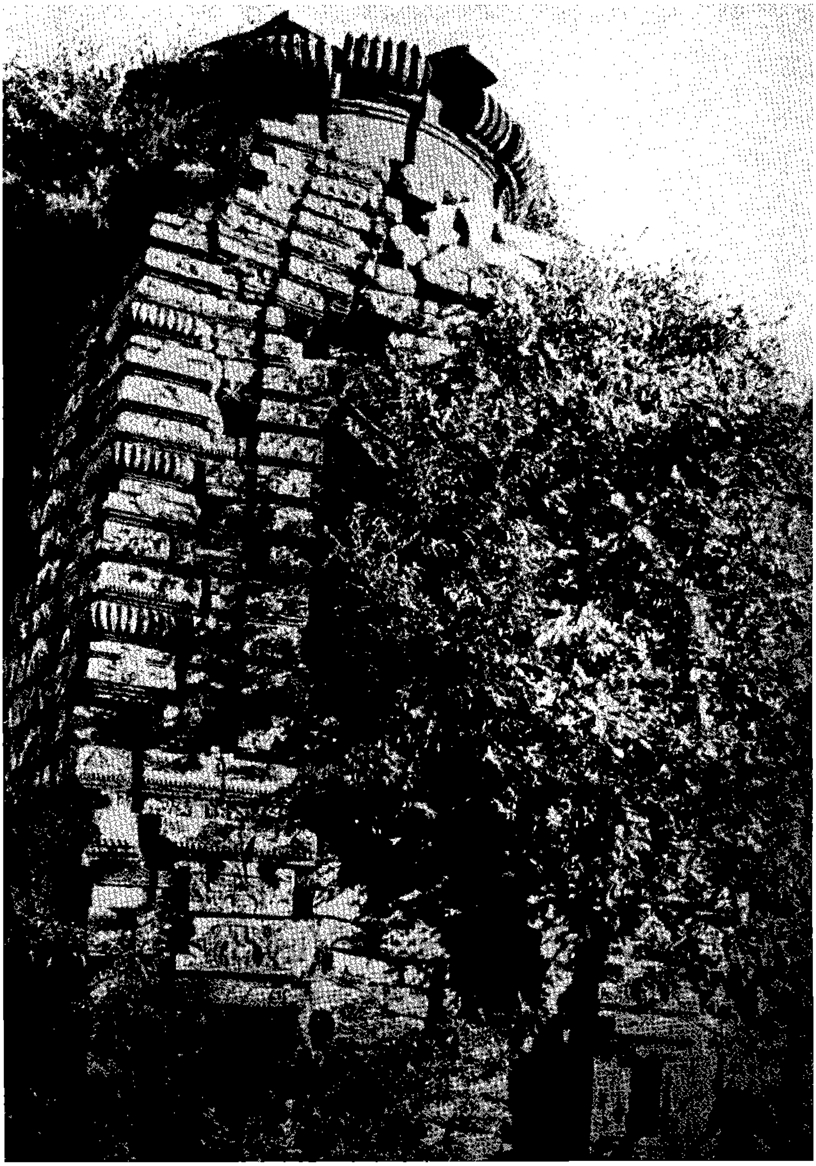


Plate 11

Bhubaneshwar, Orissa, a temple structure invaded by shrubs and trees. In the humid tropics plant growth can take place with extreme rapidity. The disruptive action of roots is particularly destructive.

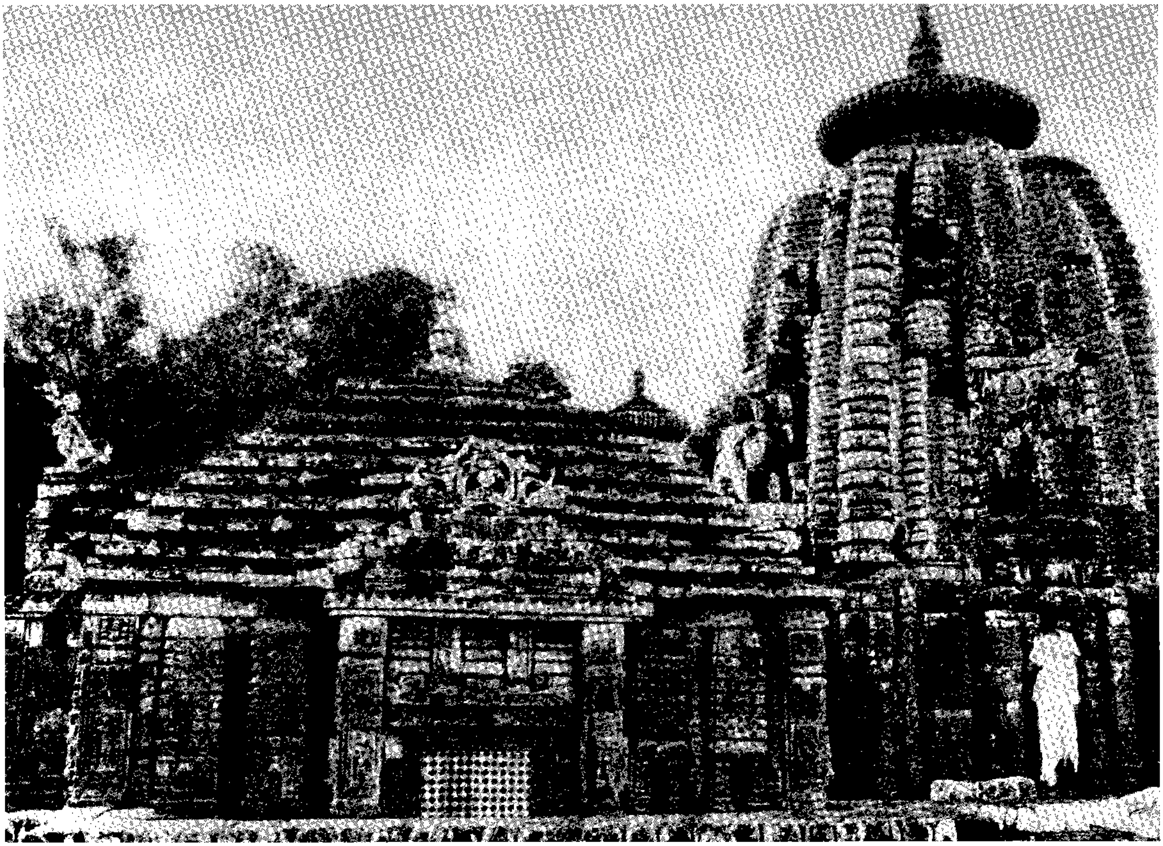


Plate 12a

Mukteshwar Temple in Orissa (India), showing the growth of moss and lichens which menace many monuments of stone in the humid tropical zones.

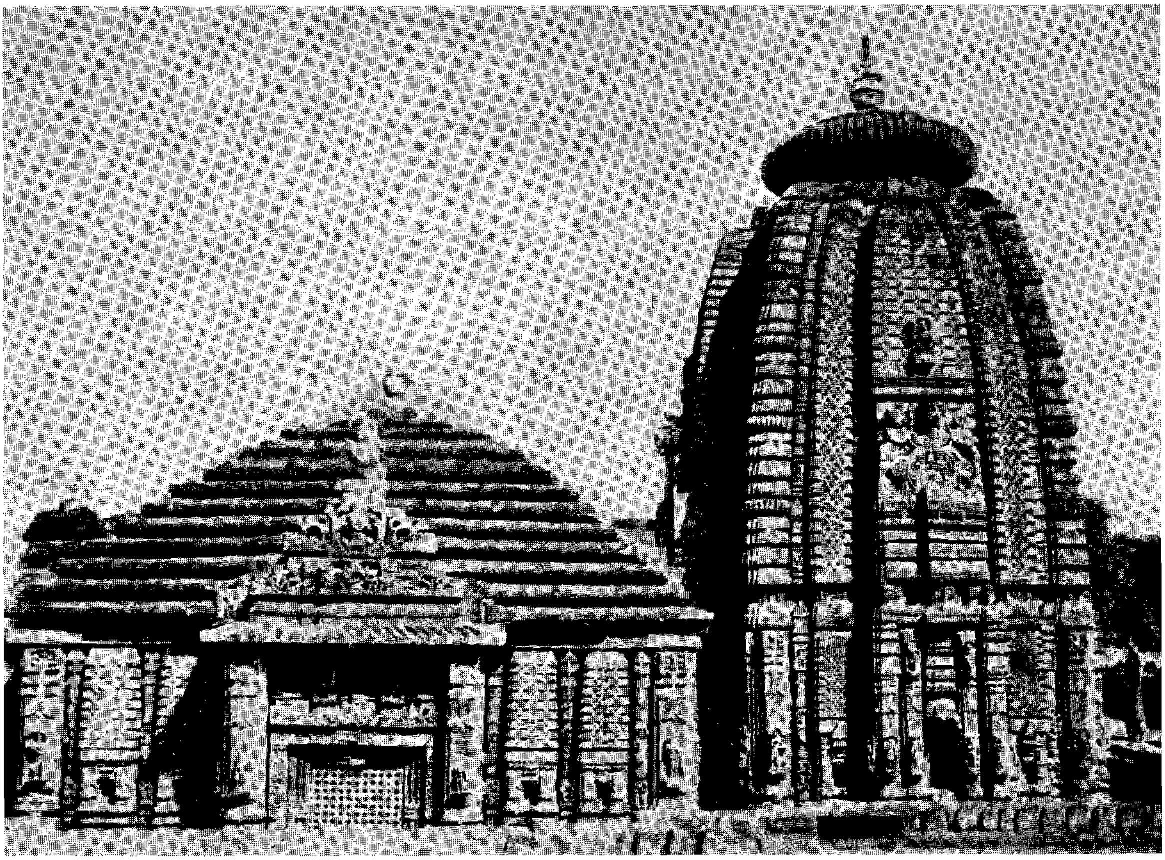
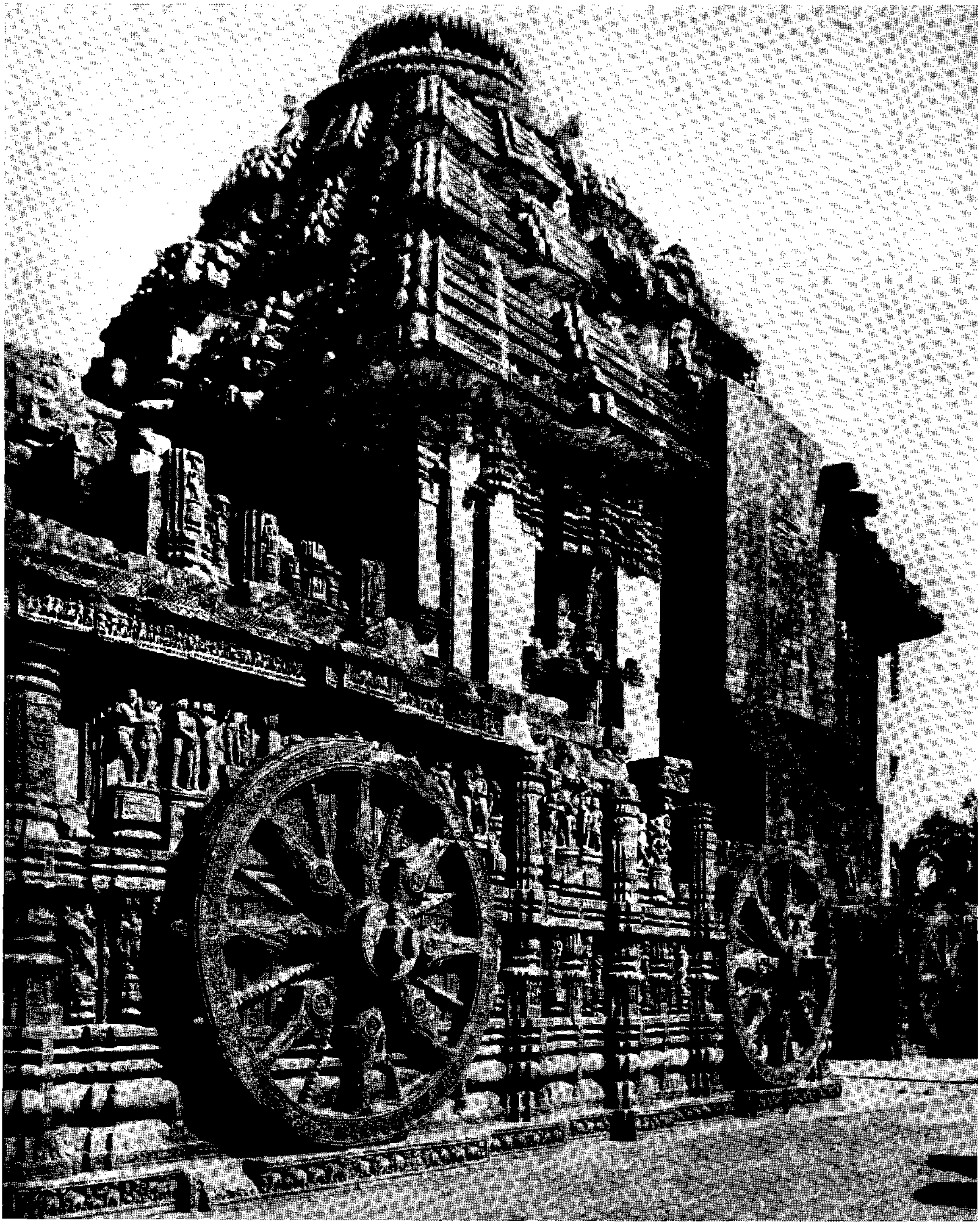


Plate 12b
Mukteshwar Temple after fungicidal treatment.



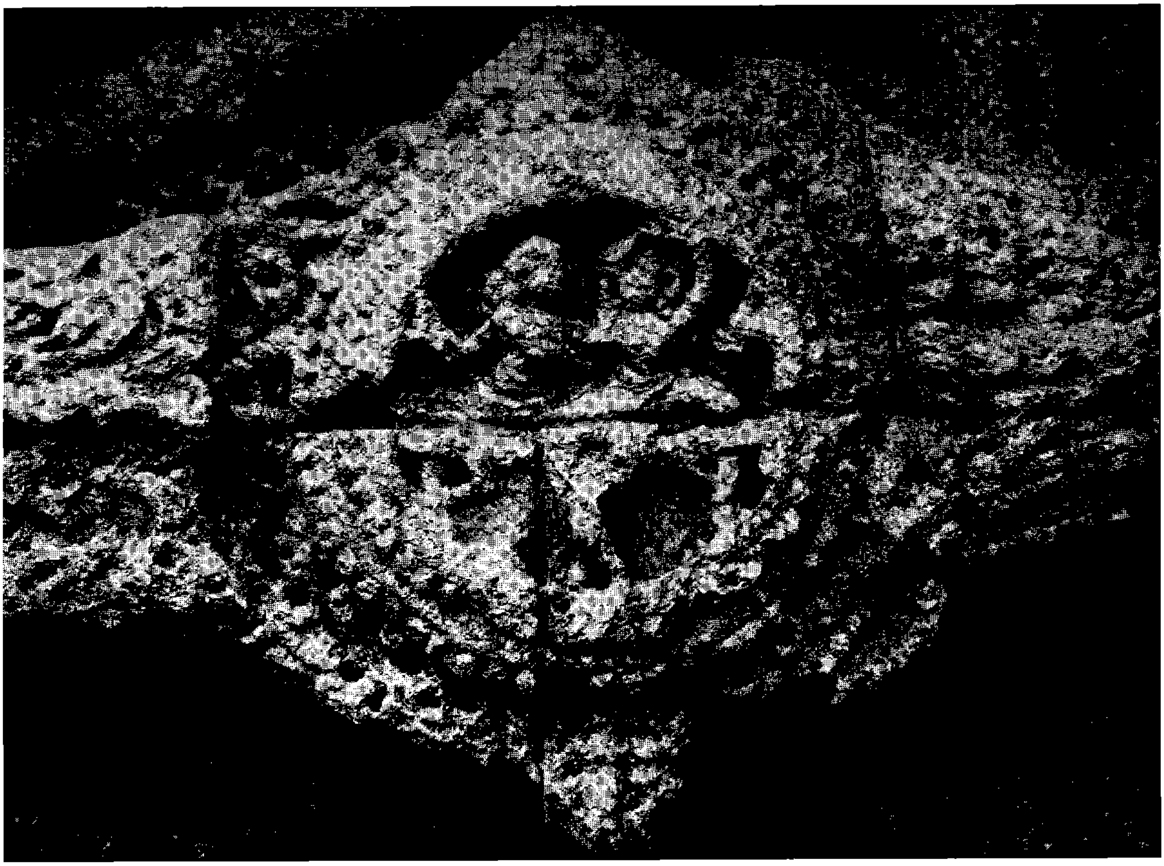


Plate 13b

Detail of leaching effects on one of the spokes of the stone wheels decorating the Sun Temple at Konarak.

Plate 13a

The Sun Temple at Konarak (India), after conservation.

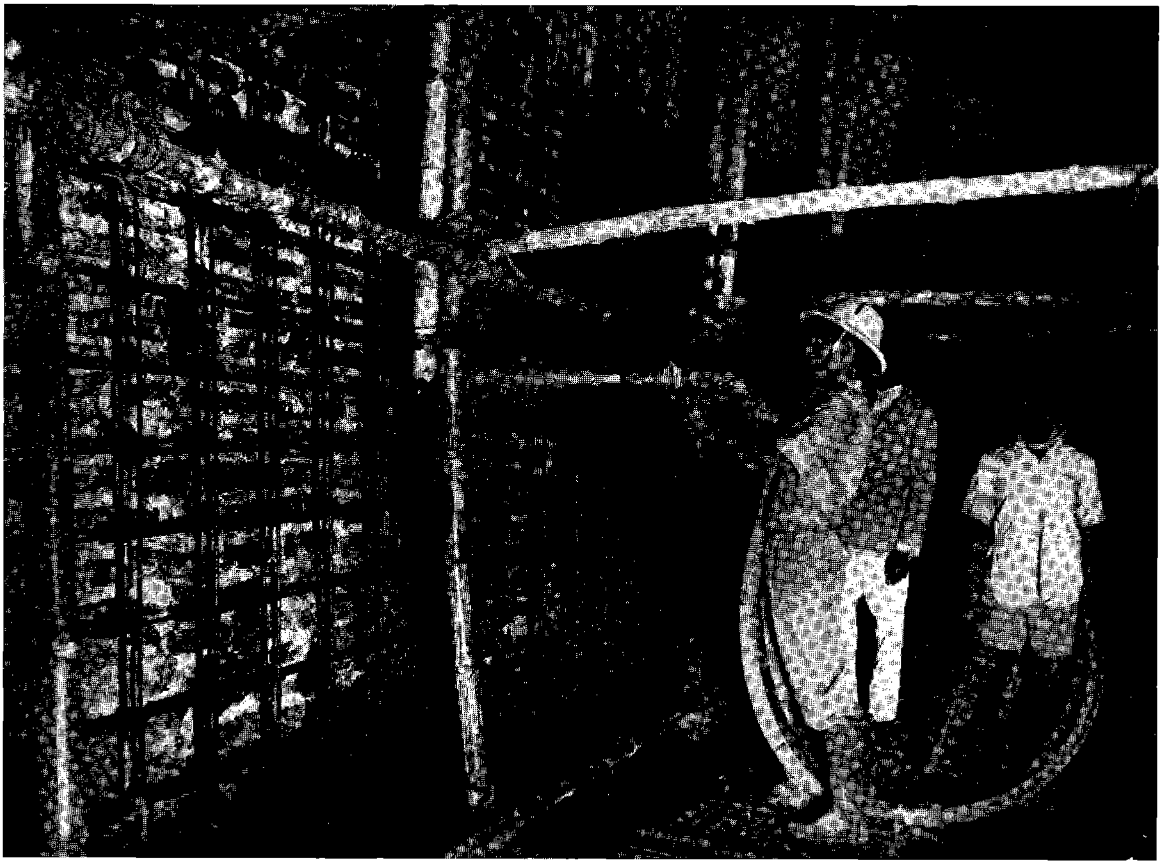


Plate 14
Gol Gumbad, Maharashtra State (India).
Reinforcement of the interior of the dome with Gunite (1949-51).

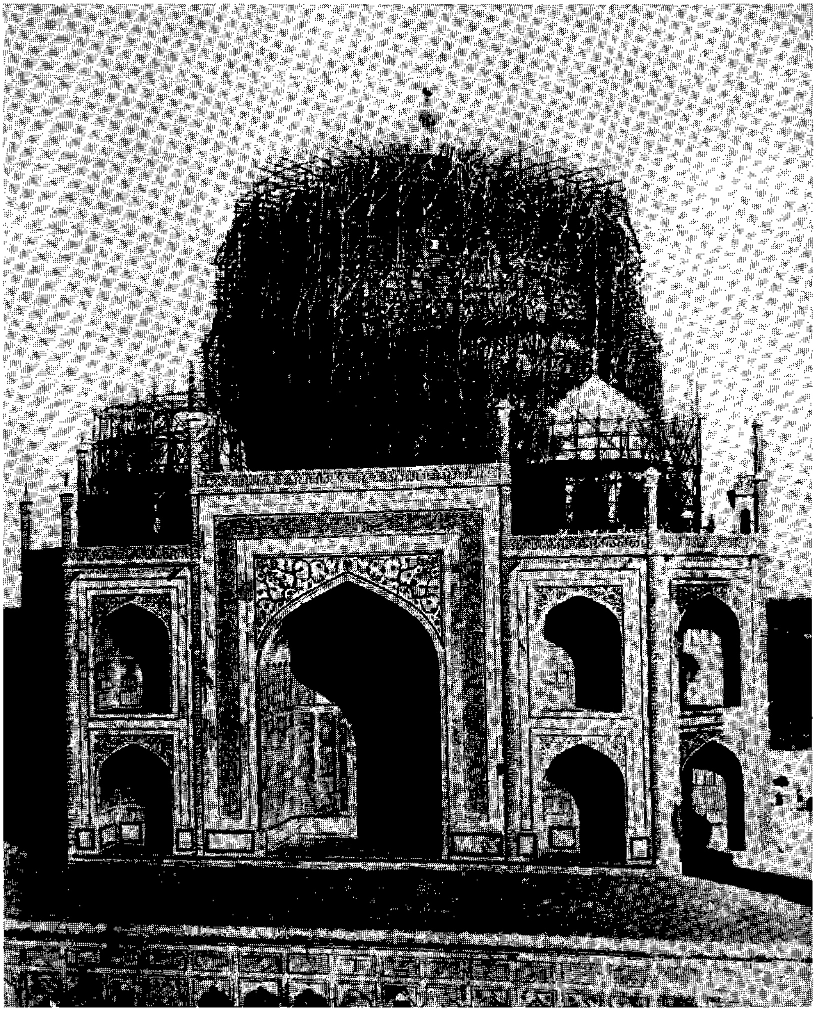


Plate 15

Repairs to the dome of the Taj Mahal in Agra.

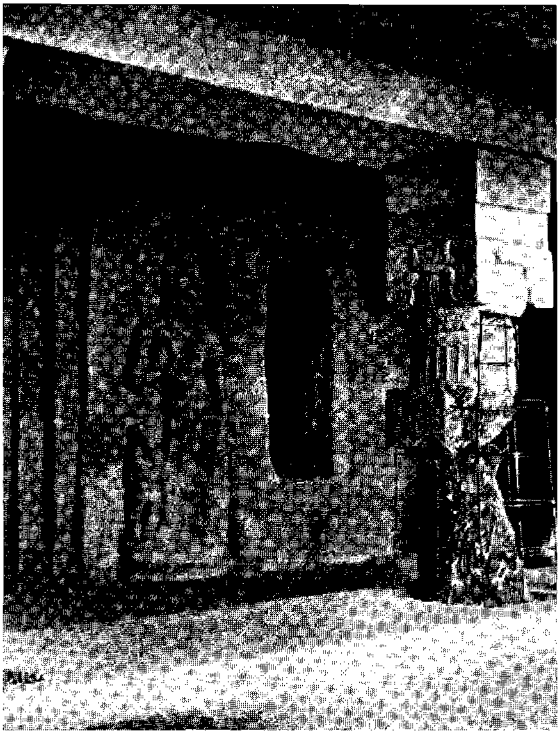


Plate 16a

Rock-cut cave at Ellora, Maharashtra State (India), showing disintegration of one of the supporting pillars.

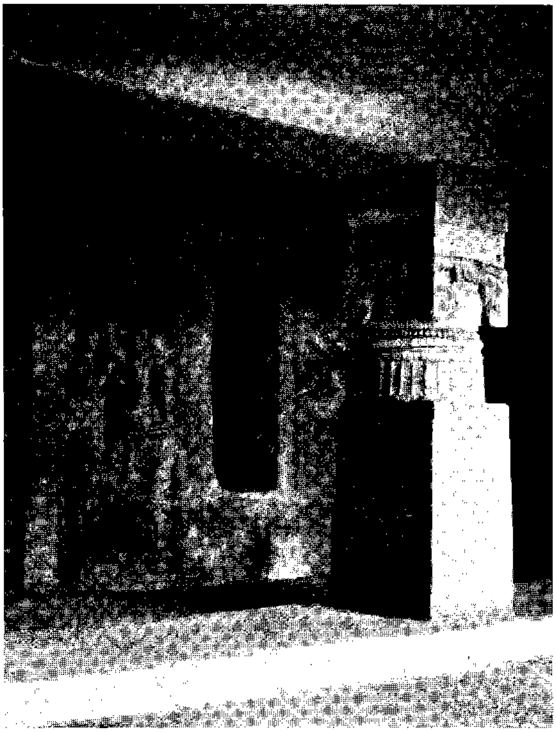


Plate 16b

The pillar after restoration.

Rodrigo M. F. de Andrade

The conservation of urban sites

11

INTRODUCTION

The twentieth century is characterized by the growth of societies whose economies are based upon industrialization and, as a result, the development of great urban centres. This phenomenon has had two aspects: the progressive diminution of the rural population—at times accompanied by the abandonment of or lessening of importance of small urban centres—and the growth of large urban units at the expense of the countryside and neighbouring population centres. Economic factors have frequently led to the progressive demolition of former small historic centres which have been incorporated in large cities, under various forms of urban renewal projects. Smaller cities or towns at some distance from major population centres are also being abandoned, or destroyed in 'modernization' programmes. In many instances individual monuments which have considerable artistic or historical value may be preserved as isolated remnants but their new surroundings only serve to emphasize their lonely survival.

Rapid 'modernization' or urban renewal programmes have also resulted in the disappearance of stable social units such as the neighbourhood. The anonymity often characteristic of large, multiple housing units may also be a contributory cause of the malaise found in large cities. Man needs roots, associations not only with contemporaries but also with the past.

It should be emphasized at once that conserving the integrity of a site does not necessarily mean preserving all the individual monuments of which it may be composed. Something may well have to be sacrificed, since even when the protection of each of the architectural units located within the perimeter may seem to be vital, the maintenance and protection of the landscape should be the major goal. The demolition of minor buildings might, in some cases, appear to be justified with the object of enhancing the significance of a major monument; but, in considering such possibilities, those responsible for the conservation of the site might very properly demur and refuse to authorize such a step if such action seemed likely to cause a lack of over-all balance or if it tended to falsify or to obscure the historical significance of the area.

While the urban site can be of significance from the point of view of the public administration of a country or of a region, there may be other valid reasons why it should be protected. For example, it may be of exceptional historical value, serving as a link with the past, or it may be equally significant from the point of view of its architecture and setting. Whatever the reason for its conservation, provision should be made for the preservation not only of the individual elements but of the original characteristics of the area as a whole. This is a fundamental. Conservation work normally observes criteria that are common to all regions of the world, but tropical conditions naturally present their own problems and this aspect of the subject will be given special consideration in the present chapter.

An example which will serve to illustrate many of the points discussed is the old city of Ouro Preto in the eastern highlands of Brazil (20°20′ S.), where the humidity and diurnal temperatures are high and the nights cool owing to the altitude (1,030-1,060 metres). From a small gold-mining settlement established in 1701, it flourished to become, in the short space of twenty years, the capital of the newly-formed province of Minas Gerais. Its present aspect, characterized by the tiered lay-out on a steep hillside, bears the marks of its history—early wealth, a period of rapid development, a century and a half of administrative power and prestige, followed by gradual decline, impoverishment and loss of status. Since 1933 the town has been a national monument and official intervention has been necessary to ensure the conservation of the site which includes the fine public buildings and civic centre subsisting from the time of its past prosperity *(Plate 17)*.

LEGISLATION

The law, decree or administrative act providing for the conservation of an old town, a village or a district, is always more complex than the legal provision necessary for the protection of a single isolated building, mainly because of the problems of multiple ownership *(Plate 18)* and human occupation. Sometimes, of course, it is necessary to preserve sites that were once highly developed but have since been deserted. Here the legal requirements are similar to those for the individual monument since the problem is one of protecting the area against further occupation and utilization. In many cases, however, historical sites have continued to be inhabited—even up to the present day—though they may be virtually derelict owing to the gradual waning and ultimate loss of the economic and social influences that first caused them to flourish. In such cases, the policy of conservation and the measures taken to carry it into effect will naturally have to be both flexible and appropriate to the individual case.

If an urban site is to enjoy a régime of permanent and efficient conservation, this must be clearly defined and backed by national legislation. The public authorities must have legal means of enforcing measures designed to maintain the integrity both of the landscape and the architectural heritage within the site so that any threat to the value of the site or its monuments can be controlled by the national legislation—by decree or by formal administrative decision.

ADMINISTRATION OF SITES

It will be the duty of the administrative services charged with implementing such legislation to ensure that the provisions of the law have been fully satisfied. Where sites are inhabited the main requirements may be as follows:

1. To establish an inspection service for permanent supervision in the area of the site and its neighbourhood.
2. To draw up an inventory, cataloguing all items recognized as cultural property pertaining to the site, whether fixed or movable.
3. To set up a special conservation department for the care of the urban site as a whole, including sections for the repair and recovery of its original elements.

Sites that are quite clearly deserted will present few difficulties other than those arising from the problems of restoration and preservation, and the consequent need for funds and trained technical personnel. But with sites that are still inhabited or are in casual occupation, careful consideration must be given to the provision of the wider range of services needed to ensure their conservation.

CAUSES OF DETERIORATION

An urban site, being more complex than an individual monument, will obviously require greater upkeep if it is to survive in sound condition. But maintenance costs money and where the economy has deteriorated and the local population has become impoverished, even the minimum requirements for upkeep are likely to be neglected; and these are so many and varied that the neglect of any one may immediately result in wholesale collapse.

Measures for the prevention of deterioration in the economic and social fields are beyond the scope of the present handbook. But, as we see it, an elementary duty of those entrusted with conservation is to foresee all possible causes of deterioration and to take appropriate counter-action in good time.

Type of construction

We have referred to the fact that certain causes of deterioration have a special significance in tropical climates. A basic reason for this is the fragility of constructions coupled with the frequent precariousness of existence within the tropical zone. A simple illustration is found in the cities erected in South America during the period when there was a great influx of immigrants searching for precious metals. Here it is seen that intrinsic factors have been a major cause of deterioration; habitations were, for the most part, wooden structures with walls of light materials and easily inflammable. In modern cities such substandard structures are disapproved of and are often allowed to disappear. The actual lay-out of towns may be allowed to deteriorate in a similar way. For example, among the interesting curiosities that are worthy of preservation in South America are the peculiar road complexes with high and low levellings which are characteristic of certain mining areas, but since the trend today is to minimize the irregularities of roads and highways, these earlier patterns are being lost. For these and similar reasons, South American urban sites are incomparably more vulnerable than those, say, in Europe where more resistant materials are generally used and works are constructed in a more durable manner.

Natural agencies contributing to decay

The three characteristic agencies of decay peculiar to the tropics are as follows:

1. Infiltration of rain-water, causing: waterlogging, erosion of the soil, weakening of foundations, and damp that encourages biological attack (rotting) in wooden structures *(Plate 19)*, with consequent weakening of and eventual collapse of the structural framework of buildings, and high humidity that destroys the plastering even of the internal walls.
2. Destructive action of insects, notably termites and ants, the former capable of devastating almost all wooden furniture and fittings swiftly and thoroughly, the latter weakening the foundations.
3. Tropical vegetation, notable for its quick and luxuriant growth bursting through roofs, disintegrating walls and undermining foundations.

Neglect

In addition to these natural factors of deterioration that are of increased significance in the tropics, there are also human factors responsible for deterioration.

Structures that have been allowed to deteriorate for a long period of time or have been abandoned obviously require major repairs. But decline in the financial resources of any part of the remaining population (even where there is a desire to preserve something of past glories) may render such repair virtually impossible.

For the same reason the decline, and in some cases the extinction, of parishes and religious communities has resulted in the deterioration or even utter ruin of places of worship. Enterprises of commercial or industrial interest have likewise suffered and only traces remain of professions that once flourished.

Modernization and rebuilding

There is yet another and less obvious cause of damage, particularly in sites that have been reinhabited or are to be 'modernized'. The newcomers naturally aspire towards progress, and in satisfying such aspirations public authorities and private persons may take steps that are detrimental to the preservation of cultural treasures. For example, the local authority may plan to widen the roads or develop public sites for building purposes. Plans may be made for new road surfaces, the repair of pavements, the installation of a grid system for the transmission of electric power, of electric street standards and modern lighting apparatus for illumination of monuments, etc. Private enterprise may undertake to enlarge and modernize existing constructions, or to put up new buildings, perhaps involving the demolition of older examples of architecture or even the utilization of common lands or green-belt areas for utilitarian purposes. More blatant is the deforming of the country-side by the building of skyscrapers, and the conspicuous posters and signs and ugly refreshment kiosks that line the roadsides. Another unpleasant modern trend seems to be universal: the parking of cars and even buses where they detract from the architectural interest and beauty of the site *(Plate 20)*. But this is perhaps the least offensive consequence of the invention of the internal combustion engine. Urban traffic has become an actual agent of destruction and the incessant movement of heavy vehicles in the narrow streets of certain areas has a cumulatively harmful effect on both foundations and structures.

Incredible as it may seem, experience has proved also that damage caused as a consequence of the economic rehabilitation of an historic urban quarter is, in the great majority of cases, more serious than the toll expected by time and neglect. The reason is that while the rhythm of the latter is gradual, the gross damage that may be inflicted in the name of progress, and of 'modernization' badly interpreted, can take place within a very short space of time and is, by its very nature, irremediable.

REGIMEN OF PROTECTION

Once the main causes of deterioration have been established, means can be devised for the consolidation and conservation of the site. Mere repair of the damaged parts, however extensive and complete, will not suffice; measures must be taken for protection in the future. For this purpose special centres should be established on the site itself with the necessary powers and administrative facilities to prevent a recurrence of deterioration and ensure adequate supervision.

SPECIAL LEGISLATION AND REGULATIONS

It is essential that the legal provisions and regulations applicable to a particular area should be stated clearly and unequivocally so that private initiative and enterprise will be duly warned of the consequences of infringements and local agents are empowered to take action promptly and effectively against such infringements or any threats to the integrity of the site. Laws and regulations, of course, cannot anticipate all eventualities, but they should be so conceived as to apply to the most likely future developments.

Official initiative

Since it is hardly possible to foresee whether the general legal and administrative principles adopted will be adequate to meet every threat that may arise in the future, there will be many cases to which no precise legal provisions are applicable. In such circumstances, the agent acting on behalf of the administrative authority must defend the integrity of the urban site and be prepared to argue the case, sometimes in the face of popular opposition, and even, if need be, by taking the matter to the courts.

Popular support

The population of the area affected by the system of special protection should not, however, resent the policy of the agents responsible for this work. It must be called to their attention that their case is not unique and that the conservation of monuments and sites all over the civilized world is organized according to the same principles and criteria. The inhabitants of the site must be made aware that their cultural property is worth preserving, even at the expense of some restrictions and sacrifices on their part, for such property is a universal inheritance and its preservation is essential to humanity. The public should also be encouraged to recognize that the official agents working for the administrative body in charge of conservation are performing a public duty. In Italy, the country with the richest artistic and historic treasures in the world, it has actually been found necessary to empower the administrative authorities to take decisions overruling those of the courts.

JURISDICTIONAL CONFLICTS AMONG AGENCIES

We must also face the fact that objections to the proper conservation of an urban site or a historic quarter do not necessarily come only from the local population. One of the commonest administrative problems, often very difficult to resolve, is the conflict of jurisdiction between the public authorities responsible for the conservation services and other public authorities having different terms of reference. For example, in the old cities built in the period of intense exploration in Brazil, the population later gradually dwindled and became impoverished as interest waned in the mining of metals and precious stones, but the ancient systems of administration were nevertheless jealously guarded. The result was that when these historic towns eventually reached maturity as city-monuments, by virtue of their historical and architectural riches, the work undertaken by conservation services was often regarded as an unwarranted intrusion by the local administration. In such circumstances, every attempt should be made at the outset to reach an amicable arrangement between the two parties, so as to obviate the possibility of conflicting jurisdiction, and to come to an agreement on general policies defining the principles of conservation without encroaching upon the authority of the local administration. Agreement should be reached, for example, as to the extent to which the local authority would be free to encourage development without depreciating the value of the site and without prejudice to the interests of the agents responsible for conservation.

SUPERVISION AND VIGILANCE

The first unit which must be organized and operated with strict discipline is the inspectorate, the body responsible for supervision and vigilance throughout the area in question. Conservation is impossible unless a thorough and permanent routine of inspection and observation is carried out, applying to the whole site as well as to the cultural property within it.

If signs of deterioration are found in a building, in the characteristic pavement of a street, or in the vegetation of an open space, appropriate remedial measures must be taken before the damage becomes too serious and long before it is irreparable. Various other losses which may occur in consequence of human action or neglect can also be avoided or corrected if dealt with in time.

Inspectors should be quick to note and condemn alterations to the old architecture, the introduction of unsuitable installations such as unsightly electrical wiring, unsatisfactory styles of street lamps *(Plate 21)*, aggressive publicity posters, etc., and other cases of misuse or neglect detrimental to the integrity and good appearance of the architecture-landscape as a whole.

INVENTORY AND CATALOGUING

Satisfactory conservation requires, secondly, the organization of a section responsible for establishing an inventory or catalogue of the cultural property contained within the site and of the natural features which give it character. This is prepared not only for purposes of specialized study and in order to furnish exact information to those who may be interested, but also in order to safeguard the material and provide documentation of the ensemble. The inventory should be an organized collection of documents, aimed at assembling all the available records relating to the area under protection. Of particular interest are topographical plans indicating the general configuration of the site (Fig. 44), drawn to a convenient scale and complete with contour lines, and a photographic survey of the complete area. In addition, photographic records should be kept of the streets and roads, and of all buildings. These records should be accompanied in each case by plans, sections, elevations, and drawings of the more valuable contents of the buildings. Buildings classified as public and religious monuments must be very carefully inventoried outside and in, and all mobile property of historical and artistic value should be inventoried separately (altars, decorated ceilings, murals, etc.). The documentation should be such, in its detail and coverage, as to provide not only a sound basis for the task of conservation, but a complete record from which an exact reconstruction of the whole site could be made if it should be destroyed by some catastrophe.

PLANNING

The maintenance of a single monument that has always been under care and presents no signs either of structural or secondary deterioration, may not require any special planning. The same is true of old cities that are no longer inhabited and are not menaced by occupation or modern development. Provision for conservation in such cases need be made only as required or when special contingencies arise. However, when it comes to dealing with a busy urban site with an active population, no adequate means of conservation can be devised without carefully considered plans of operation (Fig. 45).

A great number of factors, both material and social, must be taken into account. The planning should not be restricted to measures aimed exclusively at the protection and conservation of cultural property. It must also take account of the needs, convenience and natural aspirations of the people actually living on the site, particularly as regards comfort and opportunities for progress, for it would be quite unfair to impose upon them the unnecessarily rigid styles and conditions of life of some past age.

Policies to be followed

In planning the conservation of the historic quarter itself, the aim should be to protect not only the distinctive features and the general configuration, but also what might be called the geographical accidents. Discontinuities in ground level, traces of old road systems, typical local architectural styles, public and private green areas should all be preserved. In short, any distinctive evidence of features of interest which have fallen into ruin or have been mutilated

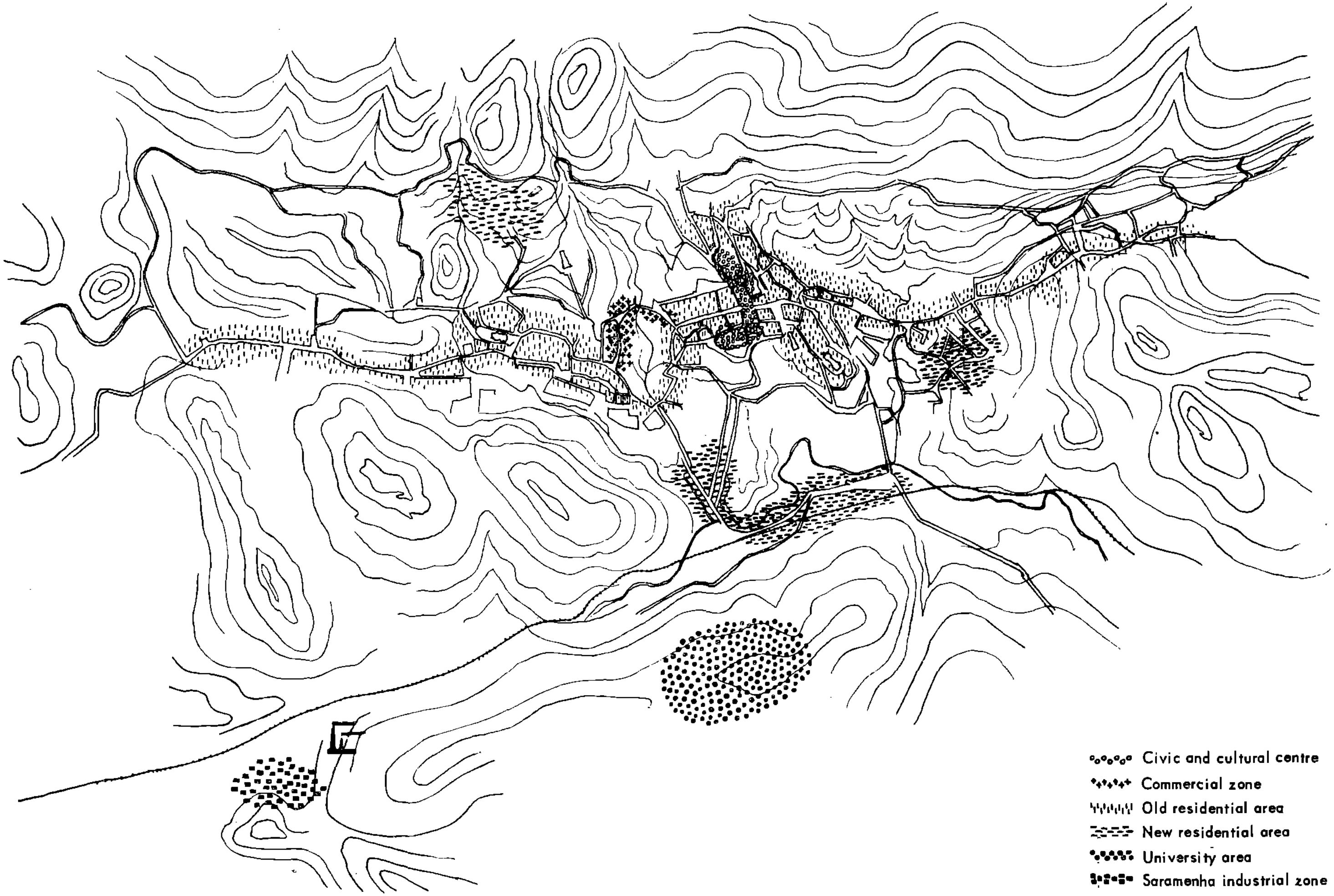
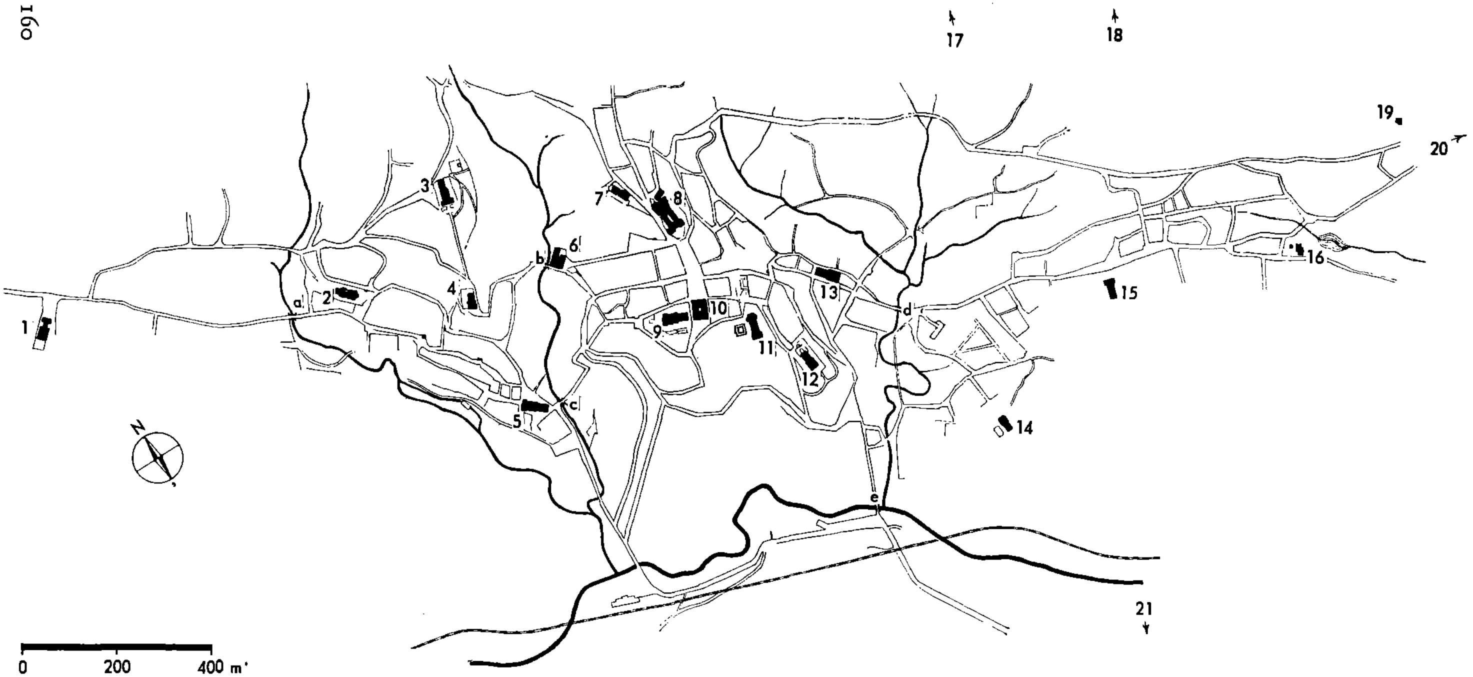


Fig. 44. Sketch plan of the city of Ouro Preto (Brazil).



(a) Rosário Bridge
(b) São José Bridge
(c) Pilar Bridge
(d) Antonio Dias Bridge
(e) Barra Bridge

1. Church of Senhor Bom Jesus de Matosinhos
2. Church of Nossa Senhora do Rosário
3. Church of São Francisco de Paula
4. Church of São José
5. Chapel of Nossa Senhora do Pilar
6. Casa dos Contos
7. Church of Nossa Senhora das Mercês e Misericórdia
8. School of Mines
9. Church of Nossa Senhora do Carmo
10. Museum of Inconfidência
11. Church of São Francisco de Assis
12. Church of Nossa Senhora das Mercês e Perdoes
13. Chapel of Antonio Dias
14. Chapel of Nossa Senhora das Dores
15. Church of Santa Efigênia
16. Chapel of Padre Faria
17. Chapel of São Sebastião
18. Chapel of Santana
19. Chapel of Nossa Senhora da Piedade
20. Chapel of São João Batista
21. Chapel of Senhor Bom Jesus das Flores

Fig. 45. Sketch plan of Ouro Preto showing location of the principal monuments.

Plate 17
Ouro Preto: view of the historical quarter of the municipality. The eroded hillsides in the background are the results of gold-mining operations.

Plate 18
Ouro Preto: a cluster of buildings belonging to different owners showing interdependence of the roofs.

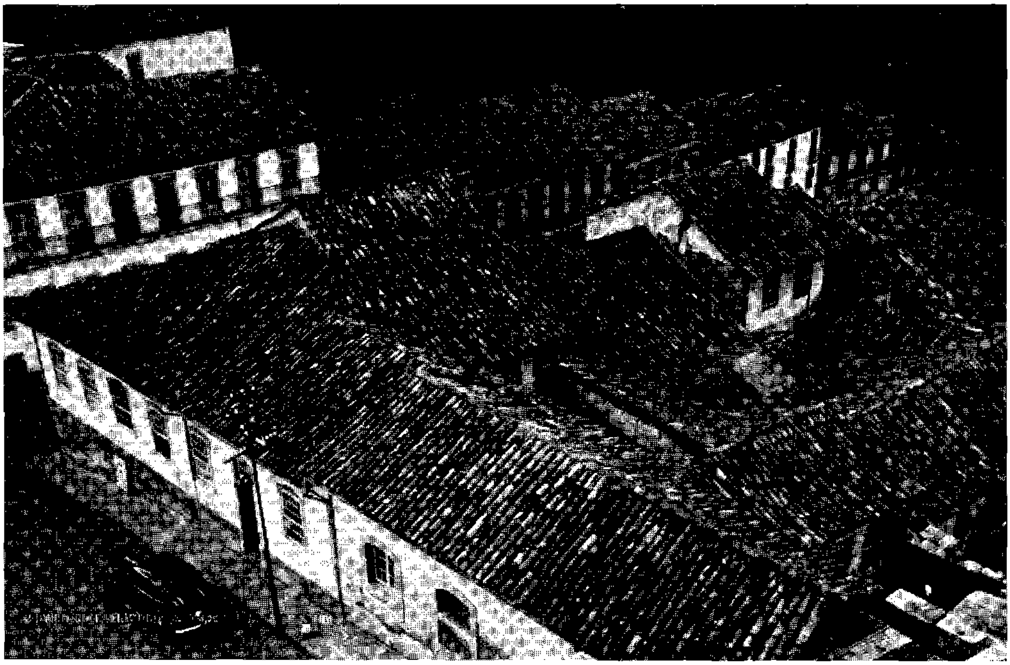


Plate 19
Ouro Preto: the rear of houses built of wood are threatened by rot (cryptogamic attack) and termites.

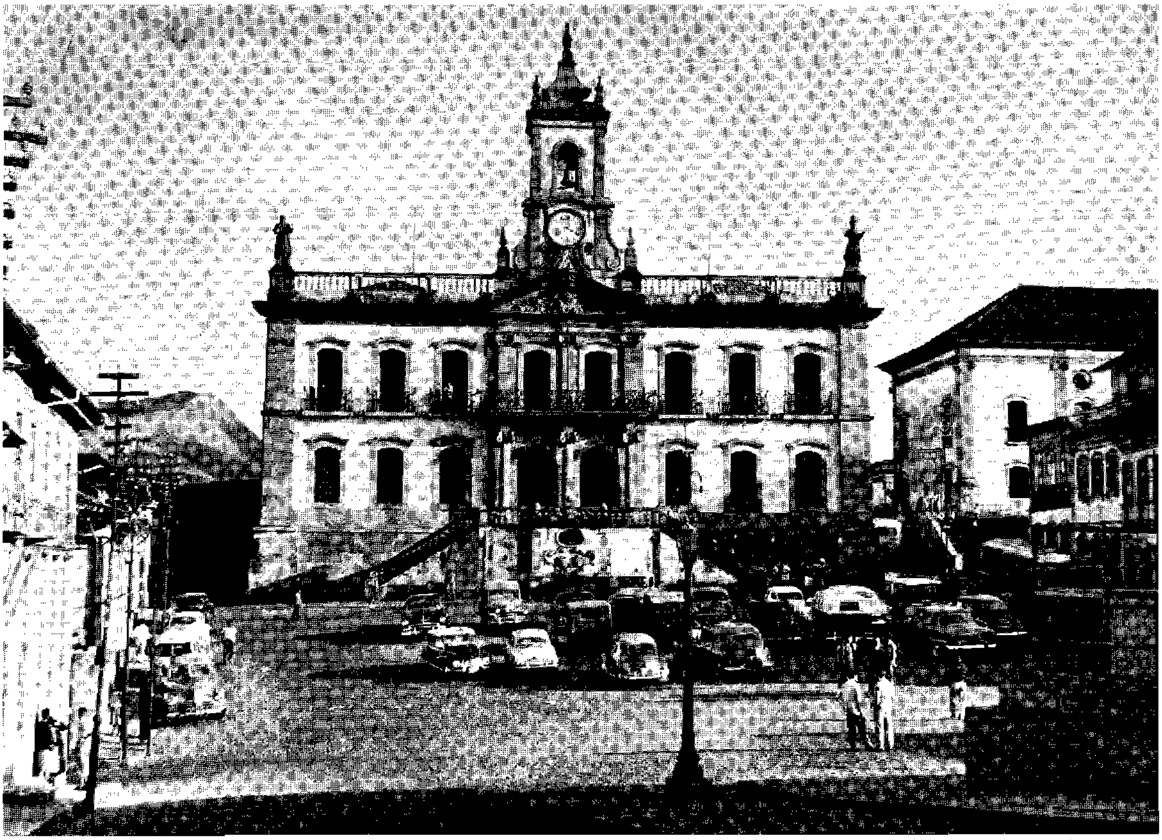


Plate 20

Ouro Preto: utilization of the square for parking distracts attention from the monument and gives an impression of crowding instead of spaciousness.

Plate 21

One of the historic monuments of Ouro Preto.
Exposed wiring and poorly designed lamp
standards are æsthetically displeasing
and clash with the style of a monument built
in an earlier period.

should be studied with a view to both preserving them and enhancing their effect, in particular the nobler monuments and the more picturesque localities of the site. Constant interest should be taken in the surroundings also, to ensure an adequate panoramic setting, and prevent the introduction of new constructions of inappropriate height or the destruction of the original levels.

Zoning laws

It is essential, however, that in making plans for the redevelopment of an area the importance of improving the standard of living of the population should not be overlooked. The zoning of new districts or satellite cities which are needed for expansion should be studied with a view to foreseeing possible encroachments on the older urban quarters.

Zoning should be planned and protected by legislation in order to provide for the needs of the local population and regulated strictly according to the requirements of conservation. No other challenge will be more imperative than this, for, when the technicians entrusted with the protection of the site are faced with possible encroachments by industrial installations or various branches of commerce, they must use all their imagination and ability to protect their interests even to the point of finding more suitable locations for business and industry elsewhere. In establishing a zoning system which will provide for both present and future, the nature of the land and its various potential uses and the activities and installations which may be considered to be appropriate to the area will all have to be taken into consideration. But the first goal should always be the conservation of the national heritage.

CONSERVATION IN PRACTICE

The scientific and technical aspects of conservation within the urban site are largely covered in the present work by Chapters 10 and 14 dealing with monuments and stone respectively. It will suffice to add here a few recommendations arising from the special features of composite urban sites.

Preservation of the character of an urban site

As has been pointed out, the integrity of an urban centre or historic quarter should be protected under the same laws as those applying to a single or detached monument; it is as important to protect the setting of a whole area as it is to protect that of a classified monument. The characteristic atmosphere of an old quarter should be preserved at all costs, for incomparable damage to the panorama would result from the introduction of obtrusive new built-up areas. New edifices should not be allowed to be built on a scale which would be out of proportion with the scale of the existing buildings, and rigorous laws should be passed to prevent old structures from becoming submerged in building developments. The traditional names of the streets should also be maintained, or restored if they have been changed for more recent names, even with the commendable object of commemorating great events or outstanding personalities. In operations for the repair and stabilizing of edifices, it is advisable to keep to the original mode of construction (except in cases of *force majeure*) and also to use the original style of paving in the streets and roads. Typical details of construction and finishing of roofs, cornices, sashes, casements, etc., should be respected and the same original colours should be used both for the exterior and the interior walls of the buildings.

Modernization of an historic urban site or quarter

The integrity of the site will not necessarily be threatened, however, by alterations which are restricted in scope or not too readily visible. Alterations of this kind may be tolerated, either because they affect buildings of secondary importance, or because they are in inconspicuous places. The external aspect of the original building or of any of its characteristic elements that remain must be strictly protected, but usually no harm is done if the inside is changed or modernized, always provided that modifications are not made, even to the interior, where the plan is of exceptional interest or significance. Structural or decorative elements of outstanding value should be similarly protected.

RESTRICTIONS ON COMMERCIAL OUTDOOR ADVERTISING

The satisfactory conservation of the site further demands the discouragement of certain practices, chief among them being certain forms of commercial advertising. Posters and brilliant signs, whether using steady or intermittent light, and often of vast proportions, have come to be characteristic of the evening scene in our cities which rely on their luminosity and festive glow. But in protected sites such publicity is inadmissible. It would be quite impossible to preserve the original features of an old site, were the intrusion of posters and neon signs condoned, for it is in the nature of an advertisement that it should have the maximum prominence in the most conspicuous place. The beauty and picturesqueness of historic urban approaches are destroyed by the intrusion of these alien elements. Monuments and even the less obtrusive historic buildings cannot be utilized as mere supports for the varied inventions of publicity enterprises without loss of nobility and dignity. The coloured posters and the billboards which line the highways of all but the most advanced countries destroy the poetic element of landscapes. Authorities responsible for the conservation of protected sites must therefore take strong measures to prevent the introduction of such posters or other garish commercial advertisements both in and near their neighbourhood. Strict regulations must be passed concerning the size, shape, disposition, location and content of all advertisements and posters permitted in or near any site scheduled for conservation.

TRAFFIC AND PARKING

Heavy road traffic, the parking of vehicles of all kinds and the loading and unloading of merchandise from trucks are inevitable features of life in modern towns. In the large cities the excess of traffic brings, proportionally, an increase in the number of parked cars. This is a modern trend, parking facilities are invariably inadequate and the problem becomes steadily more serious in every country in the world. And yet no solution seems to be in sight.

Accommodation for tourists

Where restrictions can be made, for example, in the vicinity of scheduled monuments, parking difficulties arise not so much from the needs of the local population as from those of visitors to the site. This is not to suggest that there is anything against sites or monuments becoming public attractions; quite the contrary, tourism has important economic and cultural connotations and both public bodies and the conservation authorities should foster it, being trustees for the body politic. After all, it would be absurd to attempt to maintain the areas entrusted to their protection in isolation or to render them difficult of access.

The influx of visitors and tourists is both necessary and useful, not least for the expansion of trade that inevitably results. Adequate parking facilities should therefore be provided, conveniently situated in relation to the monument but without creating a nuisance. There is then little reason to complain of the bustle and excitement which enlivens the streets for a few brief hours daily, when it brings with it such exceptional advantages.

Problems posed by large vehicles

In addition, in order to avoid damage to the integrity and beauty of the site, two important steps must be taken. The circulation of trucks carrying very heavy loads must be prohibited, as often neither the pavement nor the stability of the buildings can withstand the extra stress and vibration so caused. For the same reason bus terminals should not be allowed in the vicinity of monuments or in the most typical parts of a historic or artistic quarter.

As for through traffic, bound to farther destinations, it is the duty of the public authorities to provide, in accordance with the road system of the region, a peripheral highway or bypass (Fig. 46) to prevent unnecessary circulation in congested areas, whatever their cultural significance.

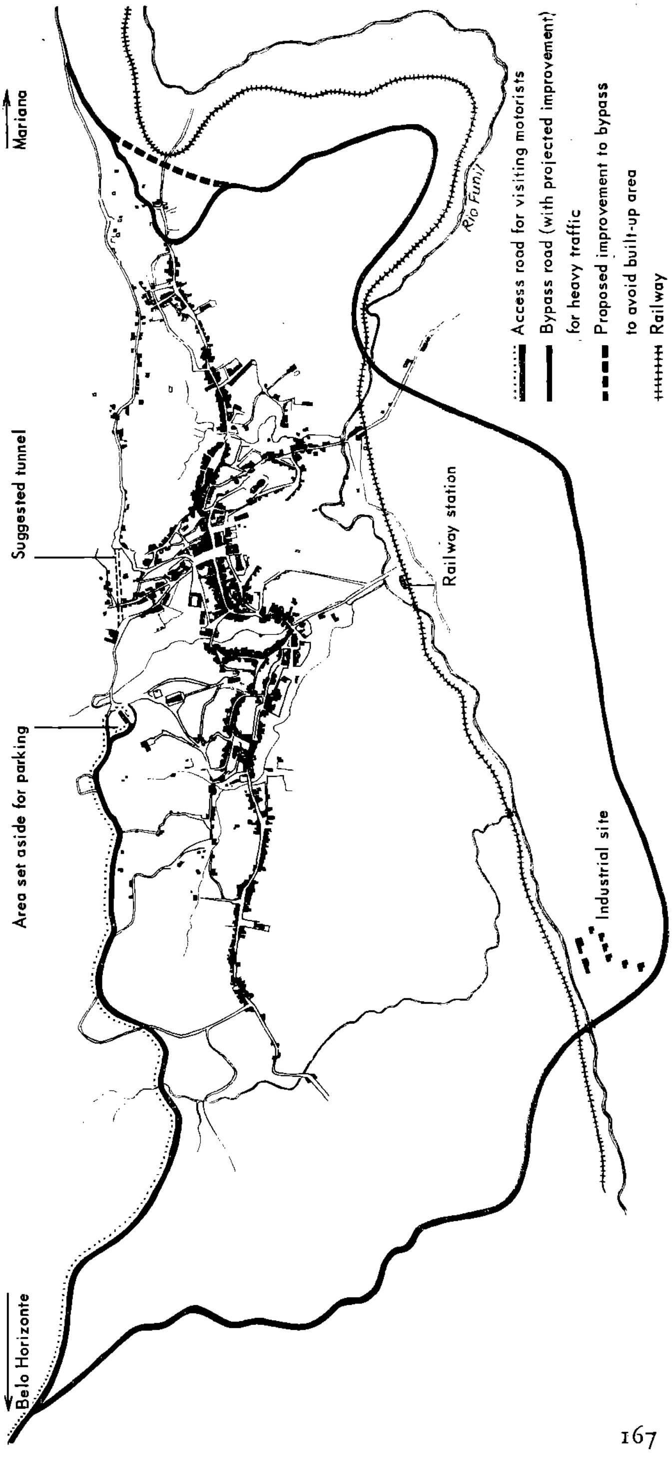


Fig. 46.

Plan of Ouro Preto showing access and through traffic routes (rail and highway).

ARCHITECTURAL CRITERIA

Should new buildings in old quarters consist of modern reproductions of historical forms and styles or should they boldly proclaim the idiom of their own period? In other words, which should prevail: the radical purism which is hostile to any kind of counterfeit, or the easy academism of reproduction, faithful to the models of the past?

In answer to this fundamental question we should submit the following as a basis for judgement. When the nature of the materials and the technology is completely different, as in the case of large glass structures (curtain walls, etc.) the absolute contrast may well be preferable. When, however, it is only a question of filling up empty spaces in a historic quarter, the criterion of correct reproduction should prevail. Both in the former case and in the latter the success of the enterprise will depend on the professional quality as well as on the sensitivity of the architect in charge.

In general, contrived scenographic settings are objectionable, and, whatever the circumstances, it is most important to maintain a harmonious balance as regards colour, scale and proportions.

Paul Philippot and Paolo Mora

The conservation of wall paintings

12

THE INVENTORY

A basic requirement in planning for the conservation of wall paintings in any region is that full information should be available regarding the works to be preserved. The first step, therefore, is to draw up a systematic inventory which will serve as a basis for recording their location and relative importance, their condition and the degree of urgency regarding any preservation treatment that may be required. From this can be deduced whether, in any given case, it is safe to leave a work to be protected *in situ* or whether the only hope for preservation is to transfer the painting to a museum or gallery.

Apart from considerations of physical structure, there are also the risks to which murals may be exposed by casual visitors using caves or abandoned structures for shelter and causing damage by lighting fires or even by scratching graffiti on the walls. Photographers have been known to wet paintings to make them more apparent, often with disastrous results.

When drawing up an inventory it will be seen that certain works require special attention. A primary documentation should always be assembled, including photographs and perhaps even micro-samples taken for laboratory testing.

FUNDAMENTAL PRINCIPLES

Two fundamental principles must be stated at the outset. The first is that wall paintings are normally part of a monumental assembly for which they were expressly designed and which in turn have a determining influence on their character and aesthetic effect. This is just as true for cave paintings as it is for those forming the integral parts of an architectural structure. Every possible effort should therefore be made to conserve such paintings in their original setting. Removal will inevitably result in disfigurement and possible structural damage to the monument as a whole, to the particular architectural setting and to the painting itself. For this reason the transfer of a painting must always be considered as an extreme and exceptional operation which should not be undertaken unless it is certain that alternative measures of conservation are impossible.

The second general principle is that attempts to arrest or control a process of deterioration without identifying and removing the causes are doomed to failure. The main causes of the deterioration of wall paintings are those which also affect the architectural structures themselves (these are discussed in detail in Chapters 10 and 14). In the first place the influence of humidity should be determined and its origin identified—capillarity, infiltration or condensation—so that appropriate action may be taken from the point of view of protecting the complete ensemble. The stagnant, humid atmosphere of caves and chapels particularly favours the growth of micro-organisms and requires the control of ventilation and even, perhaps, in serious cases, a curb on the influx of visitors and the installation of air-conditioning. These are matters, however, for the attention of a technical expert.

PRELIMINARY EXAMINATION

Visual examination must always have priority and in most cases will reveal the nature and extent of the problems to be dealt with: cleanness of surface, efflorescence, incrustations, mechanical damage, etc. To assess the degree of adherence of colour and the state of the surface in general a raking tangential light can be particularly effective. A powerful electric torch, or polarized light projector, will thus reveal the slightest irregularity of surface due, for instance, to the flaking of the paint layer. To determine the adherence of the ground to the support it may be necessary to tap the surface gently with a knuckle: a hollow sound indicates the presence of an air-pocket between the ground and the supporting structure (Fig. 47). With experience one soon learns to assess the degree of adherence by the sound produced. Where lack of adherence is detected the location should be indicated as precisely as possible on a drawing or photograph in order to trace any subsequent spread of the trouble and proceed systematically with treatment. The degree of cohesion between the paint layer and the ground can be determined simply by observing the resistance of the surface to abrasion, for where there is weakness the paint becomes powdery. It is also important, particularly if there is a possibility of the mural being transferred, to ascertain the degree of resistance to humidity. This can be tested by gently rubbing damp wadding on the surface of the painting in a part of minor importance. It must be remembered, however, that certain colours are more sensitive in this respect than others and may have been applied with a special medium. In this connexion, a knowledge of the techniques of the various schools of painting in the locality can be most valuable.

White or opalescent stains may be due to the presence of micro-organisms or to saline efflorescence. In such cases, identification is best left to the laboratory.

When a much-worn painting has become difficult to distinguish it is often possible to obtain more information by the use of screened ultra-violet light (fluorescence) and the results of such an examination can be recorded photographically.

CLEANING WALL PAINTINGS

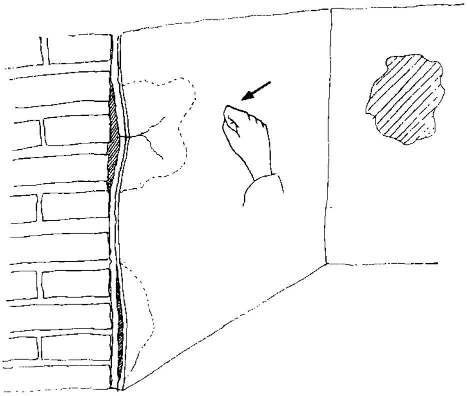
The methods employed for cleaning mural paintings vary, naturally, according to the substances that have to be removed and the materials that are to be preserved (see also Chapter 14, 'The Conservation of Stone').

Brushing. If, as is often the case, it is merely a question of removing dust, it is simply necessary to brush the painting with a soft dry brush.

Solvents. When, in addition to dust, grease is present, as is especially the case where there are smoke fumes, recourse must be had to the use of solvents, beginning with the weakest and using stronger solvents only as required.

In most cases satisfactory results can be obtained with water containing about 10-20 per cent of ammonia, the solution being applied gently on a tampon of wadding, with special care in regard to the least resistant colours. If necessary, a solution of 10-20 per cent of butylamine in water may be used, or alternatively an 80-90 per cent solution of cyclohexylamine in water, the effect of the water being to increase the solvent action on greasy substances. The latter two cleansing solu-

Fig. 47.
Wall paintings. Testing the adherence of the painted surface to the wall by tapping.



tions are also very effective for the removal of overpainted layers in oils.

Abrasives. When the surface of the painting is very hard, a mild abrasive, such as diatomaceous earth ('fossil dust') or pumice flour, may be added to one or other of these solvents. In extreme cases, the surface may be treated with a paste of ammonium stearate which is left to react for some minutes (test for the effect of softening) or hours as required.

Removal of wax. Paintings that have been treated with wax tend to acquire a sombre tone and to become dusty. Either carbon tetrachloride or trichloroethylene may be used to remove the wax but it should be remembered that the latter product is somewhat toxic and is liable to burn the skin.

Removal of resins. Resin varnishes (copal, shellac) may have been applied to a mural painting in the course of a previous restoration and may cause darkening and other damage. They are generally removable with one or other of the following solvents or with mixtures of these: dimethylformide, alcohol in turpentine, benzol, or acetone.

Removal of animal glues. Animal glues and also gum arabic, possibly applied in the course of previous restorations, are removed by the solvent action of warm water containing 10-20 per cent of ammonia, or with butylamine or 80 per cent aqueous cyclohexylamine as indicated above.

To begin with, the solvent should always be tested on an inconspicuous and unimportant part of the work, while in actual cleaning the most important and delicate parts are dealt with last.

Removal of saline efflorescences. Where soluble salts are involved, efflorescences may be eliminated by brushing, followed by washing with water. The treatment may be carried a stage further by applying a paste of moist paper pulp to the surface of the painting but only when the paint layer has proved to be adequately resistant to damp.[1] Through this process the salts are dissolved and absorbed into the pulp as it dries and so can eventually be removed with the pulp.

Insoluble salts, gypsum, stalactites or the white veil of calcium carbonate sometimes found on wall paintings present problems for which there is no simple solution except the purely mechanical one of scraping with scalpels or other dental instruments. This is not always possible, however, and in any case requires the greatest care and infinite patience.

Removal of organic deposits. It is not uncommon to find paintings damaged by accumulations of organic material, bees' and wasps' nests, bat excrement, etc. Mechanical treatment is indicated in such cases, as a

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[1] It may be necessary to protect the pigment by an application of soluble nylon or Catalan CB in alcoholic solution whilst the salts are being extracted.—EDITOR'S NOTE.

first measure, and the very thin veil of material remaining can then be eliminated by washing with a tampon of wadding moistened with ammonia and water as described above.

Removal of vegetable growths. Where growths of moss or lichen are active it will be necessary to consider poisoning the nutrient materials by treatment with sodium silicofluoride or with zinc or magnesium chloride as described in the chapters on stone and monuments. Under damp conditions, and especially in grottos *(Plate 22)* the growths may be of algal origin and are usually green when exposed to light. Under tropical conditions fungoid growths may also be expected. These should be identified if possible and the treatment for both consists of sterilization accompanied by an improvement in ventilation to allow the circulation of a current of fresh air. The usual sterilizing agents are formalin—a clear solution, which may be applied by brush or spray—or the more poisonous sodium pentachlorophenate which is applied in 2 per cent aqueous solution with a soft brush and which affords protection over a longer period. The control of microfungi and bacteria is primarily a matter of ventilation.

Removal of whitewash. For reasons of taste or expediency, religious or otherwise, mural paintings are frequently found blotted out by a layer of some opaque wash of chalky appearance, usually calcium carbonate. In such cases the nature of the covering material should be ascertained by scraping and testing the scrapings with acid, in which all carbonates effervesce. Such coatings are generally removed mechanically, but the operation is slow and delicate, requiring much patience and prudence if the underlying painting is to be exposed again in its original state. It should be borne in mind that there may be more than one layer of painting beneath layers of whitewash and careless work may ruin all.

CONSOLIDATING WALL PAINTINGS

Fixing the paint layer

Fixing is required when the paint layer is flaking or tending to become powdery. A good fixative must have sufficient adhesive power to consolidate the paint. It must be colourless, must penetrate thoroughly, must be resistant to abrasion and, above all, must not modify the colours of the picture or change the general tonality.

Among the materials now used that best meet requirements is the substance called Paraloid, a colourless synthetic resin of the acrylic type. It is applied, depending on the conditions, by brush or spray in solutions varying in strength between 1 and 5 per cent in toluene, or preferably, since toluene is toxic, in cellosolve. It may also be dissolved in chlorothene to make a 30 per cent solution which is diluted with Shellsol E so as to produce a concentration of 1 to 5 per cent of Paraloid. This formula gives better penetration, evaporation of the solvent is slower and there is less likelihood of a shiny film being formed on the picture. The most dilute solution that tests prove to be effective should be used since this will penetrate best. Too concentrated a solution leaves a skin on the surface which may actually tear the paint layer as it contracts on drying. For this reason the minimum quantity is used and care is taken to ensure that it does not accumulate to form a continuous film producing a 'shine'. Any surplus must be mopped away with absorbent wadding.

Another satisfactory fixative is Bedacryl (122 X) and in this case one volume of the commercial solution must be diluted with at least ten volumes of toluene.

Shellac was much in favour before the advent of synthetic fixatives, but although it has excellent adhesive properties, it invariably becomes yellow and progressively darker in time. For this reason it is no longer employed, or, if at all, used sparingly.

Impregnation can obviously only be carried out up to a certain depth. Should that prove to be insufficient and the upper layer of the ground still remains weak, there is no alternative but to proceed to the transfer of the painting by the *strappo* process (see below, 'Transferring Wall Paintings').[1]

Consolidation of the painting ground

Simple treatment. Two conditions may be recognized. In the first case the ground may, for some reason, have become pulverulent, in which event it may be consolidated by impregnation with a fixative such as Paraloid or Bedacryl.

Fixing a detached ground. In the second case, though solid, the ground may no longer adhere to the support and, where it is detached, a different kind of treatment is required, as described below.

Examination and preparation for injection. The sub-surface condition is first examined to locate areas of cleavage and these are then filled by injecting calcium caseinate with the addition of polyvinyl acetate (Fig. 48). Instructions for the preparation of the mixture are given in the Appendix to this chapter (formula 3) and the operation is carried out as follows. In the absence of cracks at places where they could be used for injection purposes, it becomes necessary to drill into the lacunae from the surface, care being taken to select places where there will be a minimum of damage. The holes are from 2 to 3 mm in diameter—one to each air pocket, or two if it proves impossible to inject without making special provision for the exit of air. This can be tested by applying a squeeze bulb to the hole.

Injecting the fixative. Before injecting the caseinate the way is first prepared by an injection of alcohol and water which serves the dual function of eliminating air

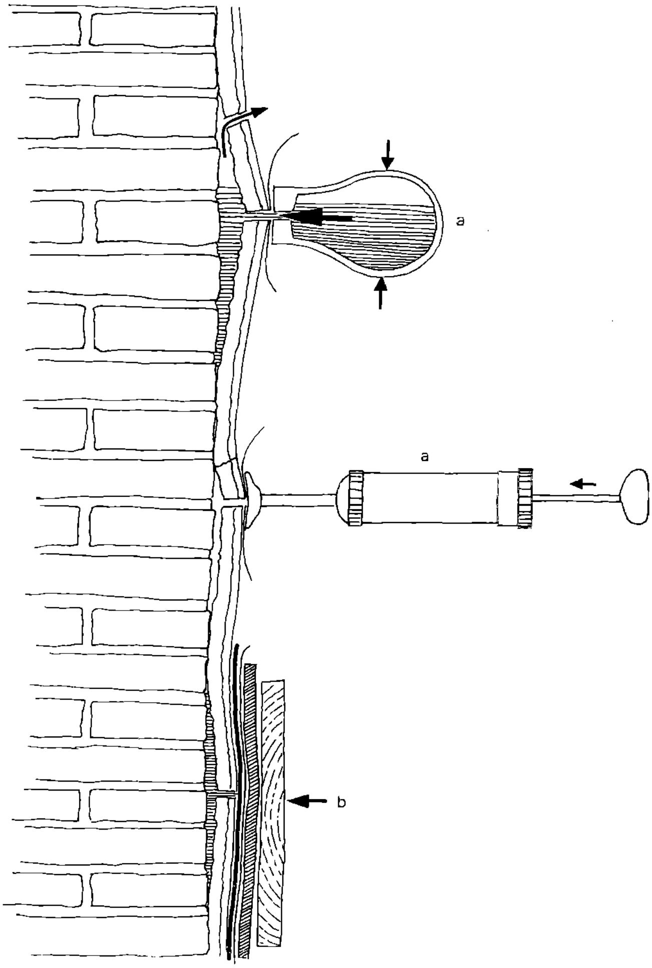

Fig. 48.

Consolidation of the paint-bearing surface against its supporting wall:
a Methods of injecting fixatives;
b Application of pressure to the surface until the caseinate is fixed.

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[1] See also the discussion of synthetic products in the Appendix, page 303.

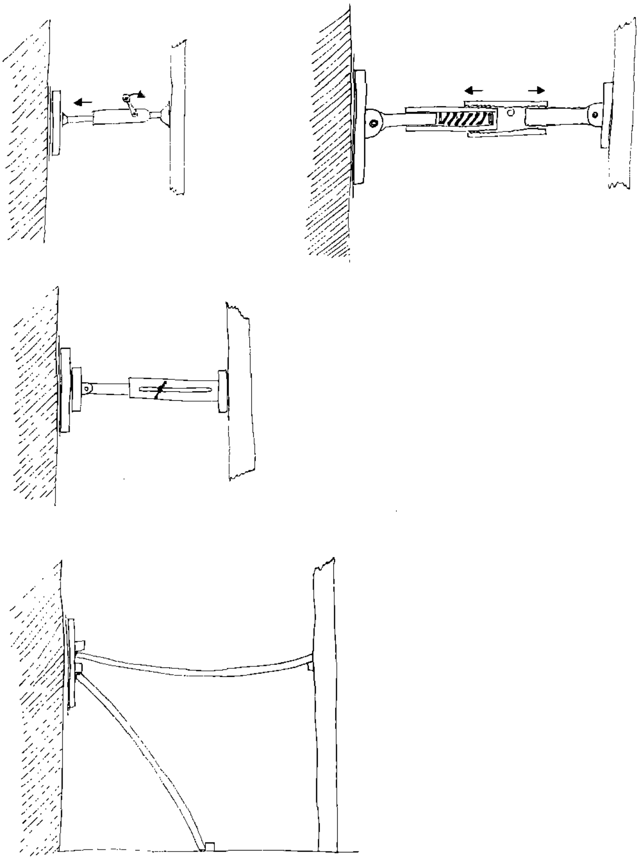

Fig. 49.
Various methods of applying pressure to the surface of a mural painting while the caseinate is setting.

and moistening the ground. Then follows the caseinate, at first fairly liquid and then thicker. If the opening to be filled is rather large it is preferable to add fillers such as fine sand or marble dust. Should there be excessive loss of injecting mixture due to a crack or fault in the support, this will require special attention. It may be that the painting is in such a condition that certain areas threaten to fall away. If so, they must be fixed in place provisionally by plaster ties or by facing with a textile fabric (see below).

Supporting the painting during treatment. During the process of injection the painting must be supported to prevent it becoming detached by pressure from behind, and when completed some form of pressure must still be applied to the surface until the caseinate is sufficiently set to bear the strain. Various devices can be employed for this purpose, including springs, flexible rods, screw jackets, etc., which should not come in direct contact with the painting but with a flat board covered on one side with felt and designed to protect the delicate surface from all local strains (Fig. 49).

Throughout operations care must be taken to prevent any drops of calcium caseinate coming into contact with the picture as, even when removed, it leaves indelible marks.

Retouching

When, as is commonly the case, a mural painting is imperfect and certain isolated portions are missing, these areas must be dealt with in such a manner as to satisfy two fundamental requirements, namely: (a) respect for the work as a piece of historical evidence, which precludes any kind of faking; and (b) as far as possible, recovery of the aesthetic unity of the work so that it can be fully appreciated. The retouching of such missing areas calls for special qualifications in the operator in addition to studio training—an understanding of the significance of the work as an artistic and historical document and an appreciation of its particular qualities. The responsibility, therefore, of authorizing any retouching is not inconsiderable and the extent of such retouching must be related very definitely to the qualifications of the personnel available for the work. Retouching, after all, is not an essential part of conservation and it must be emphasized that responsible authorities do not authorize such work unless an experienced technician is available.

Treatment of blank spaces or lacunae

Nevertheless, the lacunae cannot be neglected: the edges must be fixed and it is desirable that the general surface, normally beneath the level of the picture, should be brought up to the original level by careful plastering, but never with cement. A mortar must be used which is similar in composition to that of the painting ground which is usually prepared from a mixture of slaked lime and sand. Scrupulous care is required with the edges, which must be fitted perfectly to the borders of the painting without ever covering the colour. Finally, there is the all-important question of texture; the grain-condition of the surface must be made to match, as far as possible, the original, in the interests of continuity.

Small lacunae. When lacunae are very small or are so situated that there can be no possible doubt about the reconstruction, and when—as, for example, in the case of an obtrusive broken line or a missing part in a decorative frieze—the interruption causes a serious lack of unity, then despite what has been stated above, some degree of reconstitution may be justified *(Plate 23)*. It must never be forgotten, however, that the aim is always to restore to the original its presence and its lost authority and never to attempt to compete with it. In this respect the quantitative factor is crucial: if the retouched area is too noticeable it will outweigh the original instead of restoring it. This can be true however skilful the retouching. Where large areas are involved, therefore, the safer course is to accept the fact that much is missing and limit the treatment to consolidation since only some such modest policy enables the authenticity of the work to be perpetuated.

Before any retouching at all is done, a photographic record must be prepared in accordance with the basic principle of respect for the painting as a document. In practice, of course, it is always preferable to carry out retouching so that, while it achieves its aim of reintegration, it is recognizable for what it is, namely an addition. Time, however, has a way of causing changes in appearance that may eventually introduce doubts and this is one good reason why it is imperative to incorporate photographic records in the general documentation.

Large lacunae. It has been stated that where lacunae are large, they are best left plain and this also applies when they are in awkward situations and retouching would be difficult. But the tone to give to the stucco filling must always be very carefully studied so as to avoid its appearing like a hole in the wall! For the sake of unity, the filling must at least appear to be in the same plane as the rest of the painting. If, however, the lacune are so great as to detract from the appearance of the conserved painting, it is often preferable to keep them at a slightly lower level and perhaps to leave visible the underlayer of the ground or even the support.

Retouching can be carried out with several types of binding media: water colour, distemper or synthetic products such as Primal, which is similar to a Paraloid emulsion, or Bedacryl L (Bedacryl Emulsion). All have their individual characteristics and for each type of work a choice will have to be made of the product that appears to be most suitable.[1]

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[1] See also the discussion in the Appendix, p. 303.

TRANSFERRING WALL PAINTINGS

Introduction

As has been suggested, the transfer of a wall painting is a major operation, an extreme procedure which can only be justified when, after exhaustive study, it is decided that the work cannot be saved by any other means.

Whatever method of transfer is considered, the first essential is to assemble the documentation of the whole monumental ensemble and to make it as complete as possible. A comprehensive and detailed plan should be worked out at the same time to cover both the transfer and the reconstitution of the ensemble.

Particular care is necessary in planning the system of cuts essential to the operation. This must be as simple as possible and designed to do least damage to the painting. The testing of materials is also an essential preliminary, for the painting itself must be shown to be resistant to water or to the particular solvent that will have to be used to remove the facing fabric adhesive. For all methods involve the use of facing fabric to protect the painting during transfer.

The selection of the most appropriate method for a particular case is a matter of great importance. The three techniques which call for special mention are: (a) *strappo*; (b) *stacco* and (c) *stacco a massello*. These may be defined as follows. *Strappo* involves detaching the paint layer by pulling it away from the ground with the facing fabric which has been glued to its surface. *Stacco (Plate 24a, b, c)* signifies the removal of the painting, after facing with gauze and canvas, together with the ground by cutting the ground away from the wall with long bayonet-type knives. In the *stacco a massello* technique the picture and ground are removed with part of the support, after facing. This requires preparation for transporting a heavy and delicate load.

All three, indeed, are methods of the greatest delicacy which should only be attempted by highly experienced technicians. Nevertheless, it may be interesting to consider what is involved in these processes in a little greater detail (Fig. 50).

Strappo

General discussion. When the painting ground is found to have lost its cohesion to such an extent that consolidation *in situ* becomes impossible, the usual recourse is that of saving the paint layer itself by the *strappo* method of tranfer. This is the most direct method. It permits the removal of the largest areas in one single piece and it has proved to be the method best adapted for dealing with complicated problems (curved surfaces, vaults, etc.). On the other hand it requires particular dexterity and has a disadvantage in that, when the painting is laid down on a new flat support, it tends to present a surface which is abnormally flat and uniform. It is possible, of course, to retain such reliefs as nimbos and impastos, but the undulations peculiar to the wall are lost in the picture once transferred. For this reason *strappo* is only employed in cases of absolute necessity. To recapitulate: *strappo* is the technique usually adopted when the solidity of the ground and adherence of the paint layer are insufficient to allow of a transfer of paint plus ground, or when the ground is too thin, or when one wishes to lift the picture without unduly cutting up a very large area or when the surface is concave. A striking feature of *strappo* is that it is the only method of transfer that makes it possible to reveal the original drawing when this has been traced on the under-layer of the ground. Once exposed, this drawing, in turn, can be preserved.

Before any definite decision is made to apply the *strappo* technique it is necessary to test the strength of the glue, etc., care being taken to carry out such tests on some unimportant and inconspicuous area.

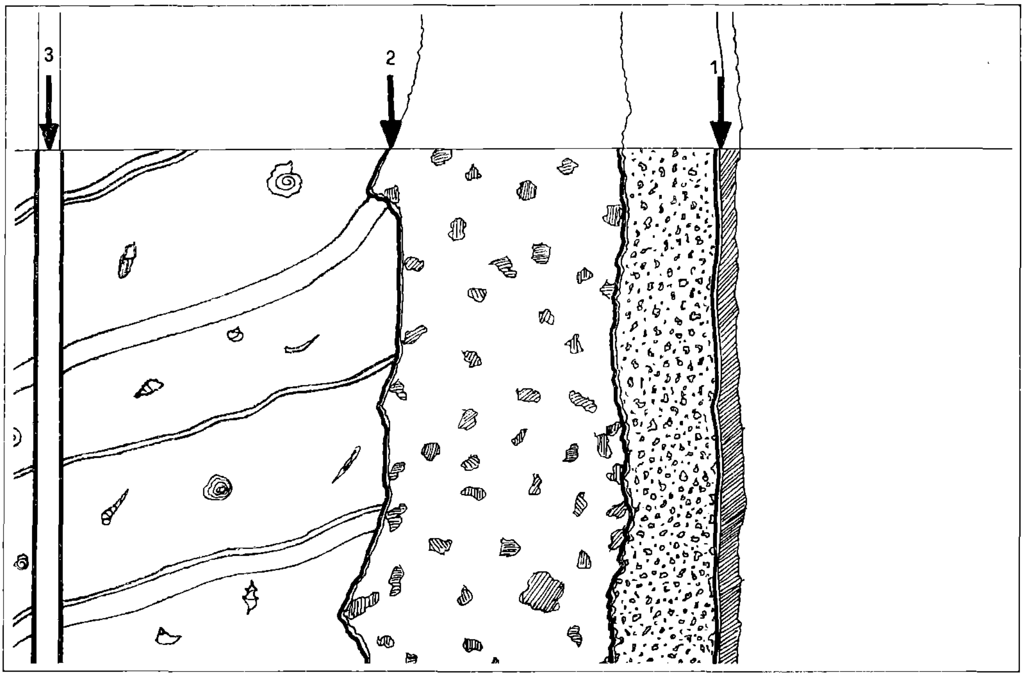


Fig. 50.

Illustrating depths of cuts required for the different methods used to detach a mural painting from the wall.

1 *Strappo:* painted surface to be detached.
2 *Stacco:* in which the fine *(intonaco)* as well as the coarse plaster *(arriccio)* layers are detached from the wall.
3 *Stacco a massello:* detaching part of the wall as well as the plaster.

General principles. A facing fabric is glued to the surface of the picture in such a way that the contraction of the glue on drying will facilitate the stripping of the paint layer. Since local humidity conditions affect the rate of drying, *strappo* transfers are always carried out during the period of the year when the relative humidity of the atmosphere is at its lowest (40 per cent to a maximum of 70 per cent). Transfers should never be attempted in frosty weather.

If necessary, the walls may be dried out in preparation for the work by small heaters or infra-red lamps placed between the walls and an adjustable screen but, of course, it is important to avoid overdrying which may cause the glue to set too rapidly.

Strappo technique. The first requirement is to clean the surface of the painting by dusting it lightly all over, taking care to remove any excrescences (incrustations, protruding edges of lacunae, spurs, etc.) that impede the *strappo.*

Facing. The facing is then applied to the prepared surface with an adhesive based on strong animal glue (see the Appendix to this chapter, formula 1: 'colletta'). When the wall is very dry, a little molasses is added to the mixture to prevent premature setting and contraction which might tear the film instead of lifting the paint layer in its entirety. In compounding the adhesive it is advisable to add a little vinegar and some ox-gall as this improves fluidity, wetting qualities and penetration. If the wall is damp and cannot be dried, the animal glue is replaced by shellac, which will set in damp conditions; while this is undesirable as a normal process, it has been used successfully in salvaging funerary paintings from Etruscan tombs where the relative humidity is as high as 95 per cent.

The facing usually consists of cotton gauze and hemp canvas. The first layer of glue is applied directly on to the painting with a brush; it should not be too liquid and should cover exactly the area of the gauze which should have been previously washed to remove the dressing, dried and teased out along the edges. The gauze is then applied to the wall with very hot glue. A margin of a few centimetres around the edge is turned back away from the wall to facilitate later stages of the operation. The rest should adhere closely to the surface, slightly stretched, but not unduly so. A second coat of glue is then applied over the gauze, great care being taken to see that no air bubbles are trapped between the painting and the fabric.

The canvas is now applied, after allowing a little time for drying, by coating with a glue that may be considerably more liquid than the first coat. The thicker glue used for the first coat prevents an impression of the weave being left on the paint surface and at the same time allows for the necessary contraction on drying. Both gauze and canvas should always be applied from the bottom of the mural upwards so that glue will not run down over the picture. The vertical edge of each new piece of fabric should overlap one or two centimetres on to the previous piece, care being taken to see that the joints of the gauze and those of the canvas do not coincide. This clearly calls for team work. A great advantage of the *strappo* method is that it allows transfer of very large areas in one piece (about 30 m^2 in normal conditions).

Transfer. The stripping operation should be begun when the facing is dry and before the glue becomes too hard.

The drying time will be influenced not only by the relative humidity of the atmosphere but by the dampness of the wall. In dry surroundings it might be a matter of two days. If conditions are very damp, the glue may take so long to dry that moulds may develop, unless recourse is had to artificial heating. Shellac and synthetic adhesives, however, dry much more quickly.

The first operation is to make a clean cut in the paint layer along the edge of the textile fabric and then to pull firmly and steadily away from the wall and at right angles to it, on one of the lower corners, watching to see that the fabric is really pulling the paint layer away from the ground (Fig. 51). The operation is continued, easing the fabric up and down with a fanning movement, the paint layer and the facing being rolled up as they detach. An alternative method involving the use of a cylinder is to roll the facing off the wall from bottom to top on a drum, but this can only be done with a very flat surface. If necessary, of course, a scalpel can be used to detach the picture cleanly where lumps of ground or other obstacles tend to impede the operation. When the transfer is completed the ensemble is laid out flat, face downwards on a horizontal surface.

Application to new support (Fig. 52). In preparation for remounting the painting the back is evened out by rasps and abrasives and strengthened with a double fabric layer.

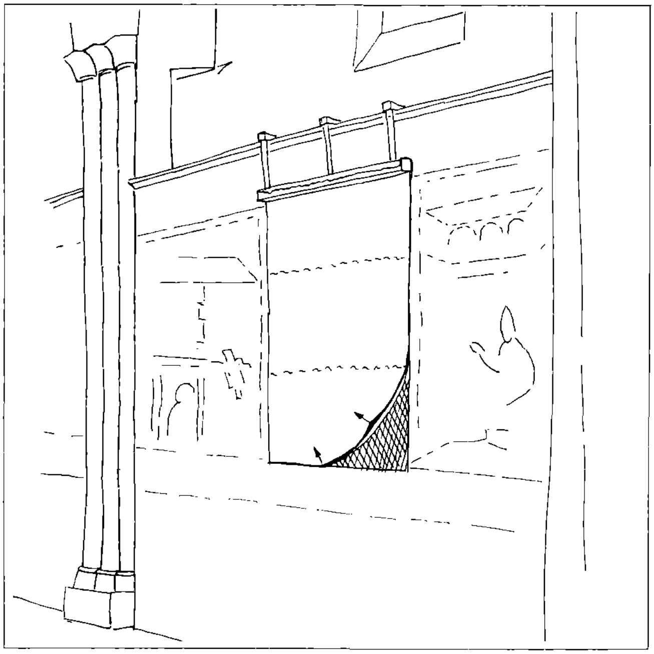


Fig. 51.

Strappo: detaching the painted surface from the wall.

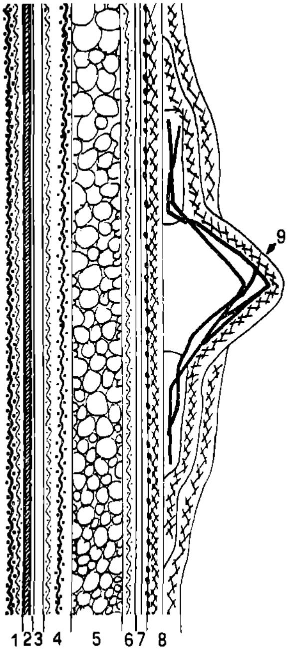


Fig. 52.

Cross-section of a wall painting which has been remounted:

1 Protective facing: this is removed after the detached painting has been consolidated to its new support.
2 Paint layer.
3 Fixative made of dilute skim milk or a diluted acrylic emulsion.
4 Gauze layer glued to the fixative with calcium caseinate—this may be reinforced with successive layers of gauze or canvas.
5 Layer of plastic foam.
6 Gauze glued with polyvinyl acetate.
7 Shellac layer.
8 Support of polyester with fibre-glass cloth.
9 Supporting frame of folded aluminium netting.

The procedure is the same as for facing except that the adhesive used is calcium caseinate—although synthetic adhesives have been used successfully, notably the acrylic resins which are soluble in toluene and acetone. Calcium caseinate, however, is the classical adhesive and it has proved to be satisfactory in temperate climates where the temperatures are moderate and the surroundings relatively dry. Excessive dryness of the surface no doubt results in a tendency to cusping and, on the other hand, excess humidity is credited with causing efflorescence—each of which conditions may necessitate some modifications. Nevertheless the traditional method will be described here, since it is the basic technique from which all others stem.

Assuming then that the transferred picture lies face down on a board and that the back has been evened out in preparation for application of gauze, the first requirement is to stretch the facing evenly and nail it to the work bench and to fix the colour at the back by the generous application of skim milk diluted with water or, alternatively, by a well diluted acrylic emulsion (e.g., Bedacryl L or Primal). When dry, these substances form a barrier to protect the facing glue from the bulk of the moisture to which it would otherwise be exposed by the application of the calcium caseinate mixture. The effect of excess moisture would be to soften the facing glue and cause an impression of the weave of the backing canvas to be formed in the paint layer. When dry, a layer of calcium caseinate is applied, tinted to reproduce the colour of the original ground. This latter precaution is of considerable importance in preserving the optical quality of the picture. The caseinate must be sufficiently thick to prevent the weave of the gauze making a permanent mark in the paint layer, but not so thick as to leave a craquelure effect on drying. A second layer of gauze may be applied in the same manner, followed by one or two canvases glued with the same calcium caseinate mixture.

At this stage it may be decided either to fix the canvas to a chassis or adjustable frame—which leaves the possibility of subsequently applying it to a rigid support—or to proceed forthwith to lay the canvas down, say, on a rigid Masonite panel, the surface of which has been covered by a sheet of plastics foam. The foam has the double advantage of ensuring that the painting will not assume an artificial flatness which is out of keeping with the subject and of allowing for any subsequent changes that may be required.

An acrylic emulsion is more resistant than casein to humidity, less liable to contraction and more resilient, but it is not as clear and if the concentration is not carefully controlled it may well come to exert an adverse influence on the tone of the painting, especially as the paint layer has been reduced to a mere film.

The best procedure, according to some experts, is to use a solution of synthetic resin in benzene and acetone for the backing rather than an emulsion or aqueous adhesive. The resin solution is claimed to yield a film that is as resistant and resilient as the emulsion and its adhesive properties are of the same order. It does not alter the colours and follows the slightest irregularities of the picture surface so faithfully that, according to Tintori, one can hardly distinguish after the event whether the fresco has been transferred together with its painting ground or not. This is due to the fact that the adhesives and solvents employed at the back do not affect the adhesives of the facing. It should be noted, however, that the solvents referred to are both toxic and inflammable.

The acrylic adhesive, once prepared, is suitably diluted and spread on the back of the painting and to this is applied the gauze, previously impregnated with a paste made from the same adhesive in which calcium carbonate has been ground. Should this paste require more thickening, some pumice powder may be incorporated as well.

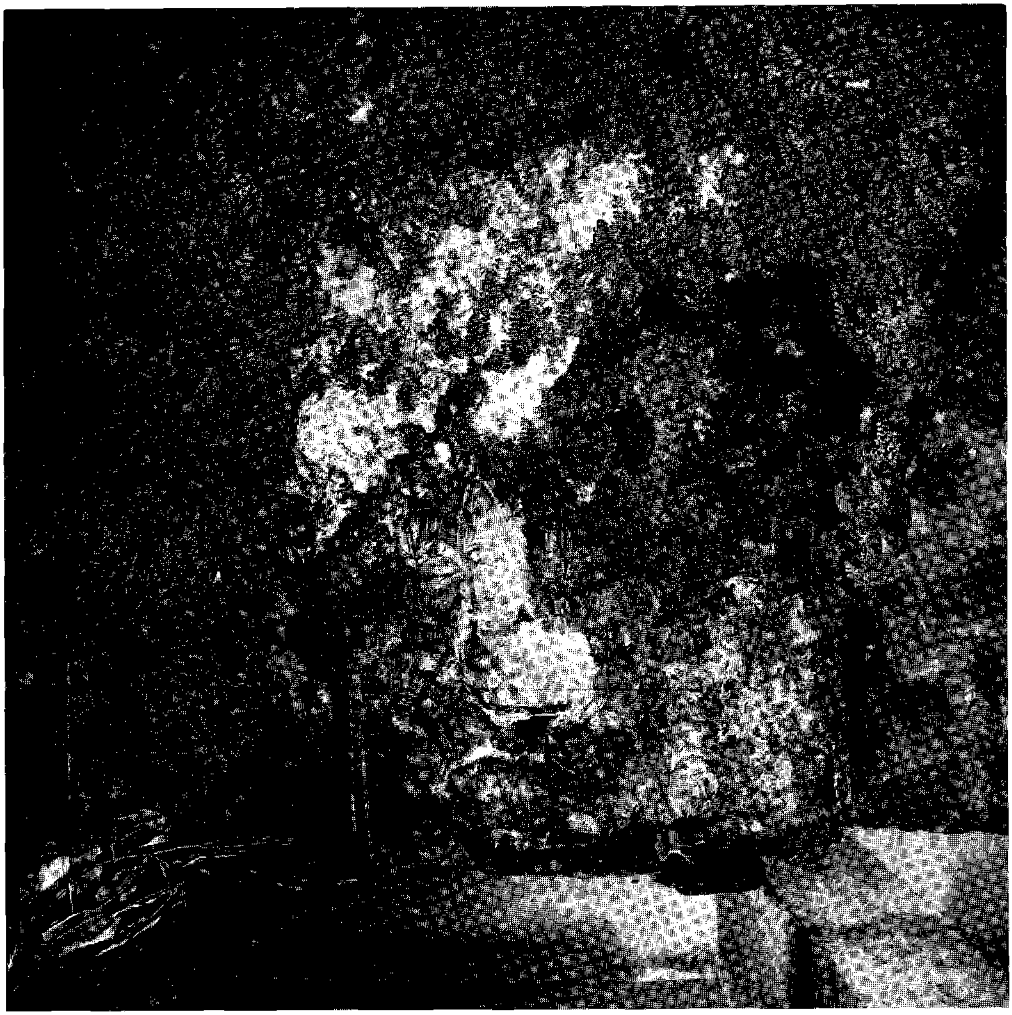
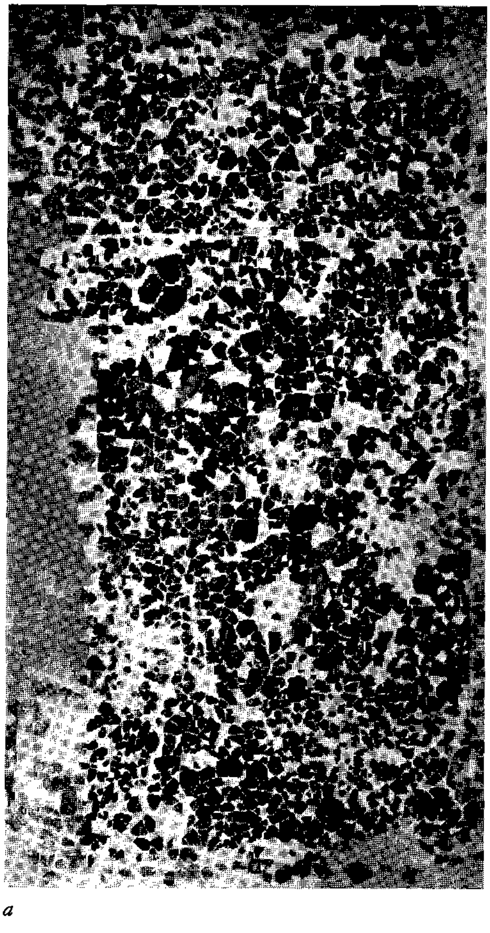


Plate 22

A mural painting in a grotto showing the results of efflorescence, the growth of micro-organisms and of plants (photo: Istituto Centrale del Restauro, Rome).


a


b

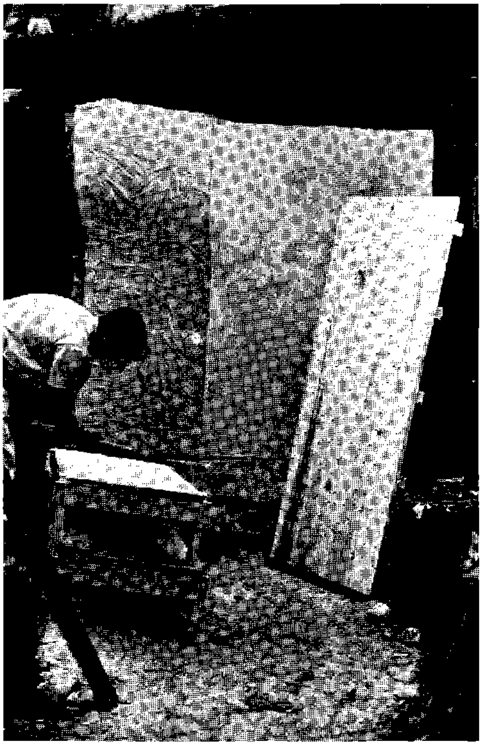
c

Plate 23

a A mural painting after consolidation *in situ* (photos: Istituto Centrale del Restauro, Rome).

b The same painting after the missing elements were restored by retouching.

c Retouched areas of a mural painting distinguished by striation *(tratteggio)* so that they will not be confused with the original.



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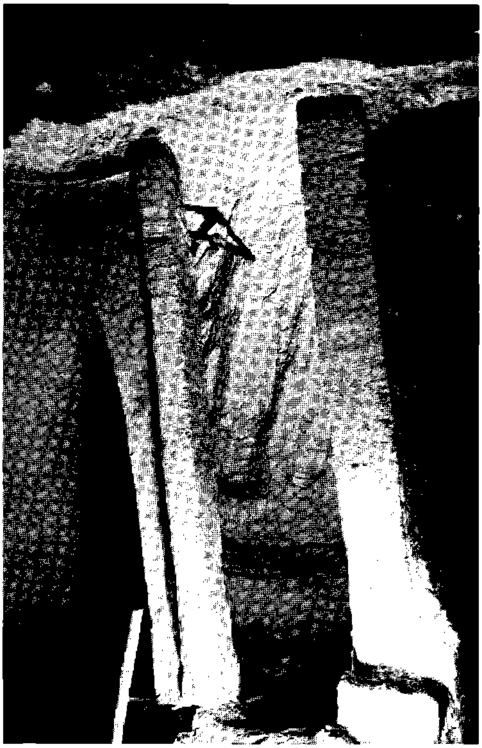

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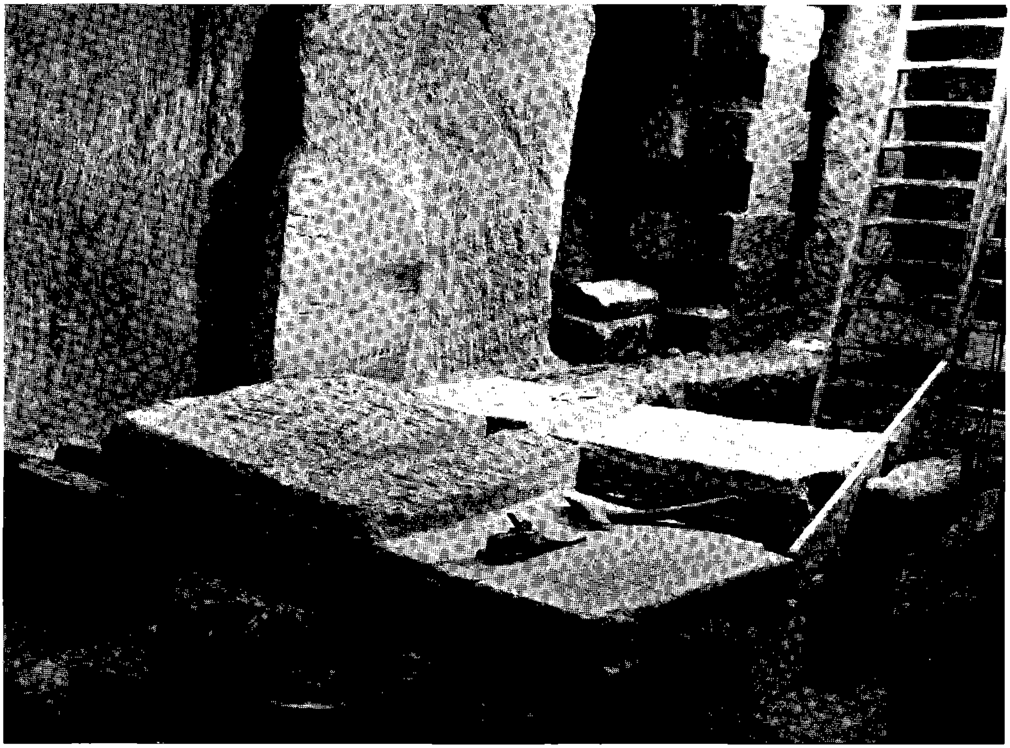

c

Plate 24

a *Stacco,* the transfer of the support together with the painting. On the right, the supporting panel. The painting has been faced with gauze and canvas. The lower cut to free the panel from the wall is being made by the technician (photos: Istituto Centrale del Restauro, Rome).

b Channel cut into the wall behind the painted surface *(stacco).*

c After the paint-bearing layer has been detached from the wall it is thinned for eventual transport and remounting.

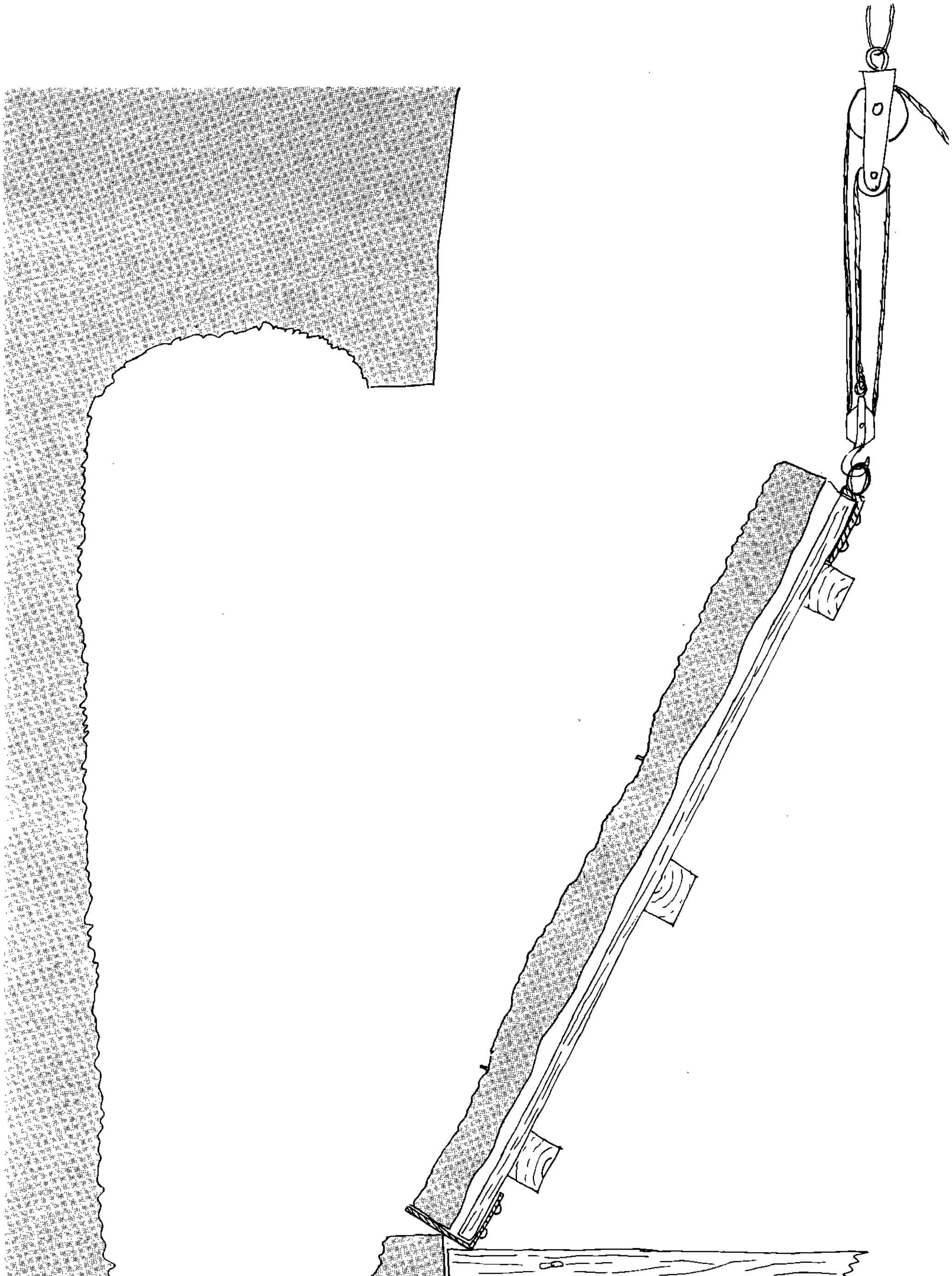

Fig. 53 *Stacco a massello*: detaching the section of supporting wall with the plaster and paint-bearing surfaces. Note the cradle used to support the detached mass.

Removing the facing fabrics. When the back is quite dry and solid, the ensemble is reversed and the facing fabrics are softened and removed, hot water being used as a solvent for strong glue, or alcohol for shellac as required. Patience and prudence are necessary in this operation. The fabrics cannot be manipulated until the adhesive is sufficiently softened for it to slide over the surface. The process may be facilitated by the use of a steam jet, or a sheet of plastics foam charged with cold water may be applied to swell the glue. Whatever the technique adopted, it is important to ensure that every trace of glue is removed from the painted surface.

Stacco

General discussion. When the condition of the mural does not make it essential either to employ the *strappo* technique or to consider transferring a portion of the support *(stacco a massello)*, the usual solution is to remove the painting together with the attached layer of ground; but this should only be undertaken if it is clear that the ground is firmly attached to the paint layer. The method is not suitable for such large areas as can be dealt with in one operation by *strappo*,[1] which means that *stacco* is both slower and more costly. It can claim, however, with *stacco a massello*, to have the advantage of respecting all the irregularities of surface which are so important to the character of mural decoration.

Preparation. As always, the first requirement is to clean the surface of the painting and to ensure that no impediment remains which might complicate the process unnecessarily. The documentation is then brought up to date as required and the surface studied all over in detail to verify that the paint layer is firmly attached to the ground and that this has a good cohesion, any unsatisfactory portions being suitably reinforced.

Facing. The facing is done in cotton gauze reinforced with one or two layers of hemp canvas glued over it in strips from the base upwards, as in *strappo*. The edges of the gauze are folded back on themselves around the borders of the picture so as to form a kind of hem about 5 cm wide. The canvas, on the other hand, is made to extend above the painting at the top for a distance of at least 30 cm and this flap is tacked to the wall or, if the wall is painted, to a horizontal wooden beam fixed firmly in place for the purpose.

In dry surroundings, the adhesive for the facing is the ‘colletta’ formula (see the Appendix to this chapter) which does not contract on setting. Where surroundings are so damp as to interfere with the setting time of the colletta, recourse must be had to shellac or some other resinous adhesive.

Detaching the section from the wall. A cut is made in the wall with a surgical knife or fine electric saw along previously plotted lines isolating the section to be removed. At the same time a wooden panel of corresponding size is prepared to support the surface during the subsequent cutting operations when the section is detached from the wall and later to carry the section when it is finally lifted away.

The facing fabric cloth is sometimes tapped uniformly all over with a hard rubber mallet to help free the support from the ground. The panel (duly padded with felt or some similar substance) is then applied as a buttress to the painting, in register with the section to be removed, and the hems of the facing fabric are turned over its edges and

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[1] The largest surface known to have been detached in one piece by *stacco* (2.6 × 6 m) was an entire wall of the decorated room of the Villa of Livia at Primaporta now in the Museo Nazionale Romano, Rome. This, however, was a quite exceptional piece of team work carried out by experts from the Istituto Centrale del Restauro.

nailed to the back of the panel, attention being given particularly to the security of the top.

At this stage the ground must be detached definitively from the support. This is done by means of long iron bars serving as levers between the ground and the wall. They should always be pointed slightly in towards the wall, beginning at the bottom and working upwards so that rubble will not collect in a pocket behind the painting.

When the painting is completely freed, the whole slab is gradually and carefully slid down until it lies on the ground or is safely supported on its padded panel resting on trestles.

Application to a new support. First the thickness of the back is reduced and smoothed down to about 1 cm, or even less if the material is not too resistant, so that only a thin layer of ground remains. The limiting factor will no doubt be the condition of the ground, for if it is greatly weakened the *strappo* rather than the *stacco* method would have been selected in the first instance.

The new support will consist of a chassis made of T- and L-section angle-irons, covered with fine wire netting and backed by an iron grid of 50 cm squares. All the metal must be treated with red lead to prevent rusting.

In preparation for mounting, the back of the painting is treated with dilute acrylic emulsions and, also, should it be very thin, with a layer of gauze. The wire netting is then applied, embedded in lime mortar and sand with the addition of casein or, alternatively, a polyvinyl acetate emulsion. No more water should be used than is absolutely essential, and the netting should be covered with a sufficient thickness of well-compressed mortar. To avoid cracking, the mortar should be reworked when it begins to set, the surface being rewetted and sprinkled uniformly with dry, clean sand.

Only when the mounting is completed and perfectly dry, i.e., after 10 to 25 days, is the facing removed to expose the painting. Here the method adopted is exactly the same as in the case of *strappo.*

Transfer with part of the support (stacco a massello)

General discussion. The *massello* system of transfer is employed only very occasionally and in special cases, e.g., under very humid conditions, or when the ground is particularly hard and resistant, or when irregular surfaces are involved where the relief must be preserved at all costs and, of course, when the mural is painted directly on rock.

Preparation. Cleaning is always the first operation and is carried out as described above; then reinforcement and documentation as necessary.

Pins are then stuck into the wall at right angles to a required depth, normally between 2 and 5 cm, thus serving as indicators of the thickness of the slab to be removed.

The pins should be stainless and about 1 mm in diameter. They should be inserted either in existing holes or in holes drilled for the purpose at points where they will not damage the picture.

Facing. Facing is done as for *stacco* but with 2 layers of gauze and 1 of canvas, the latter applied only after the gauze is dry, avoiding superposition of overlapping joints.

A supporting panel or cradle is prepared as for *stacco*, but of sturdier structure since it has to carry a greater weight. After the painting has been protected by its gauze and canvas facing and by a sheet of polythene, a creamy mixture of plaster of paris is poured between the polythene and the panel, i.e., on the front side, and this becomes anchored to the panel as it sets around the nails that have been left protruding from the wood. The plaster must be built up in height gradually, some 50 cm at a time, until it fills all space between the polythene and panel.

However, before pouring the plaster (which will fit exactly into all the irregularities of the surface) a narrow horizontal groove is cut across the lower edge of the painting, 10-15 cm deep, into which is slid an L-shaped angle-iron of appropriate size, the projecting face of the iron being fixed rigidly to the supporting panel and the other firmly fitted into the groove. This angle-iron will act as girder to support the weight of the mural when it is finally freed from the wall.

Detaching the section from the wall. The outline cuts are now made, with either mechanical cutters or hand tools, and a narrow tunnel is then driven across the wall behind the picture at a depth of some 10 or 20 cm from the surface. Starting from this, the back of the painting is gradually cut away until it is held only by the rock at the top. The top attachment is then cut while the whole mass is braced by wooden bearers, the weight being taken by the angle-iron support which acts as a hinge. The section is thus released from the wall and lowered to the ground (Fig. 53).

Application to a new support. A new support is prepared as in the case of the usual *stacco* transfer and after mounting in the usual manner, the facing can be removed and the surface cleaned.

Presentation. When the last trace of adhesive has been removed from the surface of the paint, a detailed examination of the mural is made to see that it adheres all over to its new support. Cleaning and retouching follow as usual and require no special comment here. Paintings transferred in several pieces will have to be reassembled, according to designs made before removal. For this purpose one large chassis is constructed with rails or racks upon which individual panels can be fixed, allowing for vertical and lateral adjustment, thus making it possible to assemble and dismantle the whole mural as required for exhibition or study. Missing sections may be reconstituted by imitating the texture and colour of the original. In reconstructing the whole of a painted room, tomb or chapel in a museum, care must be taken to safeguard the authenticity of the whole and to ensure that the backs of the panels, while concealed from visitors, are nevertheless accessible for inspection by the conservation department.

APPENDIX

FORMULAE

1. *'Colletta' for the facing for stacco (transfer with the mortar)*

Bone glue (in pearls)	3 kg	Water	1 litre

Allow to swell for 12 to 24 hours, then heat in steam-bath for 1 hour and add:

Molasses	0.75 kg	Ox gall	0.3 litre
Vinegar	2 litres		

Mix the whole by stirring and pour the hot glue into an enamelled dish where it forms a jelly as it cools. This is eventually cut into pieces which may be dried on a wire mesh (the thickness of the dried pieces is 1 to 1.5 cm).

2. *'Colletta' for strappo (transfer of paint layer alone)*

As in 1 above, but without molasses.

3. *Casein to fix the transferred painting to a new support*

Casein	100 g

Allow to swell for about 12 hours in a large quantity of water and then pour away the excess water.

Add 900 g of slaked lime and mix.

Add 100 g of polyvinyl acetate (emulsion) or another acrylic emulsion to give flexibility. Mix and sift.

A fungicide may be added.

N.B. If the mixture forms a jelly, it is too concentrated. Dilute to a creamy consistency and apply with a brush.

William Boustead

The conservation and restoration of easel paintings

13

INTRODUCTION

Many museums in tropical countries hold important collections of easel paintings, often imported from the temperate zone. The continent of Australia, which lies largely in or near the tropics, offers a particularly interesting and illustrative example of this situation. Unfortunately paintings, unlike some other museum objects, deteriorate far more rapidly in tropical climates than in the more temperate zones. Normal ageing processes are greatly accelerated and the breakdown of organic material, such as cellulose, can be extremely rapid. High temperatures and relative humidities or hot and arid conditions contribute to this, as do the photo-chemical effects of brilliant sunshine unfiltered by fog, cloud, or industrial air pollution. The depredations of insect pests and micro-organisms are also a serious cause of deterioration.

The varied nature of Australian collections also calls for a considerable range of conservation techniques. It is not unusual to encounter the widest variety of painting supports. These may be European wood panels, linen and cotton canvases, academy boards, hessian and jute bags, drawer bottoms, panels of native timbers, pine board around which bolts of cloth were once rolled, pulp boards of all varieties, sheets of glass and metal plates, and seldom of the best quality. In addition to these, plywoods and building boards have been and still are widely used today.

Among other factors bearing on stability, one of the most important—and often the most exasperating—is the diversity of technique employed not only by early artists but also by present-day painters. There are the traditional oil colour and egg tempera processes (with or without glazes), water-colours, numerous gouache techniques utilizing glues, casein and latex juice, and today there are the synthetic media such as polyvinyl acetate, acrylics, alkyds and synthetic enamels.[1]

Many European paintings executed in traditional techniques were brought by the early settlers or were later bequeathed to them, and this body of material has since been supplemented by purchases. On the other hand many of the artists who came to Australia in the early period of settlement, well trained in the artistic traditions of their countries of origin, had to make do with materials strange to them. Nevertheless, they produced works which are of both aesthetic and historic interest in the country of adoption.

The subjects were varied and included ancestral portraits, landscapes, religious paintings, stations of the cross and altar pieces. Many of these, it is true, are the work of mediocre painters, but they served their purpose in providing a cultural or a religious link between the countries of origin and the raw, undeveloped, often barbaric colonies where the owners were

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[1] See also the Appendix, p. 303.

to spend the rest of their lives. In consequence, it is important that they should be preserved.

Many of the pictures in Australian collections, as indeed in other tropical countries, have been subjected to innumerable hazards on the long voyages by sailing ship through different latitudes to their destination. The effects of storage on board ship, of exposure to exceptional dampness and to tropical extremes of temperature, as well as to movements of cargo, have resulted in damage that was only too apparent when they were unpacked on arrival. Naturally, many of the damaged paintings did not survive, but a good number were patched up and restored. As there were no skilled restorers in these new colonies and remote settlements, the restorations were usually entrusted to craftsmen of the wagon-maker class or to amateur artists and, in the case of religious paintings, to monks or missionaries who possessed some artistic talent.

At a later period the carver-gilder who possessed some experience in picture-cleaning came to the more settled communities. His usual procedure was to line damaged canvases, using animal glue, fill losses with gesso and inevitably over-retouch, usually with a copal-varnish/resin medium, Owing to the tendency for soft resins to bloom, it was the habit to finish the surface with copal varnish or by repeated rubbings with raw linseed oil.

The stability of an easel painting depends very largely upon the various environments in which it has been exposed. Paintings in these countries were, for the most part, found originally only in official residences, in churches or missions, or in the homes of the cultured and wealthy, situated either near the sea or on inland rivers a few miles from the coast. Later, as the colonies grew, many families moved inland to found plantations or to raise stock and this often meant a complete change of environment.

In Australia, for example, instead of being assailed by a monsoon climate, high relative humidities, changeable temperatures and blustering salt-laden breezes, paintings were subjected in savannah and desert regions to temperatures rising as high as 55 °C. Under these conditions the relative humidity can be as low as 30 per cent for months on end. Hot dry winds bring the dust of the desert swirling into the homesteads, causing attrition of painted surfaces. The strong light bleaches colours and promotes the oxidation of cellulose. Desiccation of the medium occurs. Dust and insects damage the paint film while termites tunnel into wooden panels.

Another problem arises in connexion with the quality of materials available in these countries.

Many of the indigenous people in tropical countries have now achieved their independence, and their keen desire to preserve their own arts and crafts and cultural relics has resulted in the setting-up of many small museums. Through education and contact with Western civilization, many of the artists are no longer content to express themselves in their conventional idiom but are also turning to other forms of art. We find people today with a long tradition of manual dexterity and a new sense of national pride, expressing themselves in a highly confident Westernized manner. Unfortunately, their choice of painting materials is usually strictly limited and highly creative works of art may be executed with poor materials which usually endure for only a few years under these adverse climatic conditions.

The housing of art collections in tropical countries is also too often inadequate. With rare exceptions museums are damp, rambling palaces taken over when the political order changed, with perhaps insect-infested or rotting and leaking woodwork, or handed over when the administrative services moved to more modern structures. Very often the curator of the collection is a civil servant who has accepted this additional responsibility because of his love of art or his passion for the preservation of the cultural and historical records of his country. Thus the training of museum curators is obviously of the greatest importance. With this in mind, the Art Gallery of New South Wales, Sydney, has instituted a training scheme for restorers, with special attention given to the problems encountered in tropical climates. Simpler processes of conservation and restoration which can be applied by personnel with limited experience and faculties are described below.

THE CONSERVATION OF EASEL PAINTINGS

Fungicides

The tropical climate being what it is, the conservator is forced to make a special study of the methods of preventing and eradicating growths of micro-fungi. Experience has shown the futility of attempting to carry out mycological research in unsterile surroundings and without specialized training and equipment. And one has to recognize what are the basic requirements for mould growth, what materials are the best nutrients and what substances can be used as fungicides *(Plate 25)*.

Most of the fungicides which have shown great promise in laboratory tests have been found either difficult to apply in the tropics or dangerous to paintings and their sterilizing action seems to be transitory. Indeed, when mould growth has become deeply entrenched in a paint film, whether oil acrylic or polyvinyl acetate, no fungicide seems to have the slightest effect in preventing further growth as soon as conditions are again favourable for the mould. Moreover, some species of mould become immune to certain fungicides and can develop extraordinary powers of resistance.

It is sometimes possible to soften the surface of oil paint by solvent action and then apply the fungicide with a small brush to the various colonies, but this is only practical when the mycelium has not penetrated too deeply into the paint strata and when the attack is very local.

In the case of water-colours, where the technique consists more of colouring the paper by pigments and of using the colour of the paper itself and its fibres to provide a certain tone and texture, the response to fungicidal treatment is much more favourable then is the case with heavily-bodied layers of oil paint. But with water-colour drawings there is another restriction due to the possibility of staining. Although, for example, the fungicidal action of chlorinated phenol is extremely high when applied to infected paper, its tendency to produce free acid and to stain presents a serious handicap and limits its use. These objections do not apply to the sodium salt of pentachlorophenol which is effective in extremely dilute solutions (1 or 2 per cent). It must not be forgotten that most fungicides have been developed for use on materials which are relatively expendable, in that their useful life is much less than that of paintings. Consequently attempts to use commercial fungicides in the control of mould growth have, on the whole, been disappointing. An exception is to be found in Shirlan, produced specifically for the treatment of cellulose. We have used this material in a trichlorethylene/acetone solution, for spraying the backs of prints and drawings, their mounts and backboards. Such treatment is more permanent and satisfactory than fumigation with thymol, a substance of little value in the tropics because of its high volatility.

Dehumidification

The fact that mould growth becomes inactive when subjected to environments where the relative humidity is below 60 per cent makes it imperative that paintings be displayed and stored in some dry environment. A completely air-conditioned building is the ideal answer, but the cost of air-conditioning an old and very often flimsy building can be astronomical.

We had to face this problem in Sydney. Although our building is massive and solidly constructed, the problems of ducting, lowering ceilings, and sealing up various areas, proved to be insurmountable and the idea of air-conditioning could not be entertained. A compromise was effected by designing partly mobile dehumidifying units for installation in the storage areas, and it may be of interest to recount our experience with them. They are each provided with castors and flexible drain pipes and can be oriented through approximately 220 degrees.

The units are relatively inexpensive, costing £(A)800 each, and the results have proved to be satisfactory above our expectations. Our type of machine is quite simple in design, utilizing the well-known heat-pump principle *(Plate 26)*. Power is provided by a 5-h.p., 3-phase motor, and control by a Minneapolis Honeywell humidostat, with an accuracy of plus or minus 3 per cent. This can be easily calibrated by an unskilled person by checking daily with a sling psychrometer, and a self-recording thermohygrograph records temperature and relative humidity. The first unit was installed in our largest store room (1,700 m^3) in late 1962 and both mechanical and thermal efficiency have proved to be excellent. It is usual in Sydney each year to experience a wet season of three months during which high relative humidities prevail. The year 1963 proved to be one of the wettest on record. Nearly 2,000 mm of rain were recorded in seven months and this provided an excellent opportunity for the machine to demonstrate its capabilities. Where previously water welled up through the floors, damp walls exhibited efflorescence through capillary action and mould grew in alarming profusion, the result of dehumidification was that wall and floors became bone dry and mould growth was practically non-existent. (This was in great contrast to the previous year which had less than half the rainfall.) Before installing our machine, 360 oil paintings were infected by mould growth and patches of it formed on the floors and in the laboratory. Gelatine strips fixed to walls were limp and flexible and could be rolled up without breaking, an indication of excessive humidity. Moisture produced great blisters of paint on the walls, which were streaked by efflorescent salts. The relative humidity was actually seldom below 90 per cent and, in addition to the mould problem, the paint on the bottom of many canvases had begun to flake away. During the six-month trial period of the dehumidifier a constant relative humidity of 55 per cent was maintained at a temperature ranging from 20° to 23.5°C. It should be added that the water extracted from the atmosphere is piped to an external drain. By contrast, in the very dry months, the relative humidity seldom drops below 45 per cent at an average temperature of 17.2°C and no humidification has been found necessary.

Ventilation fans have been located diagonally at opposite corners to ensure that adequate circulation is maintained and these are controlled by the same humidostat controlling the dehumidifier.

Storage

On visiting art museums one very often finds that whilst great pains have been taken to display paintings in a pleasing and instructive manner in clean, well-lit exhibition courts, little or nothing has been done to provide similar conditions for paintings not required for exhibition. It is not unusual to find paintings stacked one against the other in damp, dark, unventilated basements or cellars, where conditions are ideal for the promotion of mould growth and flaking

Plate 25

Growth of *Penicillium* moulds on a painting. Removal of the surface mycelium revealed deep-seated stains which were removed with calcium hypochlorite.

Plate 26 a

Side view of dehumidifying unit
installed in the oil painting section
of the Art Gallery in Sydney (Australia).
Specifications: 5 h.p., 3-phase electric
motor, 350 dew point. Controls:
Minneapolis Honeywell humidostat.

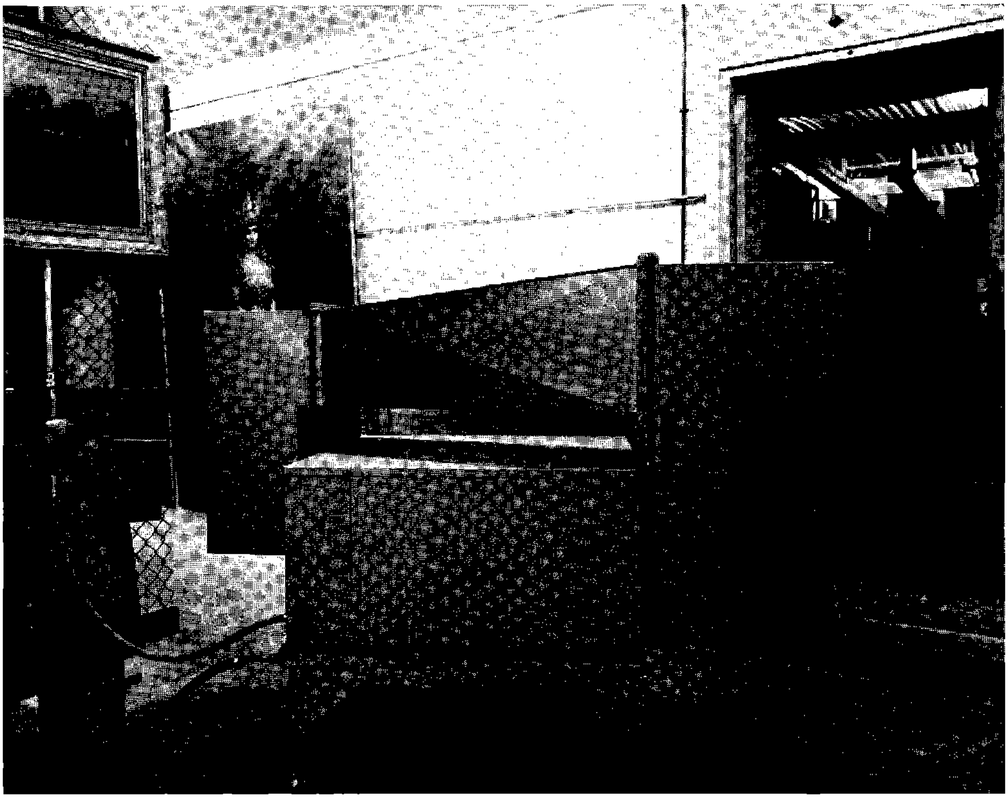

Plate 26b

Front view of dehumidifying unit. Note simple storage racks built of galvanized chain link fencing attached to insect-proof hardwood frames.

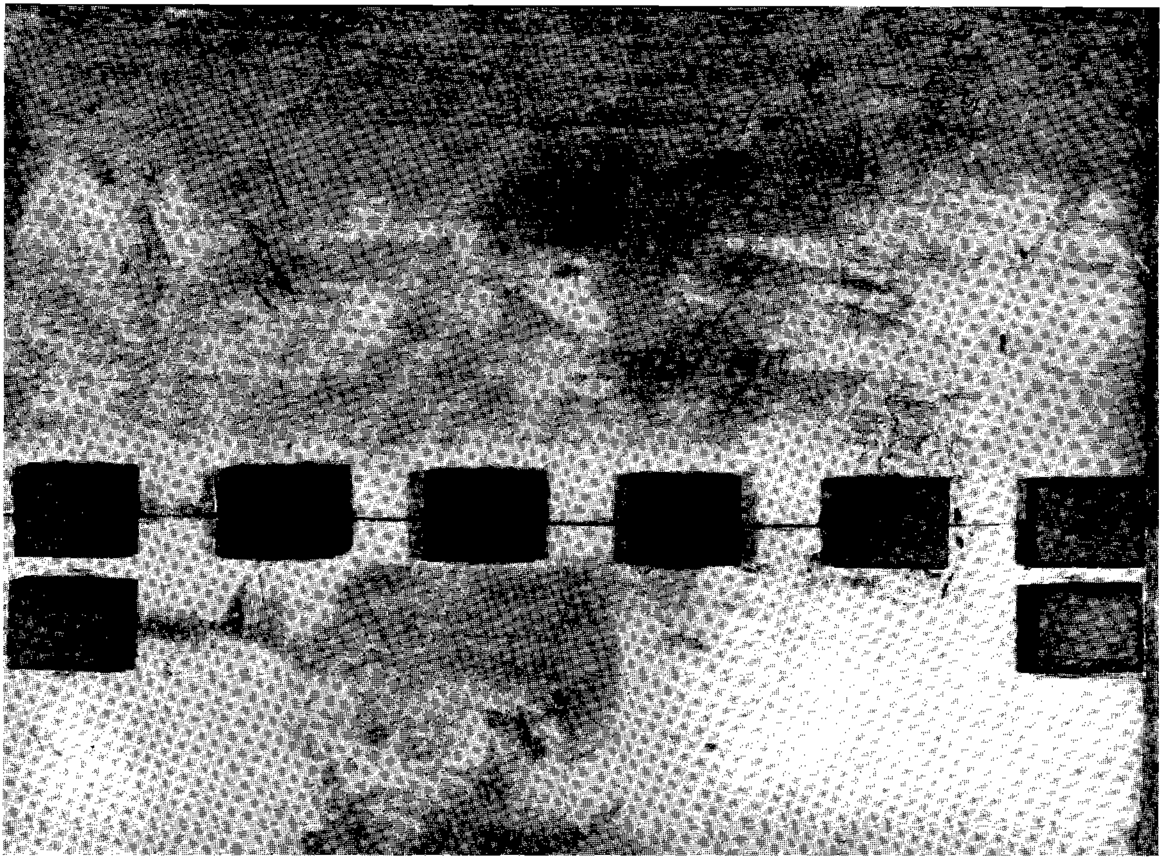

Plate 27

One of the methods used to repair a split and buckled panel. The panel was treated with dichloroethyl ether, dieldrin and white spirit.

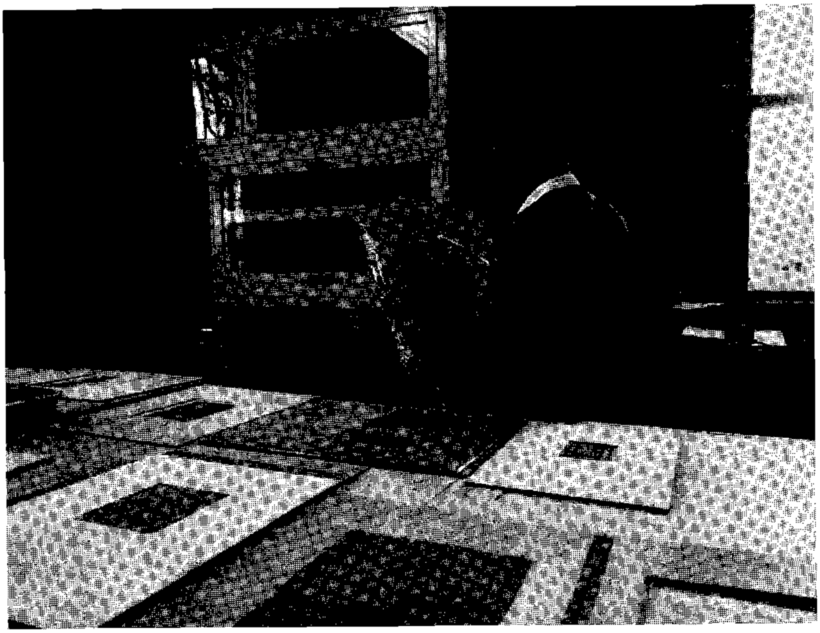

Plate 28

Dehydrated print sealed in a polythene envelope. Dehumidifying cabinet shown in the background.

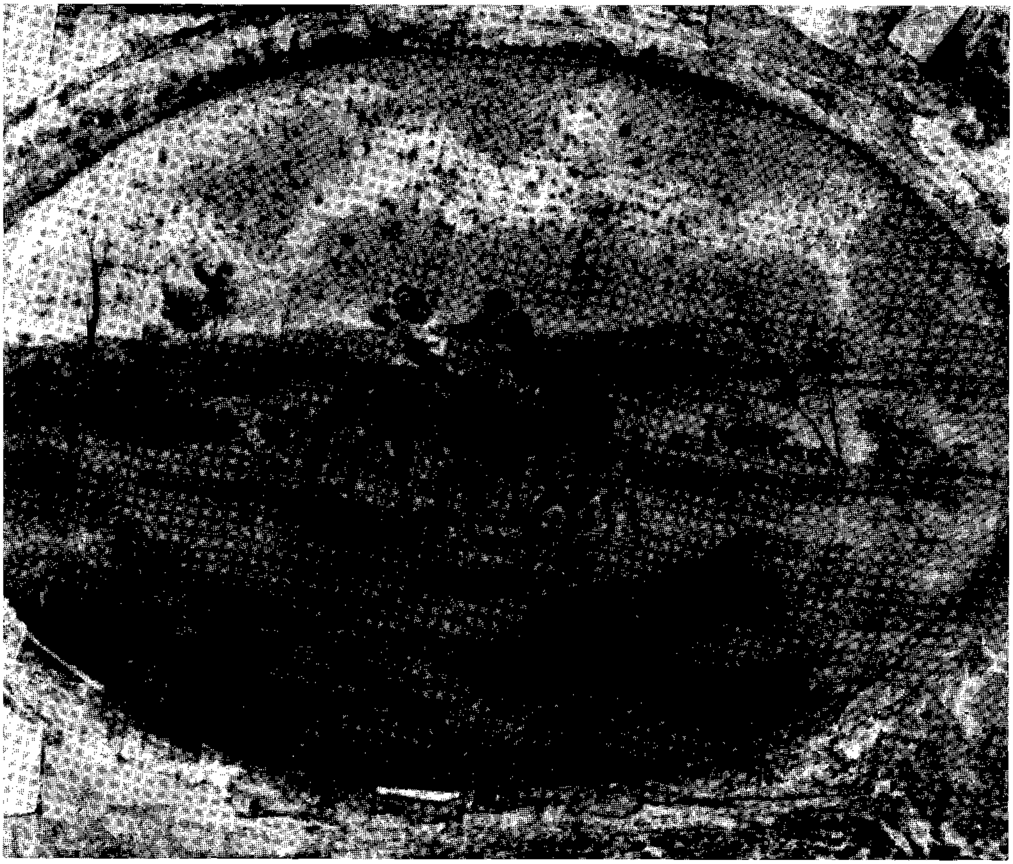

Plate 29 a

A badly 'foxed', water-stained and yellowed early Australian water-colour. Silver fish and cockroaches had attacked the outer edges where the support had been glued to its mount.

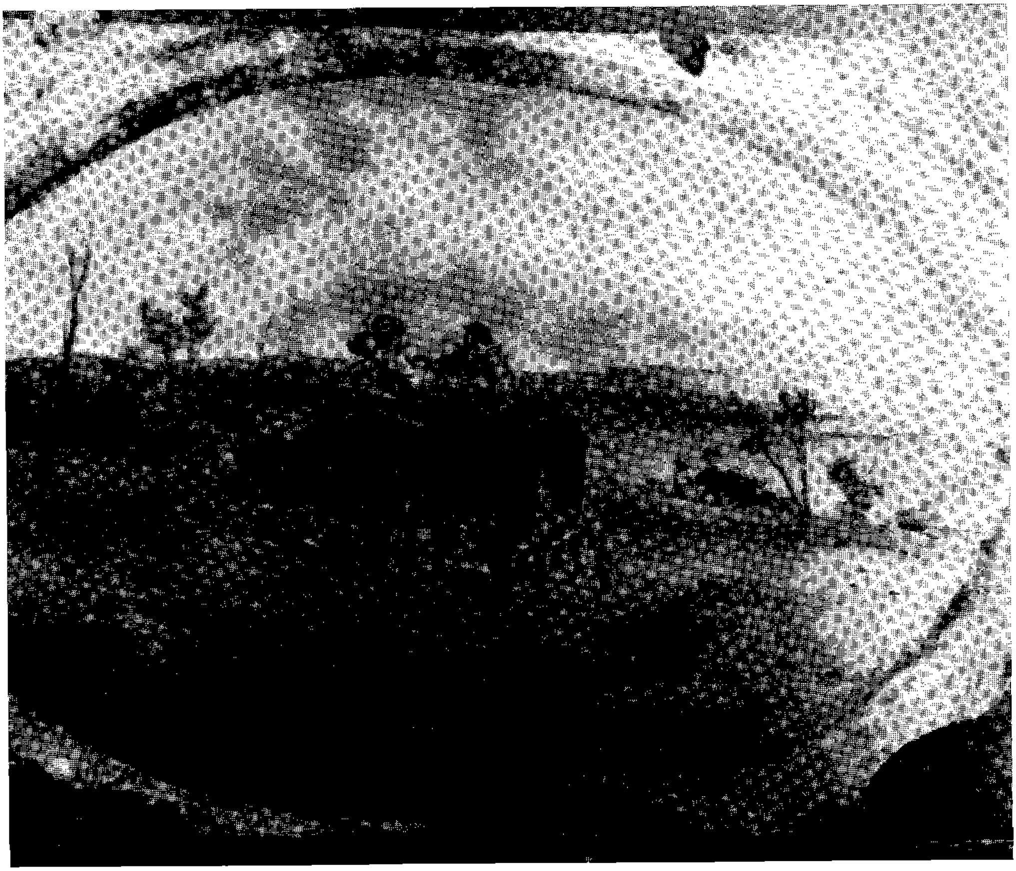

Plate 29 b

Water-colour after restoration.
A solution of calcium hypochlorite was
used to remove foxing and water stains and to
bleach the paper to its original shade of white.
The rear support was sprayed with a solution
of Shirlan in acetone and trichloroethylene.

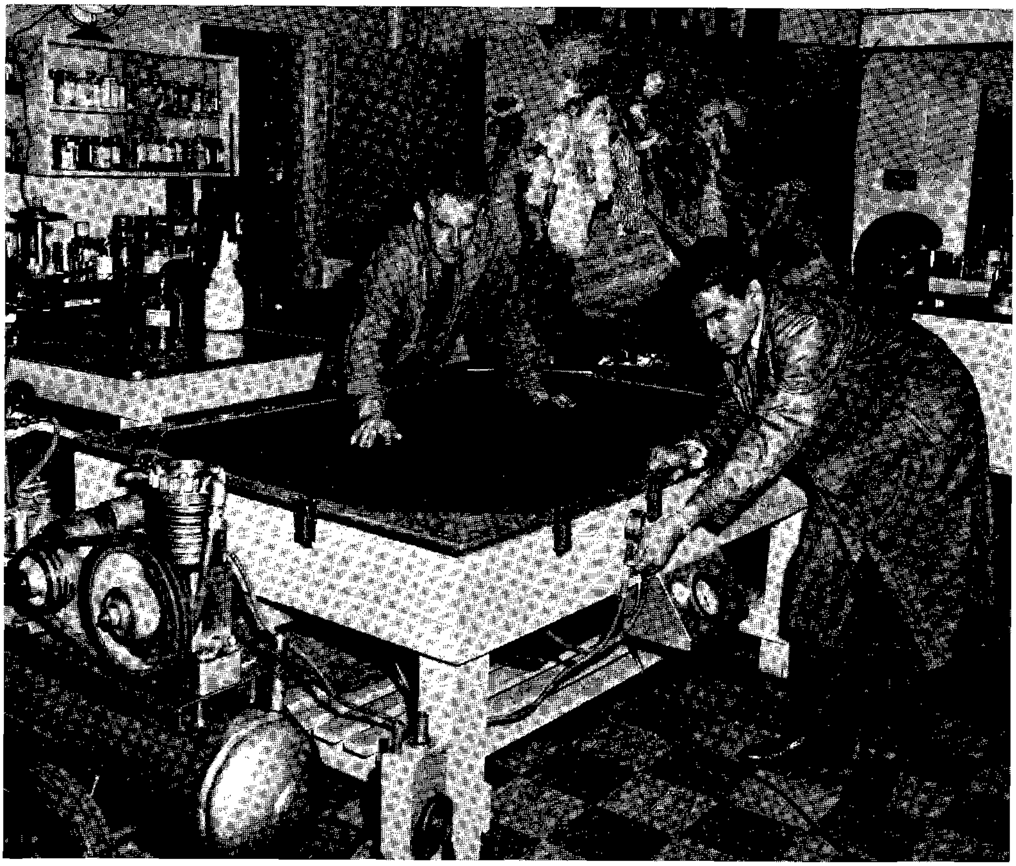

Plate 30

Simple vacuum hot table utilizing the suction or inlet side of an air compressor as a vacuum pump. The heating element is made of Pyrotenax cable laid beneath an aluminium panel. Temperature control is effected by a simple simmerstat.

paint. With a little time and effort much can be done to mitigate this undesirable state of affairs.

Storage areas should receive as much or more attention than that paid to exhibition galleries. No debris should be allowed to accumulate and scrupulous cleanliness should be observed at all times. Walls and woodwork should be painted with a high-gloss paint, preferably based on zinc oxide and containing a fungicide.

In the absence of proper storage racks, a substitute can be erected simply and economically by stretching galvanized fencing wire on to wood frames. This reduces the incidence of mould infection and permits ease of inspection. Mould colonies thrive in darkness and it is essential that adequate illumination be provided even in the store rooms. Where there is no possibility of controlling the humidity of the atmosphere, ventilation fans should be installed to provide adequate circulation of air. Stagnant air assists greatly in the propagation of mould spores, whilst circulating air not only helps to prevent spores that are suspended in the air from settling and germinating, but it assists in keeping the area dry.

Regular inspection of stored paintings should be rigidly maintained. There is no substitute for constant care and vigilance. Both the painted and unpainted sides of canvases should be carefully examined, inch by inch, under a low-powered binocular microscope, for signs of mould mycelia. Often spores and mycelium which have not yet penetrated the paint strata can be brushed off. Brief exposures to sunshine or ultra-violet rays can help sterilization.

The backs of easel paintings

The reverse side of the canvas should be carefully cleaned with a small, high-powered vacuum cleaner. This greatly assists in removing mould spores and also spore-carrying mites (psocids) which travel from one painting to another, conveying the minute seeds of destruction. Surface-cleaning of paint films should follow, to eliminate dirt, dust and pollen grains which tend to absorb moisture and often provide nourishment for the mould spores.

The area of the painting behind the lower bar of the stretcher frame should be examined for any sign of dust or mould growths. To do this the tacks should be removed from the canvas and the bar taken out. Whenever possible copper tacks should replace the conventional iron ones which rust easily and rot the canvas, whereas copper exerts a slight fungicidal action.

It is a good practice to apply a fungicide to the unpainted side of the canvas. For this purpose spirit-soluble Shirlan is recommended, but if the crackle of the paint layer extends through to the canvas, care should be taken that solvent action does not take place on the paint film and varnish. The application of any protective layer, even to the rear of the canvas, which cannot later be removed is to be strongly condemned. In the event of cleavage or flaking of the paint film it might otherwise be impossible to effect impregnation from the rear.

Sealing-off the rear of the canvas by affixing a protective panel to the stretcher frame is sometimes advocated. If plywood is used it should be of the marine variety utilizing a non-aqueous adhesive between the layers of veneer. Tempered Masonite is excellent although it tends to be somewhat heavy.

The panel should be prepared previously with a row of holes at least 2 cm in diameter bored a few centimetres below the top and above the bottom rails of the stretcher frame. A fine-mesh protective screen should cover these holes to prevent the entry of migrating spores and psocids (dust-carrying lice). It is incredible how the latter can find their way in and we have experienced some difficulty in finding a mesh coarse enough to permit the painting to breathe and yet fine enough to prevent the entry of such pests.

PAINTINGS ON WOOD PANELS

Damage by termites is sometimes encountered in panels which have been stored in complete darkness for long periods. It is rare for these pests to penetrate the paint surface, but their activities can reduce the wood support to a mere shell.

Panel paintings which are of the nature of fixtures or have been in direct contact with the walls of such buildings as churches are a prey to termite action. The remedy is to take down the panels, replace the damaged wood in accordance with accepted restoration practice, treat it with an insecticide such as Dieldrin or Aldrin and to make sure when the panels are replaced that they are insulated from the walls *(Plate 27)*.

It is futile to attempt to treat stretchers which have been infested with wood beetles. They should be destroyed and replaced with deciduous hardwood.

GLASS COVERS

The value of using glass as a protective measure to cover framed paintings is debatable. In regions where high humidity is prevalent it can provide an additional hazard. Moisture condenses on the inside of the glass, leaving deposits which assist in the propagation of mould growth. Persistent high humidities cause a chemical change in some glasses, rendering them partially opaque and porous.

On the other hand, in dry desert areas glass proves to be an asset, particularly when the painting is unvarnished. Here the common house-fly is a pest, prevalent during most of the year. It deposits its excreta on painted surfaces, particularly the light areas where more white lead has been used, leaving brown specks which are usually impossible to remove without lifting the underlying paint.

PAINTINGS IN DESERT CLIMATES

In the more stable climates found in dry desert country the absence of recurring contraction and expansion is a great asset in assuring stability and, in general, paintings fare much better here than in moist tropical regions. In dry climates where dehydration becomes extreme, however, this may be prejudicial to stability, but it is then possible to introduce humidifying units spraying fine water vapour. Unfortunately, rain-water is usually at a premium in these areas and is sparingly used. Artesian bore water is not so satisfactory because such water is hard and full of salts and these tend to cling to the fine diffusion ducts. The escaping water vapour usually leaves mineral deposits on everything it encounters, and when the evaporation rate is high, no beneficial results can be expected unless the exhibition and the storage area are reasonably confined. Panel paintings generally display much more stability in dry climates than when exposed to varying humidity.

SOME NOTES CONCERNING WATER-COLOURS

Storage

The storage of unframed water-colours and drawings presents quite a problem in the tropics as they cannot be hung on storage racks and must perforce be stored away on open shelves or closed cabinets.

Museums which have a surplus of naturally insect-resistant wood cabinets are fortunate indeed. The aroma from certain woods discourages the activities of most insect pests and the cellular nature of the wood acts like a reservoir by both absorbing and giving off moisture. Unfortunately, as collections grow and these well-constructed wood cabinets become less available, the only recourse is to utilize the mass-produced metal cabinets and these leave much to be desired. Moisture condensing on the metal surface is absorbed by the drawing and its mount. Fungicidal crystals placed in the drawers for prophylactic reasons tend to soften the paint on the metal and rust soon appears.

Dehumidification

The use of dry silica gel crystals as a dehydrating agent has not proved successful in our country. We found during the wet season that we were re-activating 27 kg of silica gel each week. This is a time-consuming process when a small oven is the only means of effecting regeneration. The problem had to be attacked from a different angle. Our new cabinets now have expanded metal mesh drawer bottoms which allow some circulation of air and free passage for the volatile fumes of insecticides.

Before storage in metal cabinets, the residual moisture contained in both mounted and unmounted drawings is reduced by placing them for an hour or so in a dehumidifying cabinet which maintains a constant relative humidity of 40 per cent. They are then checked with a moisture-indicating gauge before being sealed off in polythene envelopes which also have been subjected to dehumidification to remove absorbed moisture *(Plate 28)*. Humidity indicator papers are placed in the envelopes in such a way that they do not directly contact the mount or the drawing. During routine inspection, changes in the colour of the indicator paper provide a ready and reasonably accurate assessment of the moisture content within. This routine seems to be working very well and for over nine months drawings so treated have revealed no signs of further moisture absorption.

Sealed containers

Sealing each individual drawing also had the beneficial effect of protecting it from the depredations of silver fish and small cockroaches which have done tremendous damage in the past. Perforation of the paper and pittings in the surface, where the pests have eaten into the paper and the paint layer, are very difficult and often impossible to restore effectively.

Plexiglass covers[1]

Interesting claims are made for the use of ultra-violet-absorbing Plexiglass where the framing of delicate water-colours and Eastern paintings is concerned. Moisture does not seem to condense so readily on Plexiglass as on ordinary glass, but it has the disadvantage that it scratches easily. This is most unfortunate because in dry desert areas its use could help considerably to reduce the oxidation and fading of fugitive colours. The swirling desert dust would soon render a plastics sheet opaque and it should be added that we are still uncertain as to how the acrylic resin will stand up to the possible etching effects of mould.

Mounting water-colours

Poor-quality mounting boards and mats are readily infected by mould which soon spreads to the water-colour or drawing. It is usual to see brown fox marks spreading in from the edge of the drawing where it has been in direct contact with the mat. Even slightly infected mats and mounts should be discarded and replaced. Good-quality linen boards are expensive and hard to come by and are often not thick enough to provide adequate support for the drawing. When there is no recourse but to utilize poor-quality pulp and pasteboards, they should be thoroughly treated with a fungicide before the drawings are mounted. In this instance spirit-soluble Shirlan dissolved in a solvent of trichlorethylene/acetone and sprayed on the boards provides excellent

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1. A discussion of the use of Plexiglass is given in *Temporary and Travelling Exhibitions*, p. 66-68 (No. X in this series).

protection against all fungoid attacks. *(Plate 29)*. Solid pasting down and the use of pressure-sensitive tapes should be avoided as they make removal difficult and tend to produce permanent straining. It may be added that regular inspection under an ultra-violet lamp utilizing a Woods filter often reveals the presence of incipient mould growth not visible in ordinary light.

In framing pictures of any kind, glass should never be allowed to come into direct contact with the painting. Sweating paint and resins which soften under high temperatures tend to cling to the glass and their separation may result in serious paint loss. Direct contact with water-colours should also be avoided, as the moisture which finds its way in and condenses so readily on the inner surface of the glass encourages mould growth.

RESTORATION

Except in certain circumstances, restoration practices should follow very closely those utilized by the more enlighted Western art museums and fully described in the literature.

The emphasis should be on conservation rather than restoration wherever possible. Where oil paintings are concerned, processes should be reversible and it is good practice as mentioned above never to do anything that cannot be undone.

Cleaning

It is not proposed to enter the controversy of deep cleaning versus moderate cleaning, suffice it to say that in tropical regions it is often imperative to deep clean, removing every trace of the brittle, yellowed varnish which imposes additional strain on fragile paint films and causes cleavage and cracking.

Cleaning can be quite a problem when the medium contains a proportion of soft resin. We have found cyclohexanol a very useful solvent when dealing with these difficult cases. Decalin and tetralin are excellent surface-cleaning agents and although slow in action and requiring repeated application are often more successful in removing embedded dirt and soot than other available solvents.

The removal of old, darkened copal resin varnish has always been extremely difficult owing to its insolubility. Some solvent action has been obtained by using acetone to which a few drops of ammonia were added, but great care must be exercised in applying this method, particularly when certain colours, such as ultramarine, are present.

When cleaning paintings, particularly in hot, humid climates, a swivel-head electric fan should be used to dissipate toxic fumes, and in spraying varnish containing fungicides it is advisable for the restorer to wear a double-diaphragm protective mask or to carry out this operation in a hooded cabinet equipped with exhaust fans.

Filling

The use of gesso (glue size and white) for filling lacunae, is not recommended for use in tropical countries. It has a tendency to expand and contract in response to fluctuating weather conditions and to set so hard as to make it impossible to remove without damage. Attrition must be used to get it down to paint surface level and sizing, usually with shellac, must be applied to prevent absorption of the ensuing retouches.

We have found a wax-resin filler, consisting of beeswax, A.W.2 resin, gum elimi and kaolin, to be much safer and considerably more flexible in application. This can be applied with mild heat, is easily modelled to imitate texture, can be removed without difficulty and is compatible with retouches using synthetic resin mediums.

Retouching

In the case of tempera painting we advocate the use of tempera emulsions for retouching, but not for other purposes as the preparation of the tempera medium is difficult to accomplish in tropical climates without mould infection, it has little flexibility, and is difficult to remove.

We have found either tube colours or powder colours, ground with A.W.2 resin, to provide a medium having more advantages than others. It darkens less easily than oils and can be removed more easily.

Varnishing

Although a number of picture varnishes are available which possess certain individual advantages, we know of none that is ideal. All soft resin varnishes, whether natural or synthetic, have a tendency to bloom. This tendency can be reduced considerably by making certain that varnishing is only carried out when the weather is warm, dry and without wind.

Although it scratches easily and is rather inflexible, we prefer the synthetic resin A.W.2 to the natural soft resins dammar and mastic, although there is no doubt that a well-prepared, properly applied soft resin varnish can do a great deal to protect the surface of a matured paint film.

Supports for paintings

The resistance of canvas supports to adverse climatic conditions is largely determined by their constituent fibre. Cotton fibres, with their high cellulose content, display poorer resistance to mould growth and react more violently to changes in humidity than do canvases containing bast fibres. They are for this reason not suited to humid tropical climates. However, in hot, dry climates they do not break down so readily and they show greater resistance to solar radiation than do jute and ramie fibres.

The animal glue used to size canvases produces additional hazards, by providing a high degree of nutrition for mould colonies, and alternately swelling in wet weather and contracting in dry weather. This continual movement imposes considerable strain on superimposed paint layers. Old and desiccated paint films undergo stress and develop cracks in which airborne mould spores lodge and find, in the underlying glue size, the nutrients essential to their growth. Trace elements in certain pigments provide additional nutrients which stimulate the spread of the web-like mycelium.

Canvases subjected to the hot, dry and more stable conditions encountered in desert regions react in a different manner. Jute, ramie and, to a somewhat lesser degree, flax fibres become oxidized and brittle. The general condition is one of extreme fragility and in certain cases even a slight knock may be enough to cause the canvas to fracture. Consequently such canvases are inclined to require lining much sooner than those kept in more temperate zones.

The new fibre support should be altogether more resistant. Today a variety of synthetic fabrics is available, each possessing individual characteristics. After much experiment we have decided to use a fibre-glass fabric which we feel possesses superior qualities. It is resistant to mould growth, it is not affected by heat and it is completely inert during humidity changes. It does not absorb moisture and it is transparent enough to permit inscriptions on the back of the original canvas to be easily read.

Relining

The lining or mounting of damaged canvases on to new supports is best carried out by the vacuum-press or hot-table technique. This eliminates flattening of paint caused by the old method of using hot flat irons and it also permits much greater penetration of the wax-resin adhesive through the canvas weave into the paint film. This is a tremendous asset where cupping, cleavage and a general lack of bond between paint film and support is concerned.

An elaborate press with electronic controls, etc., is not strictly necessary and often requires the services of skilled technicians to keep it in correct adjustment.

Several years ago we designed and built a simple vacuum hot press in the Conservation Department of the Art Gallery of New South Wales and this has given splendid service without breakdown or need for adjustment *(Plate 30)*. It consists of a Pyrotenax cable of 2 kilowatts embedded in a cement mixture below an aluminium plate. The heating is controlled by a simple thermostat, and vacuum pressure by utilizing the suction or inlet side of a large compressor which may also be used for spraying paint and varnish. A large dial-type thermometer is fitted to indicate the required temperature.

Adhesives

No animal glue should ever be used for the lining or mounting of canvases in the tropics. We have already stressed the ill-effects of aqueous adhesives and recommended the use of wax/copal resin mixtures. The thermo-plastic qualities of wax-resin lining adhesives ensures that the original canvas can always be removed from its new support by simply subjecting it to moderate heat on the hot table. The use of polyvinyl acetate is restricted to bonding a canvas to a five-ply wood or a tempered pressed wood-fibre panel when it acts to a certain extent as a moisture barrier.

The so-called 'Masonite Tempered Prestwood' is a synthetic hardboard, manufactured in Australia from hardwood fibres, and it displays good resistance to mould growth, does not absorb moisture as readily as timber or plywood panels and, where small canvases are concerned, is ideal for mounting. When used for mounting drawings a shellac coating should be applied to prevent the seeping through of oils incorporated in manufacture which could stain.

Only in extremely rare cases is the use of thermo-setting adhesives recommended. Their usual application is to canvases which have buckled or cockled so badly that the moderate adhesive power of a wax-resin mixture is not sufficient to restore the flatness or act as a satisfactory bond between the original support and the new.

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R. V. Sneyers and P. J. de Henau

The conservation of stone

14

INTRODUCTION

When stonework is exposed to all the changes of a tropical climate the possibilities of protection are very limited and the tendency is to remove important sculptures to museums or depots where they can be sheltered from extremes and maintained under favourable conditions. The protection of stone objects in museums or private collections and the handling of stone objects from excavations thus constitute one aspect of the present chapter. An equally important consideration is what can be done to preserve exposed or decayed stone. Since this may depend not only on the chemical and physical nature of the material, but even on the composition and structure of the alteration products, it is essential, as a preliminary to treatment, to carry out a meticulous examination. Suggestions are therefore offered as to how this can be carried out and a true assessment made of the condition of the stone. Ideally, the results should be carefully recorded under the following headings and the documentation preserved as an item of case history, to be amplified in future, as required.

I. Identification of object.
II. Description with sketches and photographs, data concerning the milieu, climatic conditions, etc.
III. Examination:
  1. Material condition.
  2. Composition, structure, identification of material constituents.
  3. Identification of alterations, texture.
  4. Causes of alteration.
IV. Treatment:
  1. Aim of treatment.
  2. Date of treatment.
  3. Process adopted: (a) principle; (b) products used, with commercial names; (c) apparatus used; (d) particularities of technical application.
  4. Results and conclusions.
  5. Dates of subsequent inspections and notes thereon.
V. Bibliographical references of significance.
VI. Signature, designation of operator and date.

A satisfactory scheme of treatment should fulfil certain conditions. It should be effective in arresting deterioration and durable in its protective effect. At the same time it should change the appearance of the object as little as possible and be simple to apply and comparatively inexpensive.

The condition of reversibility, that is the possibility of subsequently removing materials used in treatment which is so important in so many types of conservation work, is subject to certain exceptions when it comes to stonework, notably where heavy masses of stone must be cemented together with insoluble cementing materials. The same may apply to maintaining the appearance of the object depending upon whether the stone is coated with a dust layer forming a disfiguring scum of dirt, or whether, on the other hand, it bears a fine protective patina of aesthetic value. It may be, and sometimes is, possible and desirable to remove the dirt layers but the patina must always be preserved.

In applying the treatments referred to below the conservator must bear in mind that they may well have to be adapted to the particular nature and condition of the specimen in question and that this may be only possible after carrying out surface tests, or even tests on a similar but less important stone (no risks should be taken with valuable cultural material).

As a guide to identification, the following section outlines briefly the composition and properties of the principal rocks and their mineral constituents, it being understood that this is merely by way of introduction.

ROCKS AND MINERALS

THE MATERIAL AND ITS ORIGIN

It is now generally agreed that our Earth was once part of a nebulous cloud from which spheroids were detached, forming the planets and their satellites. Gas gave place to liquid and liquid to solid as the earth gradually cooled, and a surface crust was formed of rocks consisting mainly of compounds of silicon, oxygen and aluminium—the first igneous rocks. Other elements were present too in lesser quantity, and these elements combined in different ways to form the natural compounds known as minerals. A rock is an agglomeration of such minerals. It need not be of constant composition. The minerals, on the other hand, are definite entities and the same minerals may enter into the composition of rocks of many kinds.

The liquid or pasty precursor of the rock is known as magma and all rocks are, within limits, derived from this. But the action of water and the physico-chemical changes suffered throughout the years have caused decompositions, alterations and adjustments so that today we find, in addition to igneous rocks, vast deposits of so-called sedimentary rocks and metamorphic rocks and these show infinite variation in chemical composition and in physical characteristics.

CLASSIFICATION OF ROCKS

Each of the three main groups: Igneous, Sedimentary and Metamorphic Rocks, can be subdivided according to chemical and mineralogical composition and texture, large crystals being characteristic of slow cooling as found in the deep-seated Plutonic Rocks (Granite, Syenite, Diorite and Gabbro), while the Extrusive Rocks that arise from volcanic action are usually incompletely crystalline, fine-grained and even sometimes glassy in texture (Obsidian). An intermediate form of rock results from the expansion of magma in the cracks and fissures of the cooling crust where crystallization is slow and one system of crystals is then sometimes seen to be locked within another; these are the so-called porphyries.

The sedimentary rocks result from the erosion of igneous rocks and are found mainly near the surface of the earth's crust. They may be composed of detritus transported by air or water and consolidated by cementation, or they may result from the chemical interaction of elements in solution with the precipitation of insoluble carbonates, silicates, sulphates, etc.

A third type is colloidal in nature, being derived from the clay minerals, the aluminium silicates. But these three types are often blended to give sedimentary rocks of intermediate composition and properties.

Plate 31

Amaravati sculpture defaced by the decomposition of pyrite and marcasite crystals, India (photo: Institut Royal du Patrimoine Artistique — IRPA).

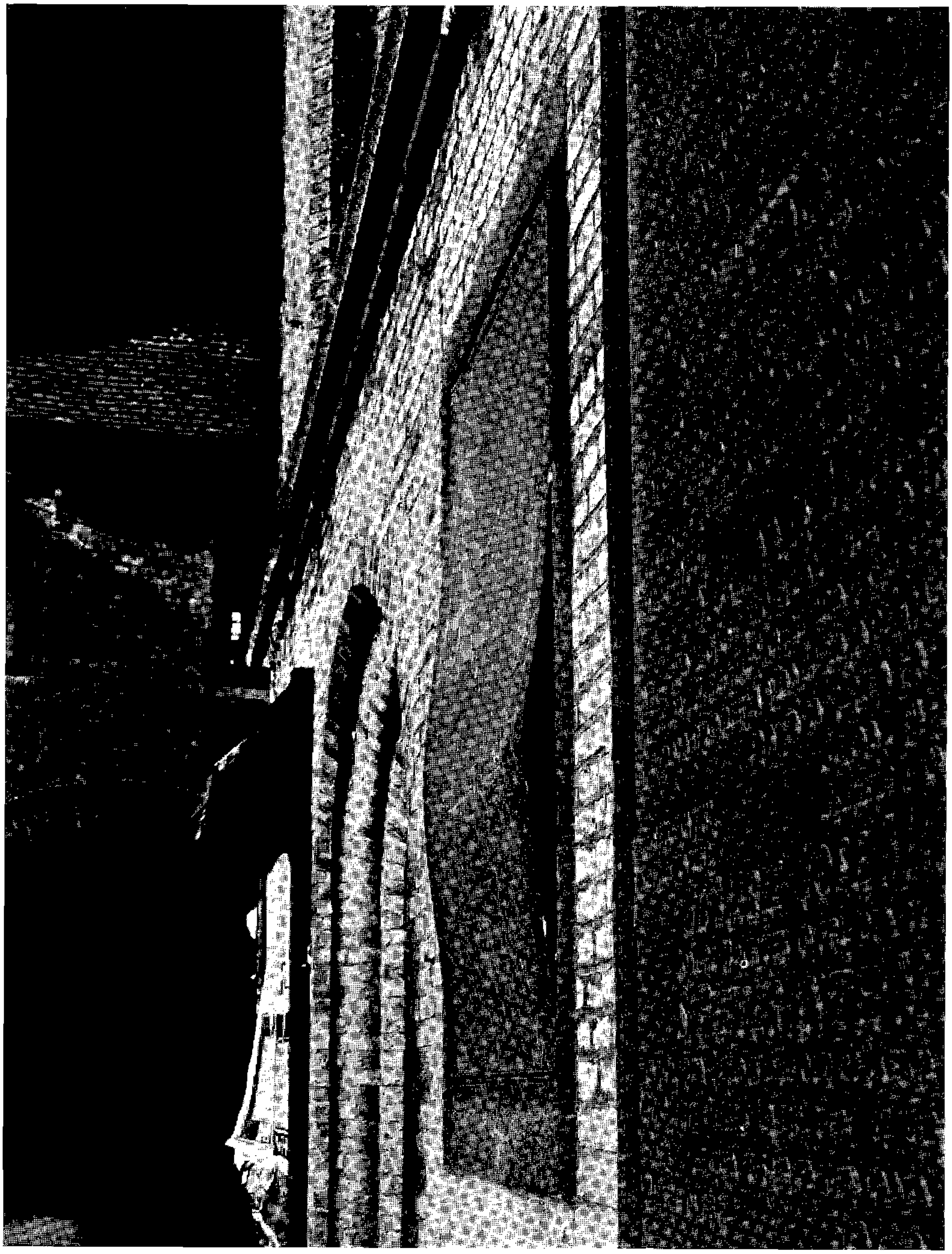

Plate 32 Marble slab deformed by heat (photo: IRPA).

The carbonate rocks. The carbonate rocks represent about 15 per cent of those exposed at the surface of the earth. Calcium carbonate is the commonest and as a rock it presents an almost infinite variety of structure, coloration and hardness.

Carbonate rocks are classified either according to the nature of their minor mineral constituents or to the nature of the so-called cement that holds the grains compactly together. The generic name, limestone, is qualified by such terms as sandy, argillaceous, dolomitic, siliceous, ferruginous, etc., and when derived from organic structures it may be named after these, shell, crinoid, etc.; it may be compact, granular or oolitic. Again combinations may exist and one may find, for example, a compact crinoid siliceous limestone.

The degree of cementation and the shape, nature and percentage composition of the grains influence the resistance of the stone to alteration and determine its properties.

The marbles are composed of calcite crystals interlocked to form a dense and compact rock without any voids. The name rightly belongs to such compact limestones as are capable of taking a high polish, but is often used to describe purely siliceous rocks that present a decorative aspect when polished.

The sandstones. The sandstones, being composed of quartz granules cemented together, present a granular structure on the fractured surface, usually coloured yellow or red. They may be dense or friable. They are classified according to the nature and size of the grain or according to the nature of the cement. Thus we may have quartz grains associated with mineral detritus yielding green sandstones. The cement may sometimes be chalcedony and very hard. At the other extreme there are the weak argillaceous sandstones and the ferruginous sandstones that are red or brown and sometimes green. There are also the metamorphosed types that have recrystallized to the extremely durable quartzite group of rocks which break characteristically with a conchoidal splintery fracture.

Other sedimentary types. Passing reference should be made to the schists resulting from the consolidation of clays (grey, black, bluish-green or red); to the slates from a similar source which cleave into great sheets; and to the saline rocks which are really minerals such as gypsum (a hydrated calcium sulphate) and alabaster of similar composition, both of them of value in the arts.

Metamorphic rocks. Reference has been made to the metamorphic types: marble, quartzite and slate. Metamorphic rocks result from the physico-chemical readjustment of either sedimentary or eruptive rocks under the influence of temperature and pressure, etc., and such changes are often accompanied by important changes in mineral composition and appearance. Additional examples of metamorphic rocks are gneiss and the various micas, chlorites and teleschists, steatite and the serpentine series which may contain green minerals that have not suffered transformation such as olivine, pyroxene and amphibole.

CLASSIFICATION OF MINERALS

The geologist classifies minerals into types and groups and series, but for our present purpose it may suffice to refer to some of the main rock-forming species classified according to colour.

Light-coloured minerals.

(a) *Quartz* (silicon). This occurs in crystalline form or as grains of irregular fracture having a greasy chine. It may be transparent, colourless, or reddish. Quartz scratches glass.

(b) *Feldspar and plagioclase.* Aluminium silicates of potassium, sodium or calcium, the latter two forming a mixture in the plagioclase series—grains or tablets with marked cleavage. Feldspars are opaque, white, brownish or rose and plagioclases greyish-white, pale green or brownish or bluish. Moderately hard. They scratch glass with difficulty.

Dark-coloured minerals. These are mostly compounds of iron and magnesium.

(a) *Micas and chlorites* (hydrated silicates). Thin, cleavable and can be scratched with a knife. Mica may be colourless, white, brilliant and silvery or black, green or yellow. Chlorite is generally green or yellow-green. Elastic films may be sliced from the micas but the films from chlorite though flexible are not elastic.

(b) *Amphibole and pyroxene.* Silicates of calcium, magnesium and iron forming two similar series of minerals differing in the siliceous structure of their molecules.

(c) *Olivine.* Silicate of iron and magnesium. Grains or crystals of vitreous sheen, translucent yellow-green becoming green-brown by alteration. Unequal fracture. Scratches glass.

Pyrite and marcasite. These sulphides of iron are found in calcareous rock fossils and schists. Having a metallic lustre they have been employed in the arts for carving and as inlays in marquetry. Pyrite alters slowly to form brown limonite but when marcasite is present, decomposition is liable to take place much more rapidly, especially in damp surroundings, yielding ferrous sulphate (greenish) which eventually releases sulphuric acid. The acid attacks the calcium carbonate and the stony matrix is thus discoloured by rust stains and eventually disintegrates *(Plate 31)*.

METHODS EMPLOYED FOR THE IDENTIFICATION OF ROCKS AND MINERALS

Macroscopic. By visual examination or with the aid of a hand lens the following characteristics of a rock may be recorded: texture, colour, shine and transparency, type of fracture, etc.

Physical tests. These are conducted to determine: hardness, cohesion, density, porosity, permeability, effect of heat, etc.

Chemical tests. Examination for resistance to water, and to cold and warm acid, may be followed by the microchemical determination of ions in solution.

Chemical analysis. Total or partial analysis may be required.

Microscopic examination. Minerals can be characterized by the optical study of their sections under the microscope and by the examination of powdered material to determine refractive index.

Special forms of examination to determine structure. For example, X-ray crystallography and other similar advanced techniques.

It would be outside the scope of the present work to enter into the details of such forms of examination, but for those who wish to follow this up, a complete bibliography is appended.

POROSITY PHENOMENA

Stones may absorb water, forming an intergranular film, notably in clays, micas, chlorites, etc. This film is strongly attached and can only be removed by molecular exchange. By capillary attraction the porous spaces in stone are filled with water which is retained and this water can only be removed when forces are applied that are greater than the forces of suction determined by the capillaries. Water contamination may also result from moisture moving freely in larger microchannels; this free water can be extracted without difficulty (Fig. 54).

Permeability is the characteristic that makes it possible for a fluid to circulate in and even to traverse a substance and this can be easily measured by saturating the object concerned under controlled conditions of temperature and pressure.

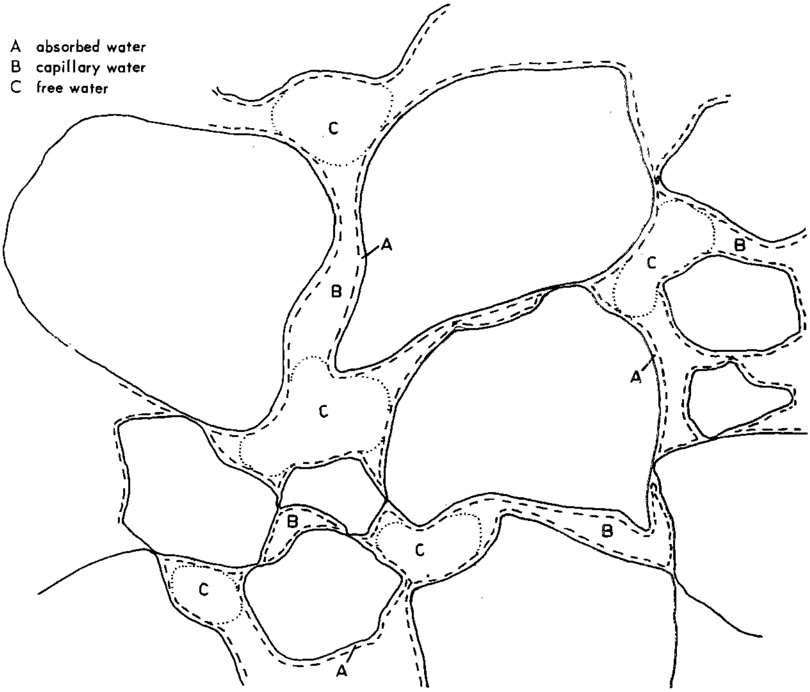

Fig. 54.
Schematic representation of the distribution of water in a porous material.

Capillarity phenomena can also be measured. Information on the retention of capillary water gives an indication of the size of the pores of various types of stone.

FACTORS CAUSING CHANGES IN STONE

The combined action of meteorological agencies (water, temperature, wind, storms, etc.) is known as weathering, which causes not only the direct disintegration of rocks but also various indirect or secondary forms of attack that may be equally devastating (growth of bacteria, the transport of soluble salts and leaching of soluble constituents, etc.). In certain rocks changes of a physico-chemical nature are observed.

While it is impossible, in practice, to isolate any one agency as being solely responsible for the decay of stone, the principal causes of decay can nevertheless be distinguished for purposes of study as physical (temperature, hydration, frost, crystallization of salts), chemical (solution, oxidation and reduction, hydrolysis), and biological (biochemical and biophysical processes). The most important of these are noted below.

Temperature. Considerable changes between day and night temperatures are common in tropical and desert areas and the alternation of sunshine and rain have a destructive effect on stone. Since stone is a bad conductor of heat the forces thus set up are further exaggerated by shaded areas and between surface and interior layers. This causes flaking to take place and to some extent granulation.

Marble is in a rather special category for, though it is well crystallized, dilatation takes place at different rates at right-angle axes *(Plate 32)*. Temperature effects are minimal below 100°C. Calcite crystals can be deformed by mechanical pressure, slipping over one another in a reticulated pattern to establish a new equilibrium, and when this is attained the deformation is permanent. There is no means of restoring such deformed marble.

The role of temperature as an agent of decay is for the most part indirect. It reacts on the humidity in the pores of the rock and on the solubility of salt and of dissolved gases, influences the rate of chemical reactions and promotes hydrolysis. The rate of hydrolysis is considered to be doubled with every rise of 10°C in temperature.

Hydration and crystallization of salts. Hydration is often accompanied by a considerable increase in pressure within the pores of stone, a typical case being the change from anhydrite (anhydrous calcium sulphate) to gypsum by the addition of two molecules of water. This is said to develop a pressure, due to hydration, of some 1,100 atmospheres.

The crystallization of salts in stonework is a constantly recurring problem, especially in the case of excavated stones that are brought into a museum. It is a major cause of deterioration since the salts deposited in internal cavities near the surface may impose strains sufficient to cause complete disruption and defacement of surface modelling and ornamentation.

Frost. In cold or mountainous countries, even in the tropics, frost can cause serious damage. Water increases in volume by about 9 per cent when it freezes, thus disrupting porous structures It is interesting to note, however, that laboratory tests have shown that damage is not necessarily proportional to porosity but is related rather to the morphology of the pores.

Oxidation and reduction. While of general occurrence, the processes of oxidation and reduction are most dramatically illustrated by the behaviour of iron in mineral compounds. This metal is found both in the reduced ferrous (bivalent) condition and in the common rusty red oxidized ferric (trivalent) condition. It is very easily oxidized and when this takes place the crystalline network becomes fractured. The ferromagnesian minerals are the most susceptible to such changes, the iron being reducible by humic acids in the ground or oxidized even more easily to the coloured hydroxides that constitute rust.

Hydrolysis. The phenomenon of hydrolysis is widespread and its effects are particularly observed when solutions are subject to exposure at high temperatures. Such decomposition also takes place when ion-exchange conditions are established and in this respect the silicates are particularly vulnerable. Acids in the ground cause the disintegration of limestones in the presence of moisture. Water containing dissolved carbonic acid dissolves carbonate rocks of all kinds slowly but inevitably, forming a dilute solution of calcium bicarbonate which is readily deposited again as carbonate. This is responsible for fixing the patina of marbles and indeed, in geological periods of time, has resulted in precipitation of the well-known rocks, travertine and stalagmite.

In museums, carbonate rocks are sometimes damaged by the action of acidic substances ill-advisedly used for cleaning *(Plate 33)*. A curious case was that of coral damaged by an accumulation of acetic acid in the hermetically sealed boxes of oak which were used to contain it *(Plate 34)*.

Biological action. In the humid tropics the incidence of biological attack is considerable and deterioration may take place rapidly, invariably resulting from the combined action of a number of agencies such as the oxidation/reduction action of bacteria and the solvent action of the complex acids produced by organic growths or more obviously by turgescence, i.e., the strains caused by the swelling of the growing roots of higher plants.

Arenation and laterization. Attention may be drawn to two forms of deterioration of stone that are found particularly in the humid tropics: arenation and laterization.

The first phase of arenation may be the hydrolysis of feldspars and biotites without change in the external appearance of the stone. In the second phase microdivision and hydrolysis are intensified, admitting percolating solutions, and the ferro-magnesian minerals and plagioclases are destroyed and partly leached away leaving only white mica, quartz and some alkaline feldspar. For such an action to take place high temperatures are required and an abundance of water as is found in the tropics. Under such conditions arenation, together with laterization, may account for material losses of up to 80 per cent of the substances affected.

Laterization is a form of decomposition characteristic of tropical areas where there is considerable rain and high average temperatures promoting intensive hydrolysis. The silicates are completely hydrolyzed leaving behind quartz, iron and alumina which may suffer a form of reorganization into secondary minerals. The shell of laterite is typically an accumulation in depth of the oxides of iron and aluminium. It may form in any climate but not necessarily as a static deposit.

Atmospheric pollution. A normal atmosphere far from industrial areas is found to be composed as follows: nitrogen 78 per cent, oxygen 21 per cent, rare gases 0.95 per cent, carbonic anhydride 0.03 per cent, and a trace of ozone; but the combustion of coal and other fuels releases solid substances (dust, soot) into the atmosphere and gaseous contaminants as well (sulphuric and carbonic anhydrides). The result of this contamination may be so slight as to have little effect on analyses, but the cumulative reactions in time of airborne contamination on stone are very considerable.

As a result of exposure to industrial atmospheres, solid substances are deposited on stone to form a porous crust which condenses and retains gases and atmospheric moisture. The increase in the carbonic anhydride content of the atmosphere from 0.03 per cent to about 0.05 per cent slightly increases the solvent power of rain-water. The sulphuric anhydride, though present in comparatively small quantities, dissolves in fog, rain and snow to form sulphurous acid, which transforms readily to sulphuric acid, and this acts immediately on calcite, forming a mixture of calcium sulphite and sulphate. These salts are changed by oxidation into gypsum.

This complicated series of reactions may be regarded as affecting stone in two phases:

1. Superficial attack. The carbonate rock is gradually transformed from the outside inwards, forming a hard impermeable crust of gypsum mixed with soot and dust *(Plate 35)*. On stones that are not very porous this crust may adhere well and may actually be protective to some extent, as it is resistant to fumes.
2. The second phase is characterized by the break-up of the crust, often caused by the percolation of saline solutions into the interior of the stone. The surface becomes powdery and the crust is deformed and eventually detached, exposing a sensitive interior easily eroded by rain. The stone is then in a most vulnerable condition and may be deformed, as by a canker. The cracks and crevasses are probably intensified by the fact that the linear dilatation of gypsum is about five times that of calcite. The crystals slide over each other, gypsum recrystallizes in the fissures, and cornices and carvings may be seriously damaged.

This is a disease of the industrial north rather than the tropics but it is well to bear in mind that all calcareous rocks are directly threatened where industrial fumes are released freely into the atmosphere and the results are not only deterioration in appearance but also a very real and sinister form of material disintegration.

PRACTICAL GUIDE TO THE TREATMENT OF STONE OBJECTS [1]

MAINTENANCE AND CONSERVATION

In the museum or antiquarium the first essential for good conservation is to keep objects free from dust by periodic cleaning, for which purpose a brush with long, soft hairs or a feather duster should be used. Surfaces should always be brushed from top to bottom, taking care not to brush away loose or delicate fragments of stone or polychromy. Cloths should never be used since they rub the dust into the pores of the stone and eventually give a greasy or shiny effect to the reliefs and fill the hollows with dirt.

Even so, there comes a time when washing with water is necessary, particularly in the case of light-coloured stones like marble. For this purpose the British Museum uses a dilute aqueous solution of good-quality white soap or sodium oleate. Care should be taken to see that the water is not ferruginous or too hard. Hard water precipitates a disfiguring calcium soap on the surface of the stone, covering it with a greyish-white film. When in doubt use filtered rain-water or ion-exchange purified water or distilled water. These precautions in the choice of soap and water are particularly important when dealing with white marble.

The soap solution is prepared in a glass vessel and should never be allowed to be in contact with iron. The formula recommended is as follows: soft soap, 10 g; distilled water, 100 ml; ammonia (0.88), 1 ml.

In cleaning white marble, for instance, the object is first dusted. It is then washed from top to bottom with a soft brush—a paint brush or shaving brush—small areas being worked on at a time so that dirty water is not allowed to remain for long in hollows of the carving. After cleaning, each area is mopped dry with a soft, clean rag before the next one is tackled. Finally the marble is washed down all over, very thoroughly, with fresh water so that no soap remains to form a sticky film.

In cases where maintenance has been irregular and dirt is excessive it may be necessary to use a detergent such as Lissapol N (Imperial Chemical Industries), Teepol X (Shell) or Xilon (Tensia)[2] at a concentration of 60 g to 5 litres, but nothing stronger should be used and such treatment should be regarded as exceptional. The same general precautions in the washing process should be taken as with soap.

More dilute solutions of detergent (5 to 10 g in 5 litres of water) can be used in place of soap when it is certain that the stone does not absorb water. Some rocks, cements and slaty materials are quite absorbent. For example, in the case of a mica-schist from India which seemed to be compact, fine details became detached in the process of washing, despite the fact that there seemed to be no sign of cleavage before wetting. In assisting the penetration of water these detergents might well initiate a migration of soluble salts to the surface. If only for this reason, caution in the use of detergents must be recommended. They have the advantage over soaps, however, that a scum is not formed when hard calcareous water is used and this at times can be of great convenience.

In damp climates, the dirt that collects on stone harbours spores and encourages the growth of bacteria, moulds, mosses and algae. When microbiological organisms are present, the soap solution should be fortified by the addition of one or other of the following aqueous solutions in small quantity:

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[1] In writing this section we have drawn freely on the work of Dr. Harold J. Plenderleith.

[2] Tensia, rue Rouveroy, Liège, Belgium.

Aqueous sodium pentachlorophenate (1 g/100 mg liquid);
Aqueous sodium salicylate (1/100);
Aqueous zinc or magnesium silicofluoride (4/100);
Aqueous formaldehyde (5 ml/100).

The sterilizing agent selected should be added to the wash-water in the above proportions. As it is only exceptionally that one takes the trouble to identify the micro-organisms, tests should be made on small areas to determine that the strength of solution eventually employed for the general cleaning will control the growths at least for several weeks.

As a germicide and fungicide one might also add to the wash-water Noramium S.75 in strengths of 0.05 to 0.1 per cent. This is a quaternary ammonium compound dissolved as a concentrated solution in isopropanol. Noramium is compatible with detergents whether they are non-ionic or catonic. A 10 per cent solution of the commercial product is first made in water. A solution of 0.1 per cent is then made from this by stirring 50 cm^3 of it into 5 litres of water.

White marble that is badly stained is often very difficult to clean by water or indeed by any solvent. Acidic substances must be absolutely excluded because they at once attack and decompose all types of carbonate rock. Certain impurities in white marble that are not apparent on the surface, on the other hand, are turned yellow or brown by alkalis and the greatest care must be taken to rinse thoroughly with fresh water if ammonia or amines have to be employed in removing specific stains. Preliminary tests are always made in such cases to check the action of solvents by applying them locally on cotton wool wrapped round a match-stick. The commonest stains are ink, oil, paint, tar, moulds, lichens and algae. Red or black ink stains may be removed by using a freshly prepared aqueous solution of chloramine-T of 2 per cent strength followed, after some time, if necessary, by treatment with hydrogen peroxide (20 vols.) to which a drop of ammonia has been added. The object should then be thoroughly washed.

Oil-paint stains can be scraped fairly clean with a scalpel and the residue dissolved away using a 3/1 mixture of methanol and triethylamine or perhaps pyridine or morpholine, or even Carbowax (polyethylene glycol).[1] In the latter case the pasty condition of the material allows it to be used conveniently on vertical surfaces and even on ceilings.

Bituminous tar stains respond to a 1/1/1 mixture of benzene, ammonia (0.88) and methanol, applied by stencil brush, the area being thoroughly washed afterwards with fresh water applied on cotton wool.

Most mildew stains respond to the treatment suggested above for inks.

Lichens and algae are softened by brushing with dilute ammonia; the stone can then be thoroughly washed. A hard layer of old algae is best treated at first with formalin vapour (40 per cent formaldehyde) which facilitates the removal of the desiccated tissues.

Certain kinds of stain seem to defy all solvent, and can only be taken away by using a plastic stripping film—a method developed for removing fossils from coal. The process consists in the application of a viscous film of nitrocellulose obtained from one or other of the formulae given below:[2]

For rapid drying: methanol, 1 vol.; ether, 1 vol.; castor oil, 5 per cent by volume.
For slow drying: acetone, 2 vols.; amyl acetate, 2 vols.; triacetin, 2 per cent by volume.

Insoluble crusts of foreign material causing local damage to polished marble can only be removed by scraping with a scalpel or riffler file followed by judicious polishing with a suitable stone or powder.

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[1] Union Carbide Corporation.
[2] H. Duerden, *Ann. Bot.*, 1931, Vol. 45, p. 376.

PRESERVATION

Historical background

Until recently no protective treatment, as such, was applied to stone but the various decorative processes used, involving painting and gilding, nevertheless had a real protective effect. Only during the last century have methods been devised and applied in the attempt to slow down the deterioration of stonework exposed to weathering. One approach was to apply adhesives based on boiled linseed oil, tung oil, resins, bitumen, rubber, lime wash, sodium and potassium silicates, fluosilicates and fluorides, silicones, silicon esters and silicon tetrafluoride. Attempts were made to consolidate surfaces of stones exposed in the open air to weathering by impregnation with solutions of such materials and also with beeswax, paraffin wax and shellac, lime water (sometimes alternating with casein solution), vinyl resins such as the acetates and acetals of polyvinyl, acrylic resins (methyl and butyl polymethacrylate) and metallic soaps such as aluminium and zinc stearate, polyesters, epoxy resins, ethyl silicates, colloidal silica and alkaline silicates deposited by electro-osmosis. These methods, when applied to stone in the open, have all proved to be unsatisfactory, although the more reliable may be of some service where periodic treatment can be given for maintenance. Chemical treatment is not generally necessary for stones kept indoors although impregnation may be desirable in cases where a stone is porous or fragile, or perhaps rendered vulnerable as a result of exposure or of contact with soluble salts or humic acids in the ground.

Among the more reliable materials adopted for preservation are the following: beeswax, paraffin wax and such like, often replaced by microcrystalline wax (to which dust is less adherent), dissolved in a mixture of turpentine and toluene; a 3 to 5 per cent solution of polyvinylacetate in a solvent consisting of equal volumes of toluene and ethanol; alternatively, a 5 per cent solution of methyl methacrylate in a mixture consisting of 75 per cent toluene + 24 per cent methyl alcohol + 1 per cent dibutylphthalate.

The crystallization of salts, as has been suggested above (p. 216) is a major cause of decomposition. Storage in a room or vitrine in which the air is conditioned will of course arrest the movement of salts and preserve the stone. But air-conditioning is costly, particularly for large objects. The vitrine idea is not conducive to good presentation and for such reasons it is generally preferable to extract the salts from the stones. Besides being the cheaper alternative, it is, in the long run, the more certain method of ensuring preservation.

Methods of removing soluble salts

Immersion in water. The stone object, mounted if necessary on a wooden chassis, is lowered into a tank and completely immersed in water. As diffusion is a slow process there is little advantage in using running water. Depending on the size of the object, the tank water must be removed and changed periodically—daily for a small object, weekly or even at intervals of about fifteen days for a larger object, according to the progress of the washing as determined by tests made on samples of the tank water.

The progress of the reaction is followed by measuring the electrical conductivity of the water.[1] As the salt content of the water is reduced, the resistance increases and washing is considered to be complete when tank and the wash water register the same degree of resistance.

For stones containing much chloride, as is usual in rocks from desert countries, it may suffice to check the process of washing

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[1] For this purpose a Philips conductivity meter is convenient, type GM 4144/01 with GM 4221 electrodes.

Plate 33

Detail of a cameo made of coral which is partially encrusted by a hydrated efflorescence of calcium acetate formed by vinegar which had been used in cleaning the mounting (photo: IRPA).

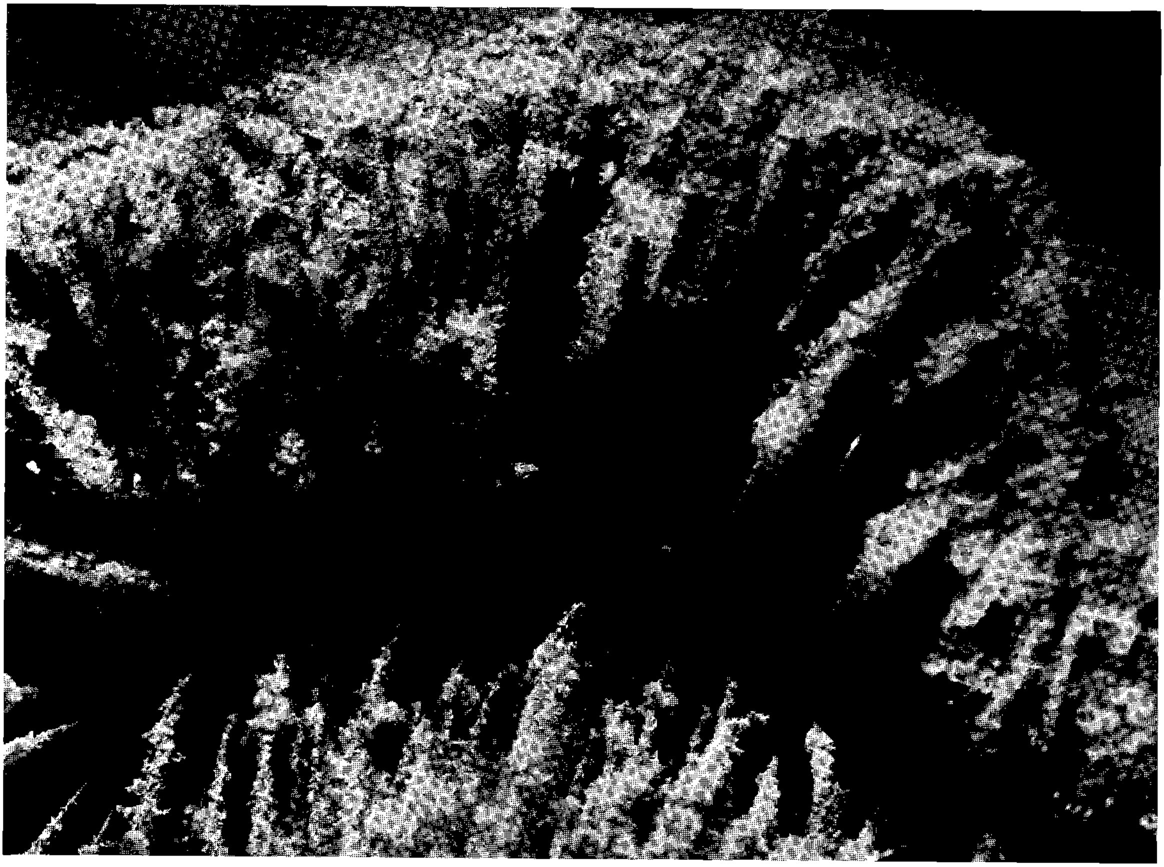

Plate 34

Detail of a madrepore coral covered with efflorescent calcium acetate (photo: IRPA).

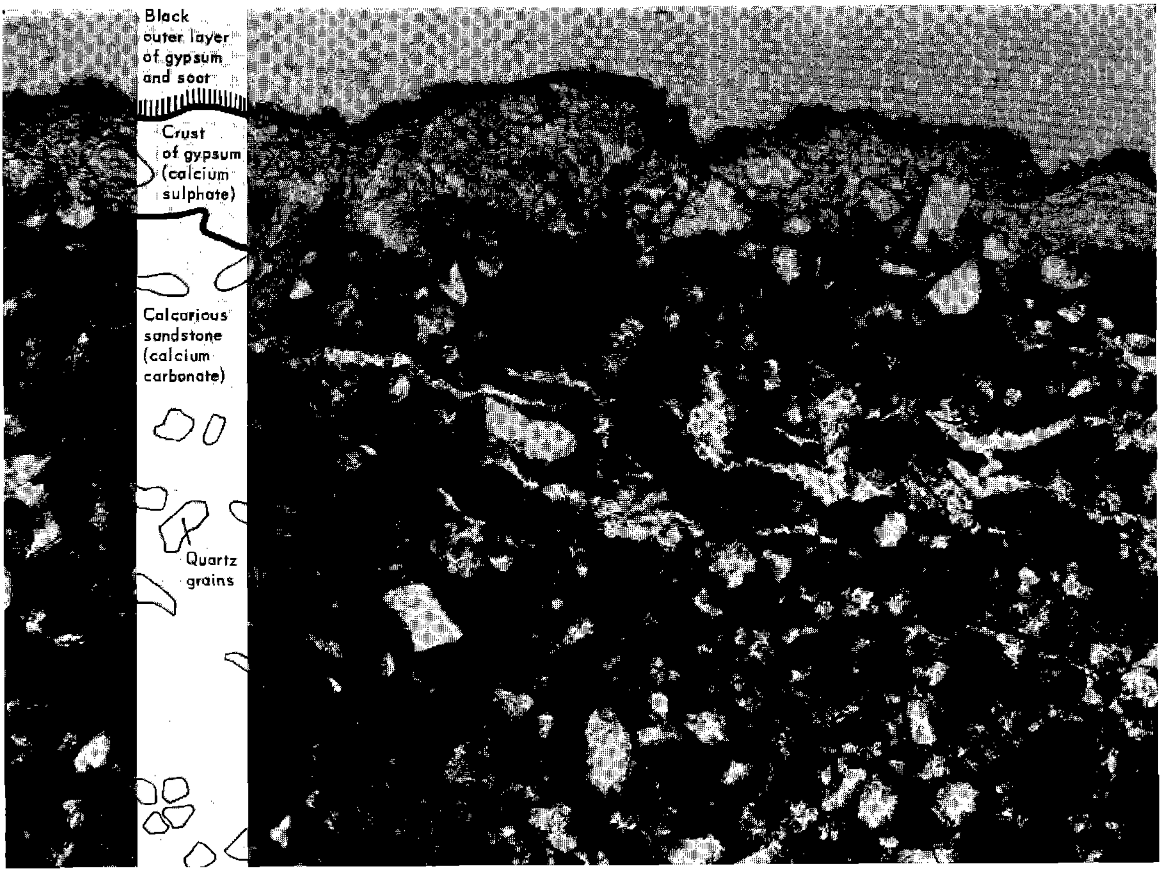

Plate 35

Thin section micro-photograph of calcareous sandstone from St. Michael's Cathedral in Brussels. The crust of gypsum was formed at the expense of the calcareous cement as shown from the remaining quartz grains still cemented *in situ* (photo: IRPA).

Plate 36

Head in Egyptian limestone.

a Before treatment (photo: IRPA).
b After impregnation with wax.
Note that it was impossible to remove the salt as the stone would have collapsed. Impregnation seals in the salts and prevents hygroscopic action (photo: IRPA).

by making tests for chlorides on samples of the water. This is easily done by adding a few drops of silver nitrate solution to a sample of the water previously acidified with nitric acid. The presence of chlorides is indicated by the appearance of a white flocculent precipitate or, if only a little salt is present, by turbidity which, incidentally, should be completely discharged by the addition of a few drops of strong ammonia.

The stone must not be allowed to dry while the water is being changed or more damage may be caused by further crystallization.

The immersion tank can be made of glass, rubber or plastics material such as PVC or polyethylene, but never of iron or copper for these metals may stain the stone with rust or with green copper compounds. For very large stones it is sometimes convenient to use a heavy wooden box as a tank, the inside having been lined with one or more layers of polythene sheeting to make it waterproof.

The water may be rain-water, well water, or even the ordinary domestic water supply as long as it is not saline and not ferruginous. It is perhaps best with small objects to complete the treatment by using distilled water.

Should the stagnant water in the tank ferment or produce algal growths it should be renewed at once and a bactericide/fungicide added to the fresh water, e.g., a quaternary ammonium compound such as Cetavlon (ICI) or Noramium S.75 (Prochinor), concentration 0.1 per cent.

When a stone lacks cohesion, when its surface is fragmented by salt action, or when it is decorated with polychromy, as is often the case with stones from Egyptian tombs, the weak parts and the painted parts must be fixed with a consolidant before immersion.

Fixing and consolidation can be ensured by one or two applications of a 3 to 5 per cent solution of Calaton CA in alcohol (Werner, 1958). Calaton is a modified nylon made by Imperial Chemical Industries Ltd. and soluble in ethanol or methanol or in industrial alcohol (industrial methylated spirits) or in a mixture of 70 per cent of these alcohols with 30 per cent of water. The solution may gel at ordinary temperatures but liquefies readily when immersed in water at about 40°C; it should be kept away from naked lights of all kinds as it is highly inflammable. Soluble nylon deposits a film that is insoluble in water and does not add any tension to the surface to which it is applied. It gives permanent strength to a frail surface and at the same time is permeable to salts in solution. If, after extracting the salts in the process of washing, the protective film should appear to be opaque, it can be regenerated by painting with alcohol or by the application of a new layer of dilute Calaton.

Other consolidants that have been employed with success are a 5 per cent solution in benzene of Lucite 2046 (Du Pont de Nemours), a co-polymer of 50:50 normal and isobutyl methacrylates; and Imperplex, a 3.5 per cent solution of a methyl methacrylate in trichlorethylene.[1]

Unfortunately it is by no means always possible to employ the method of soaking in water to remove salts. Large, immovable frail stones and walls, etc., require a special form of treatment involving the use of a moist paper pulp.

Extraction by moist paper pulp. The stone is entirely covered with a layer of wet paper pulp of some 5-10 mm thickness. The water is first absorbed by the stone and dissolves the soluble salts in it; then, as moisture evaporates from the pulp, the salts are drawn from the stone and eventually remain as crystals in the pulp, with which they can be easily removed. The pulp may be allowed to remain in position on the stone for some three weeks: it is taken

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[1] Imperplex, 77, rue Pierre de Coster, Brussels.

away before the operation is rendered too difficult by the hardening of the layer. Fresh pulp is then applied immediately and further applications may be given as occasion demands.

It the surface is very weak or if it is polychromed, it should be consolidated, as a matter of routine, with soluble nylon before any attempt is made to remove the salts.

In desert countries, it is possible to desalt stones by burying them in shallow sand and wetting the sand, the procedure being the equivalent of the pulp treatment, but this presupposes the existence of salt-free water as well as clean sand, and at best is an emergency procedure.

Forcing water through the stone. In this process the object is enclosed in an impermeable sheath of a plastic material. Water is admitted through an inlet in the base of the envelope and is drawn out from one or more openings connected to a vacuum pump. The method is simple and rapid but objects should be consolidated before treatment and special care should be taken in removing the plastic coating afterwards.

Treatment with warm water. Since heat increases the solvent action and diffusion of water, desalting by immersion can be accelerated if the temperature of the water is raised to about 60°C, for example by an electric heating device.

In museums that have to deal with many small salty stone objects it would be of value to install a desalting apparatus based on the Soxhlet extractor (Fig. 55). This consists of three principal elements. First there is a cylindrical tank (*A*) with a gauze platform (*B*) and an electric immersion heater (*C*). The tank has an inverted conical copper cover (*D*). A smaller tank (*E*) is designed to take the object under treatment and it is fitted with a siphon (*F*) passing through the gauze platform to tank (*A*) below. Fresh water in *A* is heated and distilled into *E* where a saline solution accumulates and is eventually siphoned back.

This extraction by hot distilled water is very rapid and the process can even be applied to a frail object, simply by keeping fragments in place by bandaging with lint.

Sealing-in the salts

It sometimes happens that the pressure of salts is so great as to have caused such a general collapse of the stone that their removal by any of the methods described above is out of the question. Any attempt to consolidate such a porous mass by a resinous substance would undoubtedly result in the formation of a hard impermeable layer or crust which would impede the extraction of salts.

In such cases one might envisage impregnating the stone completely with a mixture of beeswax and paraffin wax in the proportions of 2 : 8, applied in the molten condition, drop by drop, to the stone kept at sufficiently high temperature by infra-red lamps. The temperature of the stone should be high enough to keep the wax in a continuous state of fluidity so that it will be immediately absorbed and thus prevent the formation of runnels of wax which would remove powder and deform the shape.

The operation is repeated until the stone is perfectly stabilized *(Plate 36a and b)*.

Protection of stone against biological attack[1]

Vegetable organisms (plants and trees), cryptogams (algae, moss and lichens), moulds and bacteria soon develop in stonework when the humidity of the surrounding air is of the order of 75 per cent at temperatures between —5° and 40°C. This is notably the case on limestones. Moulds and bacteria may also attack the materials

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[1] See also Chapter 3.

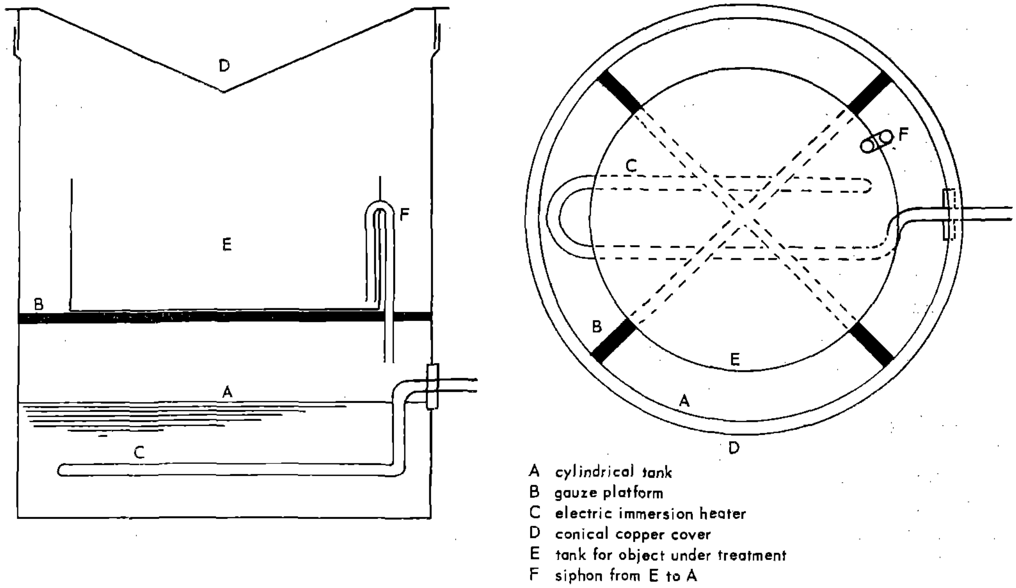

Fig. 55. Olson desalting equipment.

used for the conservation or restoration of such stones. If it is impractical to maintain conditions in museums within the limits of security, i.e., below 65 per cent relative humidity, steps must be taken to protect the stones themselves.

Great care must be taken in removing the roots of plants; mosses and lichens respond to treatment with a soft brush after softening, if necessary, with a dilute solution of ammonia. The stone is washed finally with one or other of the toxic aqueous solutions (see p. 219) say at the rate of 2 litres per square metre of surface. sodium pentachlorophenate also immunizes against the attack of certain bacteria.

The living organisms are often characterized by individual activity and it may be sometimes desirable to sterilize before beginning any general treatment. At times it may even be desirable to fumigate the room with formaldehyde vapour. This can be done by adding aqueous formaldehyde to potassium permanganate which produces an exothermic action. Details of procedure are given by Walker who recommends adding 0.45 kg of formalin to an aqueous solution containing 0.17 kg of solid permanganate in a porcelain basin. These quantities suffice for a room of volume about 30 to 40 m³.

Protection of pyritized stones

Particular care must be given to the protection of stones and fossils that are pyritized, that is, that have in them occlusions of pyrite or marcasite, minerals that decompose in damp surroundings to form sulphuric acid. Such objects must be kept very dry and must never be washed with acid or water.

The course of treatment recommended by Miss J. M. Swett consists of:

1. Elimination by scraping or brushing away the product of decomposition.

2. Neutralization of sulphuric acid by exposure of the object for at least six hours in an ammonia atmosphere in a glass vessel over concentrated ammonia (0.88).
3. Elimination of all traces of water by drying in an oven (± 105°C) for two hours.
4. Isolation of the object by varnishing with a 10 per cent solution of polyvinylacetate either in the solvent toluene/acetone (9/1) or toluene/alcohol (5/5).

The object is then dried in a warm atmosphere and finally in an oven at ± 50°C.

For fragile stones, operation 4 above is replaced by vacuum impregnation, using the same varnish so as to effect consolidation and isolate the object from the atmosphere and from moisture.

According to Plenderleith (1956) the neutralization of free acid in pyritized fossils that are already partly decomposed may take several months and there will always remain a certain uncertainty as to the efficiency of neutralization. For this reason, such objects should be subjected to periodic inspection.

Pyritized fossils and nodules of marcasite may sometimes be preserved by two hours' heating at ± 105°C followed immediately by one hour's impregnation by immersion in molten waxes (beeswax 2/paraffin wax 8). To obtain maximum saturation, objects are only withdrawn from the wax after a degree of cooling when the wax begins to solidify. It should be added however, that when marcasite has once begun to decompose and sulphuric acid is present, the major role in decomposition is the interaction of this acid and the carbonate that is commonly present in fossils.

CONSOLIDATION

For strengthening fragile stones one may adopt a method of impregnation using either mixtures of molten waxes or solutions of waxes, resins or ethyl silicates as consolidants. Efficiency clearly depends upon the degree of penetration that can be achieved; indeed, if this is unsatisfactory, surface deposits are liable, in time, to cause sealing and to intensify the rate of deterioration of the very stones that require protection. It must be emphasized, therefore, that the efficacy of wax treatment is a function of the quantity of wax absorbed. Resinous treatments on the other hand require only the minimum of consolidant necessary to re-establish connexion between the grains of stone that have become detached from one another or are on the way towards disassociation.

Impregnation with mixtures of wax

Wax treatments are considered to be the most durable but their use on stone is restricted by the fact that they are inclined to modify the properties and appearance in a disagreeable fashion—darkening light-coloured stones, conferring superficial shine, and making the stones liable to attract dust.

Treatment is carried out by immersion in a bath of molten wax (as in the case of wood, see page 269). Care should be taken to place the stone upon the mass of wax before it is melted so that the stone will be gradually warmed with the wax and less liable to be strained by sudden heating.

The wax mixture is composed as follows: beeswax, 2 parts by weight; paraffin wax, 8 parts by weight.

Paraffin wax is used so that the mixture will melt at a convenient temperature. The beeswax confers plasticity and facilitates good contact between consolidant and the stone and this, of course, is fundamental. When it is desired to waterproof a stone completely, as is essential when it is impossible to extract all the soluble salts before treatment, it is very important that the wax mixture should be well plasticized.

Instead of the above mixture, the microcrystalline waxes marketed as Cosmolloid by Astor, Boisellier and Laurence Ltd.,[1] may be used (Plenderleith, 1956); these have the advantage of attracting less dust than others.

The adhesive properties of the standard wax formula may be improved by the addition of colophony and dammar resin in the following proportions (in parts by weight): standard wax formula, 3; colophony, 4; dammar resin, 2.

In order to protect such mixtures from attack by moulds, a little fungicide may be added.

Large stones, monuments, etc., that do not lend themselves to tank-immersion treatment may be impregnated by using infra-red radiation or ambient heat from a battery of heaters placed at some distance so as to heat uniformly the surfaces to which the wax is applied. To ensure that heating will not be too drastic, the consolidant is first dissolved in a mixture of turpentine and toluol and applied to the cold stone as a soft paste of the consistency of vaseline. As the stone becomes warm, further applications are made of wax that has already been melted.

In all these treatments the aim must be to ensure maximum saturation. This is discernible by the cessation of the bubbling of air that is released from the interstices of the stone as wax takes its place, and it can be seen in practice that when the desired degree of penetration is achieved, the stone on cooling usually has a coating of solidified wax on the surface of a thickness of about 1 mm. In practice, when one adopts the immersion method, the stone is left *in situ* in the tank until the wax reaches the consistency of vaseline. It is then removed and the consolidant continues to be applied with the aid of the infra-red lamps until the bulk of the stone is cold.

Excess wax is removed with wood or bone scrapers and later a turpentine solvent. In the final stages white spirit may be employed and the last solvent is carbon tetrachloride. Hot water from an aerograph spray is quicker in operation and cheaper, but in all this dewaxing only small areas should be worked at a time lest the consolidants should be extracted from the stone. The last process is brushing with a moderately stiff brush moistened with a mixture of equal parts of water and ox-gall.

Impregnation with solutions of synthetic resin

When a very porous stone requires consolidation, impregnation can be carried out by applying several coats of a suitable resin solution with a large brush. First of all a thin solution (strength 2.5 per cent) is brushed well in and when completely absorbed this is followed by one, two or three applications of a more concentrated solution, depending upon the permeability of the stone. Drying is slowed down by placing the object under a cover together with a quantity of solvent so that the ambient atmosphere will be saturated with the vapour, a precaution which has been found to reduce the natural tendency for the resin to migrate towards the surface.

As in many other types of conservation, a solution of polyvinylacetate is often used in a mixed solvent. This solvent may be either equal parts of toluene and alcohol or, alternatively, 9 parts of toluene to 1 part of acetone. There is little change in this synthetic resinous material with time and it retains its solubility with age. Concentrated solutions (± 10 per cent) make convenient adhesives and excess is easily removed by solvent.

Other synthetic materials favoured for treatment of porous stones are: (a) polymethyl-methacrylate (PMM) dissolved in xylene or a mixed solvent containing 8 parts toluene and 2 parts methyl alcohol (the commercial solution marketed by Imperial Chemical Industries is called Bedacryl 122X and its concentration is 40 per cent in xylene); (b) polybutylmethacrylate (Lucite 2046, produced by Du Pont

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[1] Savoy Street, London W.C.2.

de Nemours) dissolved in white spirit containing about 30 per cent of benzol or, optionally, in the single solvents benzol or turpentine.

T. R. Gairola (1959) recommends PMM dissolved in toluene for general preservation work in strengths of about 0.5 per cent for the consolidation of mural paintings, 1 per cent for treating porous stones, and 6-9 per cent as an adhesive. He removes excess material by washing with a mixture of toluene and alcohol in equal parts.

The vacuum method of impregnation

This method lends itself particularly to impregnation with synthetic resins and is generally recommended in the case of stones that are so slightly porous as to be unable to absorb enough consolidant by normal means, or which are so enfeebled that a consolidant cannot be applied by brushing without attendant damage (Fig. 56).

The object (*B*) is placed in a vessel (*C*) in a desiccator (*A*) which is evacuated to a constant low pressure shown by a manometer (*D*). A dilute solution of the consolidant is then introduced against the inner side of the vessel (and not over the object) in order to avoid sealing the pores prematurely. When the object is completely immersed the pressure is released and impregnation is then usually completed after one hour. Drying may be carried out as previously described, using infra-red lamps. The operation of impregnation may be carried out equally well under a bell jar over a vacuum pump.

In the course of drying, some resins (notably Bedacryl 122 X) have a tendency to rise to the surface, especially when the stone is not very porous, and a film is formed there. This film arrests evaporation of solvent from within the stone. For this reason, in vacuum impregnation the solution of consolidant must be given sufficient time to be absorbed right into the centre of the stone. The evaporation of solvent may impoverish the surface, causing it to lack cohesion; one must therefore be prepared to make adjustments either by applying more consolidant or by using more solvent to remove the excess.

Impregnation with ethyl silicate

Sandstones and siliceous limestones that are permeable may be consolidated by impregnation with silicon esters (generally mainly ethyl silicate dissolved in alcohol) which in contact with atmospheric humidity become hydrolyzed, liberating the alcohol and precipitating colloidal silica. This silica covers the grains of quartz and thus consolidates the mass of material. Ethyl silicate mixed with sand forms a cement that can withstand exposure to weathering for lengthy periods.

Ethyl silicate is manufactured by the Carbide and Carbon Chemical Corporation,[1] and marketed in a form ready for use by Nubold Development Ltd.[2] There are two varieties called respectively Nubold Bonding Agent (a simple ethyl silicate) and Nubindex (an ethyl silicate solution to which a silicone resin has been added).

The solution of ethyl silicate may be applied by brush, spray, or injection. In view of the behaviour of this consolidant in contact with water it obviously cannot be applied to any stones that are not absolutely dry, since otherwise they would at once become covered with an impenetrable film of milky-white appearance.

The number of applications is governed by the permeability of the stone and tests are made on an inconspicuous place to make a preliminary assessment before proceeding with the general treatment. The work must be discontinued at the first sign of any appearance of a white veil on the surface.

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[1] 30 East 42nd Street, New York.

[2] The Mount, Crawley, Sussex, United Kingdom.

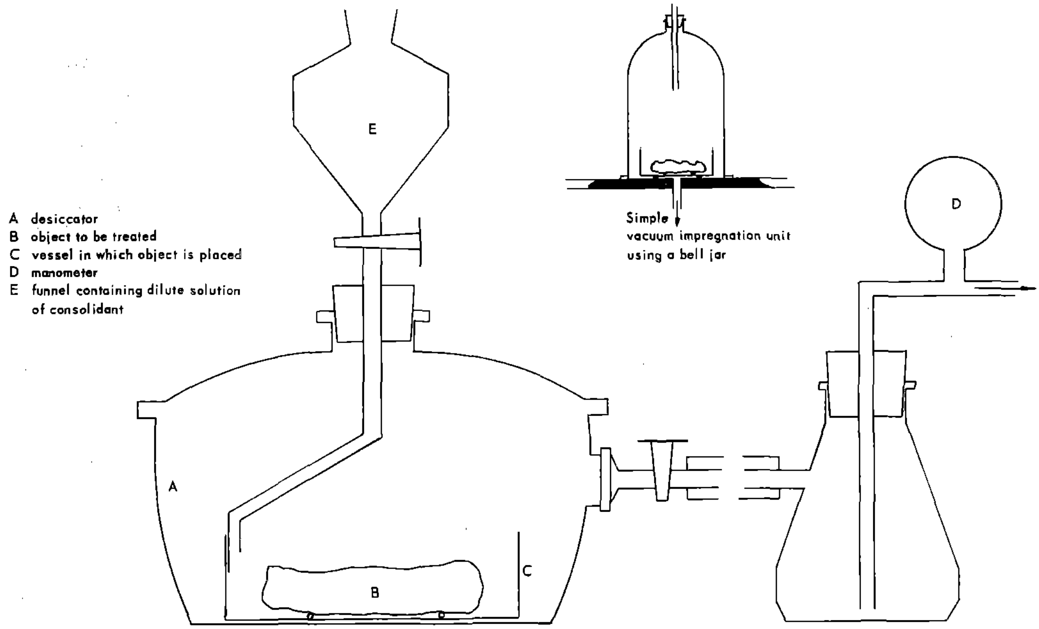

Fig. 56. Diagram of equipment used to impregnate objects in partial vacuum.

Much work has been done in an effort to perfect a method of using organo-siliceous solutions for consolidating stone.

Staff should avoid unnecessary or prolonged exposure to the vapours of such solutions and it is as well to note that they are generally inflammable.

Consolidation of marble

As has already been pointed out, the powdery condition of marble sometimes observed on protruding portions of carvings and appearing as blanched granular patches is caused by the irregular thermal expansion of the crystals of calcite that compose this stone. Conditions of this kind can be treated by local impregnations with dilute solutions of such resins as polyvinylacetate and polymethyl methacrylate. Some doubt always remains, however, as to the depth of penetration possible and how far one can go without displacing the granular surface. For this reason application of a wax salve with the aid of the infra-red lamps in order to fix the granulated stone is often preferred, and the optical effect of such treatment on the whole tends to be more acceptable.

Granular marble can also be consolidated by the application of lime water in many coats, time being allowed for complete drying between each, and it is sometimes advisable to complete the process by one or two applications of a 10 per cent solution of 'soluble casein' in water. This substance reacts with calcium carbonate to form an adhesive bonding based on calcium caseinate.

RESTORATION

Apart from the accidental staining referred to in an earlier section, certain stains on stone are due to actual changes in the surface of the material. These resist the classical methods of cleaning and call for delicate methods of treatment that can be entrusted only to a qualified restorer.

Removing iron stains from marble

Iron stains are removed by the application of sequestrating agents applied with cotton wool on the tip of an orange stick. Sequestration requires much patience and is carried out on small areas at a time. Reagents recommended are Versenol, produced by the Dow Chemical Co. (U.S.A.) and sold in the United Kingdom by F. W. Berk and Co. Ltd.,[1] and Detarol, obtainable from J. H. Shaw.[2] In exceptional cases very dilute oxalic or citric acids may be used, but these are decidedly dangerous in the hands of an amateur because they dissolve calcium carbonate and tend to leave a blanched area on the stone.

Removing insoluble salts

The removal of insoluble incrustations depends on their chemical nature. As has been stated, carbonates are decomposed by acid and if it is a question of dealing with an incrustation of carbonate the greatest care must be taken to localize the action of the reagent used in such a manner as merely to soften the incrustation. The area should then be immediately flooded with water and mopped dry and any foreign matter removed with a pointed instrument or nickel-chrome scraper. Dilute hydrochloric acid, oxalic acid or citric acid may as a last resort be employed, but never stronger than a 5 per cent solution in water.

Since calcium sulphate or gypsum dissolves very slowly in water it is generally a more effective treatment to decompose such incrustation by desiccation with an electrically heated spatula. Care is required, of course, especially where the stone is deeply carved and thin, not to overheat, since limestone is converted to quicklime at high temperatures.

Repairing broken stone objects

Small fragmented objects can be reassembled by using various cements based on polyvinylacetate or the acrylic resins. Above a certain weight, it is better to use cements based on polyesters or epoxy-resins which are more resistant. For example, for the assembly of parts of a large Jurassic fossil a polyester resin was successfully used.[3] In other cases satisfactory results were obtained with the epoxy-resin type UHU-plus.[4]

When a stone is broken in two pieces by a clean crack a satisfactory joint can easily be made by applying flake shellac softened to melting point (120°C) directly on one fractured surface as the temperature of the stone is raised. For this purpose infra-red lamps may be used or even a blow-lamp, the stone fracture being sprinkled with the shellac. The other fractured surface is heated at the same time and when the shellac is seen to be in the form of a thin continuous film, the two are brought together in register and maintained in position until the stone is quite cold.

For heavier stones, the fragments must be supported by metal dowels which will not oxidize and expand so as to cause future cracking—stainless steel or more usually brass or bronze, notably Delta metal.[5] It is often preferable to select dowels of rectangular cross-section, neither too thick nor too heavy, for the type of stone. The ends of the dowel are cut and forked so as to be firmly anchored in the hole when it is packed with cement.

Dowel holes must be carefully placed, with attentive regard to such factors as the strength of the stone, the weight of the parts, the effects of leverage, etc. Drilling and fixture is first made in the heavier fragment. The orientation of the second hole

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[1] Commonwealth House, 1-9 Oxford Street, London W.C.1.

[2] 8 Baker Street, London W.1.

[3] Type DV produced by Union Chimique in Belgium.

[4] UHU-Werk HnM. Fischer Bühl, Baden (Federal Republic of Germany).

[5] Delta Metal Co. Ltd., 295 Tunnel Avenue, London S.E.10.

is then decided, the stone being marked with chalk or fusain. After drilling a trial fitting is made to ensure correct register, and when these points are all satisfactory the work is ready to be cemented.

The cement used most commonly for fixing dowels is ordinary plaster of paris; it goes on easily and can be removed, if necessary, by scraping or by prolonged soaking in water. But it is not advisable to use plaster with very porous stones, particularly if exposed out of doors, as calcium sulphate is not insoluble and this might give future trouble. Neither is it desirable to use plaster where conditions are permanently damp. The rate of setting of plaster can be slowed down by the addition of various substances such as slaked lime or animal glue; since the lime tends to weaken the adhesion the glue is added to increase the strength of the joint.

Jointing can also be made by using Portland cement mixed with fine sand (2:1).

Today, excellent cements can be made from mixtures of sand, powdered stone and a polyester or epoxy-resin. Some restorers use only such mixtures, adjusting the ingredients so that the cement ultimately approximates in granularity to that of the stone.

The UPAT company of Emmendingen in the Federal Republic of Germany sells a type of dowel called UPAT-UKA 3 which is very easy to use. It consists of a threaded pin and a glass tube containing an epoxy-resin incorporating an accelerator, quartz sand and the hardener. The stone is drilled, the glass tube introduced by means of the same drill and the glass then broken in the hole and the contents thoroughly mixed. Coagulation is very rapid. A 12-mm dowel after 1½ hours (when the cement is hardened) will carry a maximum weight of 4,780 kg. This method, which was developed as a rapid means of anchoring machines and fixing objects to walls, offers two advantages: only small-diameter holes are required (only 2 mm greater than the dowel) and no lateral pressure is developed, thus avoiding the risk of bursting strain.

Filling open joints and cavities

Stopping is used to fill cracks and cavities when their presence is disfiguring or weakens the object. Thus, mortars may be employed or stucco mixtures, as is preferred in the case of lacunae in mural paintings or in mending broken pottery. In all such cases it is important to see that the surfaces concerned are dust-free before filling.

STORAGE, PACKING AND TRANSPORT

Although the problems of storage, packing and transport are dealt with elsewhere (Chapter 18) there are certain rules particularly applicable to stone which may usefully be mentioned here.

Storage. Objects of stone are often heavy and brittle; they should not be subjected to rough treatment and, indeed, should be moved as little as possible.

Rocks subject to cleavage should not be exposed to solar radiation which might cause the surface to scale. For the same reason they should not be placed near stoves or radiators.

Stones should never be sealed into walls or floors since they may then be exposed to the action of harmful salts or have their humidity balance upset.

When stones are set upright the arrangement should be such as to allow free movement of air to all surfaces so as to minimize the possibility of condensation and consequent biological attack.

Packing. White marble is very easily stained by contact with such packing materials as rolls of paper, straw, cloths, etc., even when these appear to be clean, as the slightest dampness in them encourages the growth of moulds. If humidity is inevitably present, white marbles should never be packed in contact with organic materials that might provide nutrients for such growths.

Transport. Certain stones exposed in the open may be so decomposed that it is impossible to transport them to the shelter of a museum without very great damage. Such objects will have to be consolidated *in situ* before removal. This operation is simple when, as in hot countries, it is possible to use a salve or fused mixture of paraffin and beeswax upon them. If the surface is dry, the surface can also be consolidated by a solution of polyvinylacetate or polymethylmethacrylate. If the stone is wet the answer is to use acrylic emulsions such as Paraloid (Rohm and Haas, U.S.A.) diluted with water or with aqueous polyvinyl alcohol to which a little pentachlorophenol or some similar substance has been added as a fungicide.

AFTER-CARE AND OBSERVATION

As in all other branches of the conservation of cultural objects, diagnosis and treatment, though essential, are only a small part of the work of the conservator. They must be accompanied by an adequate system of documentation and followed up by periodic examination. Objects that are particularly unstable or frail may need further treatment, and the relative value of alternative forms of treatment can only be assessed on the basis of experience and continued observation.

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H. J. Plenderleith and G. Toracca

The conservation of metals in the tropics

15

INTRODUCTION

The stability of metals depends upon retention of their normal metallic properties, usually thanks to the formation of a thin surface film of oxides acting as a protective coat or patina. The patina is invisible on stainless steel, but is more often coloured on copper and its alloys, brass and bronze, and may have a certain aesthetic appeal. Instability is recognized by the presence of spots, weals or gross mineral incrustations on the metal which frequently occur in the form of localized patches marking areas where active corrosion is taking place. Metallic corrosion is a term in general use to describe the changes, chemical and electro-chemical, that take place when metals revert to minerals—minerals being their precursors—as they are the equivalent of the ores from which the metals were originally won by man in the process of smelting (Gettens, 1963).

Preliminary examination

From the point of view of conservation, the preliminary study of an object made of metal takes the form of establishing (a) how far mineralization has already taken place and whether any signs of active corrosion are in evidence; and (b) assuring that the metal is dry and free from contact with materials that are likely to provoke or promote decay.

Corrosion

Metals tarnish on exposure to air due to the action of oxygen, gaseous sulphur compounds, etc. If buried, they may be exposed to more intensified attack owing to the presence of soluble salts in the soil. These salts, in the presence of moisture, act as electrolytes: i.e., galvanic actions are initiated with the result that the metal becomes emaciated. Similar observations also apply to metals recovered from the sea and even to metal objects in museums that happen to be contaminated with saline matter, such as sodium chloride.

Effects of environment

Under favourable conditions during the process of corrosion an incrustation of mineral substances may be formed that seals up the surface, protecting the underlying metal from further attack and establishing a condition of equilibrium. However, once the metal is removed from its environment, i.e., upon excavation, it is exposed to a fresh series of influences—variations of heat, moisture and atmospheric gases. Corrosion may well break out again and proceed to the limit; or, under favourable circumstances, it may be arrested by the re-establishment of a new state of equilibrium in the new environment. Changes in appearance, shape and metallic content are the results. Hence, the desirability of giving physical protection to the system, at least as a first-aid measure, and in so far as possible, to any protective crust of minerals. Normally, such a crust is brittle and readily cracked by mechanical shock, and cracks become the loci of active corrosion because at these points oxygen and moisture can have access and can penetrate to the corrosion front or stratum lying beneath the incrustation and immediately adjacent to the residual metallic core.

Tropical conditions of damp heat do not, in themselves, offer a serious threat to the stability of metal objects. They do, however, operate to intensify corrosion when it has already begun to take place. Galvanic action becomes intensified under these conditions, particularly when salts are present in incrustations or, in general, when there is a form of moist contamination (condensation) on metallic surfaces bearing stains of rancid fatty matter, residues of libations, traces of foodstuffs, etc. To this extent, problems of the conservation of metals in the humid tropics tend to be more acute than in temperate regions. However, the mechanism of change is essentially the same; and since it is a question of a difference of degree rather than of kind, the methods described in standard literature on treatment in general apply to tropical countries also. Here, for practical reasons, the emphasis is placed on treatments requiring a minimum of apparatus and the use of chemical substances that are easily obtainable, even in districts remote from sources of supply.

The interest attaching to the conservation of metals lies in the varied nature of the attack and the variety of the measures that can be taken to arrest and control deterioration. Certain general methods of procedure are applicable to most metals, but there are many specific methods which are applicable only to certain individual metals, The general methods are related to the galvanic phenomena and a simple introduction to these will be given below, followed by details of some of the more valuable specific methods of conservation. The reader is urged, however, to regard this chapter as an introduction to an interesting and rather complicated field of study and not as a comprehensive text. Clearly, the subject cannot be dealt with fully within the limits of the present volume.

ELECTROCHEMICAL REACTIONS OF METALLIC OBJECTS

The most characteristic feature of metals as compared with non-metals is their individual behaviour when in contact in an electrolyte. The relationship of the various metals one with another in such circumstances is so distinctive and striking that the different metals can be arranged in one long series from gold (the noble electro-positive cathodic metal) to zinc, aluminium and magnesium (the base electro-negative anodic metals). From the position of any two of these metals in the series, their behaviour when in contact in an electrolyte can be readily deduced.[1]

A simple amplification of these statements may serve as a useful introduction to the two general processes of treatment which will be described in more detail in the practical section. Here it may suffice to give two

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[1] A liquid capable of conducting an electric current is described as an electrolyte. The following metals are given in their position in the electrochemical series, i.e., those on the left are electro-positive to those on the right: gold, silver, copper, iron, lead, tin, zinc, aluminium and magnesium. When two different metals are in contact in an electrolyte, the metal occupying the position furthest to the left in the electrochemical series is cathodic and noble in the sense that *it* survives, whereas the furthest to the right is anodic and the baser metal of the two, in the sense that it is sacrificed (dissolved).

illustrations of galvanic action employed to arrest corrosion, but first let us examine the structure of an 'electric battery'.

GALVANIC ACTION: THE DRY CELL

A 'dry cell' designed to supply electric current (Fig. 57) consists of: (a) a zinc can acting as the 'base' electro-negative pole (the anode); (b) inside the can, a damp electrolyte (chloride mixture); (c) centrally placed in the electrolyte but not touching the zinc a positive pole (cathode), normally a carbon rod functioning as the 'noble' material. When the poles are joined together externally by a circuit through a lamp, an electric current is seen to be generated, for the lamp lights up. The electrical energy derives from the chemical corrosion of the zinc can by the electrolyte—the electric current outside the cell lights the lamp; but within the can, out of sight, the base metal anode is being sacrificed while (as a result) the noble cathode is protected from deterioration. Hence the common reference in museum laboratories to zinc as a 'sacrificial anode'.

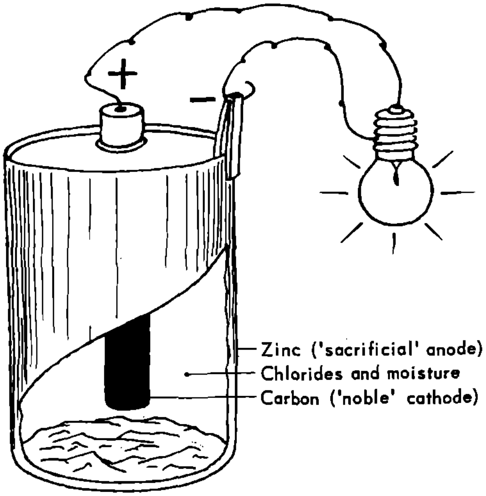

Fig. 57.
Cross-section of a primary cell.

GALVANIC ACTION AND CORROSION

Now consider a different scheme of things: a metal in contact with a corrosive salt. Let us imagine that a metal teaspoon (generally a plated copper alloy, but this is not important) is left in a cup of salt water. Eventually it will corrode beneath the water level. Corrosion can be arrested by supplying the spoon with electrons (Fig. 58). This can be done either by an electro-chemical or by an electrolytic procedure.

Electrochemical procedure. A piece of base metal (sheet zinc) is placed in the salt solution and connected to the spoon by a wire passing outside the liquid. On making the circuit, electrons are supplied to the spoon and its corrosion is arrested. The system will be seen (Fig. 58) to be essentially the same arrangement as the dry cell described above, the spoon taking the place of the carbon pole (cathode), and the zinc becoming the sacrificial anode.

Electrolytic procedure. This involves the use of an electric current generated by an external source such as a dry cell (Fig. 57) though in practice there are more efficient and economical means of supply. In the electrolytic method any metallic conductor can be used as the auxiliary electrode (stainless steel, for example, or sheet iron) and electrical connexions are made from the cell to this conductor and to the spoon, but it must be ensured that the electric current flows in the right direction. The auxiliary electrode is connected to the positive pole of the external source of current; in other words, in order to arrest corrosion the system must be so arranged that a stream of positive ions (cations) in the electrolyte moves towards the spoon.

In the procedures described above the emphasis has been on *arresting* corrosion.

It is possible to remove the corroded layers and at the same time reduce the core to a metallic condition again, as is done in conservation laboratories, by selecting an appropriate electrolyte instead of a solution of common salt. Caustic soda (sodium hydroxide) is commonly used and in this case the action causes hydrogen gas to be liberated at the cathode in the form of fine bubbles. The bubbles loosen gross incrustations and restore the metallic condition of the core. Any contamination of the chloride is removed in the vicinity of the sacrificial anode where it leaves the system in the form of chlorine gas.

Thus, the two systems outlined above form the basis of two very useful general processes available for the reduction of corroded metal objects.

Apart from the methods depending directly upon galvanic action which apply to all metals, there are certain purely chemical reactions that are specific for certain of the metals only and prove to be of great value in conservation work. For example, if it is desired to remove a mineral incrustation which is normally insoluble it may sometimes be rendered soluble by the application of a specific chemical agent or by more than one agent applied *seriatim* according to a fixed procedure. The solubilized salts are then removed by washing. Details will be found in the literature. Only a few of the more useful methods are given here.

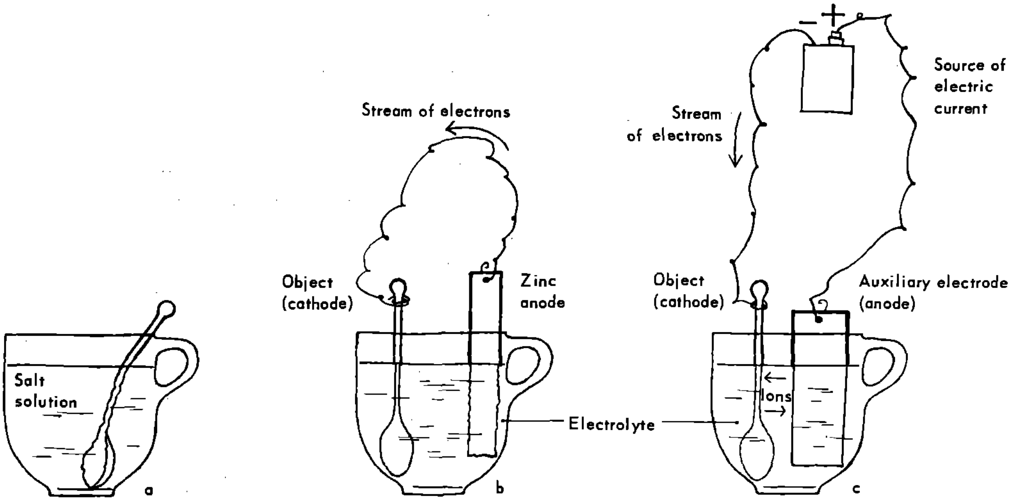

Fig. 58

Metallic corrosion and its reversal.

- a Spoon undergoing corrosion in a cup of salt water.
- b Arresting the corrosion of the spoon through electrochemical means.
- c Electrolytic procedure used to arrest corrosion.

GENERAL METHODS EMPLOYED IN CLEANING AND STABILIZING METAL OBJECTS

ELECTROCHEMICAL CLEANING

This method is unsuitable unless a sound metallic core remains within the mineralized object (Plenderleith, 1962, pp. 191-194).

	Coarse metal objects	Fine metal objects
Anodic metal	Usually zinc (granulated).	Usually zinc (powder 40 mesh) for coins, fibulae, etc.
Electrolyte	Usually caustic soda (flake commercial) dissolved in distilled water,[1] strength 10-20 per cent.	Caustic soda (10 per cent); *or* sulphuric acid (10 per cent); *or* (for silver objects) formic acid (30 per cent).
Container	Usually an iron tank.	Often a flat-bottomed glass or porcelain dish.
Procedure	Boil vigorously under a fume hood for periods of an hour or more with occasional metal brushing or other mechanical treatment. The level of liquid is maintained by frequent additions of distilled water.	Maintain 95-100°C on a steam oven or the equivalent for the time required to complete the reduction; occasional glass-brushing or other gentle mechanical treatment to assist the reduction. The level of liquid is maintained by adding distilled water.
	The object under treatment is buried beneath clean zinc metal in an appropriate container (see above), distilled water added to cover the zinc, and flake caustic soda added in the appropriate quantity. When, finally, the object is in a satisfactory reduced condition, it must be washed by the fixed procedure described below and tested till free from salts—then dried and, if considered necessary, impregnated with a protective film of wax or lacquer.	
Precautions	Adequate precautions must be taken against exposure to corrosive liquid and fumes. The object should be handled with iron tongs, using rubber gloves.	Handle with forceps or fine crucible tongs. In brushing be careful not to render the legend on a coin illegible.

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[1] Distilled or demineralized water is an essential for all chemical operations concerned with the treatment of metals.

ELECTROLYTIC CLEANING (Fig. 59)

This method is unsuitable unless a sound metallic core remains within the mineralized object (Plenderleith, 1962, pp. 194-197).

	Coarse metal objects	Fine metal objects
Anode	Stainless steel or sheet iron	Platinum, stainless steel, etc.
Object (the cathode)	Electrical contact must be made, if necessary by exposing part of the metallic core of the object under treatment.	
Electrolyte	Caustic soda in distilled water (5 per cent), the solution being previously made up in an iron vessel by slowly adding flake caustic soda to the water while stirring. The liquid becomes very warm. Avoid splashing corrosive material.	
Electric supply	Direct current of 6-12 volts as required to keep current density (C.D.) at about 10 amps/dm^2 (100 amps/sq.ft.), calculated on the area of cathode surface. A convenient source of current is the equipment commonly found in garages for charging car batteries (connect positive terminal to anode, negative to cathode).	
Procedure	Prepare apparatus as in Figure 59. Switch on current. After this the object should be removed and replaced only when current is on. At first the resistance of the incrustation may be considerable, but in course of treatment it falls, requiring readjustment of voltage to keep the C.D. to specification. Periodic removal of objects for brushing, etc. is essential. The iron anodes are heavily attacked and the electrolyte contaminated with insoluble flakes of oxide, etc. These should be cleaned occasionally. Finish by washing, applying the fixed procedure described below and testing periodically till free from salts, then dry and impregnate.	
Precautions	The usual precautions are necessary in dealing with corrosive materials (see under 'Electrochemical cleaning' above).	

MECHANICAL METHODS OF TREATING METAL OBJECTS

When dealing with partially corroded metal objects, the only way of arresting the action and effecting a permanent cure is to employ chemicals. The treatment always involves certain 'mechanical' operations also, for which it is necessary to make special provision.

Hand tools

A set of tools usually includes steel needles mounted in metal or wooden handles, or in a small chuck or mandrel, and hard steel scrapers and chisels. These are used in separating incrustations from the surface of objects. The actions performed by means of these tools might be described as picking (needles), chipping (chisels) and scraping (scrapers). Special care must be taken in performing such operations because one must realize that the stress which the metal undergoes can be much greater than would at first appear. For instance, a force of 1 kg exerted by means of a needle of 0.005 mm in diameter amounts to a pressure of the order of tons to the square centimetre.

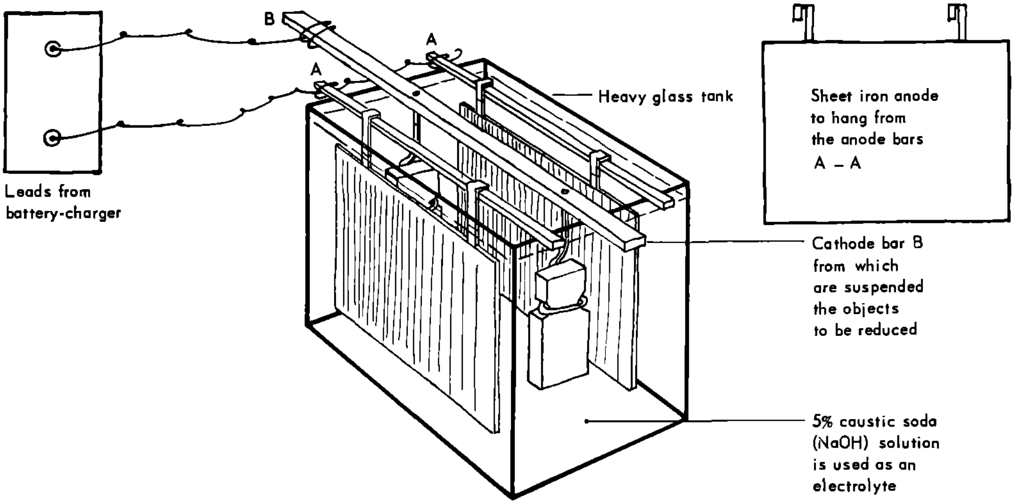

Fig. 59.
Electrolytic cleaning of corroded metal.

Mechanical tools

When excrescences are exceptionally hard, it may be preferable to grind them away. For this purpose a small abrasive wheel or inverted cone may be used on a dental drilling machine; alternatively, the grinding may be done by hand with slips of carborundum which can be obtained in various shapes and degrees of roughness.

Cutting with a hacksaw is only employed as a means of separating two objects that are corroded together into a solid mass and cannot otherwise be separated. Slit-saws are sometimes used, or fret-saws, or even a copper wire hardened by stretching, fixed in a frame and fed with carborundum powder in oil.

Brushing

This is a frequent accompaniment of all mechanical processes, its object being to eliminate foreign matter and reveal the progress of the work. Different kinds of brushes are selected to suit the type of work in hand. Hard nylon tooth-brushes are invaluable for use on bronzes during and after electrochemical or electrolytic treatment. A motor-driven wire brush can lead to a great saving of time when objects are strong enough to stand this treatment; in this case, care must be taken in controlling the depth of penetration of the bristles into softer parts of the incrustations. Glass brushes are used for fine work, e.g., on jewellery, or for polishing silver inlays in iron; they are indispensable in the laboratory.

Shot blasting

One of the most effective methods of mechanical cleaning, shot blasting is a delicate process which is not as violent as the name would seem to imply: it is based on the used of a jet of particles of abrasive substances blown from a modified spray gun. The jet may be dry (air and abrasive) or wet (water and abrasive), the wet system allowing for more accurate control of the operation. The amount of abraded material and the texture of the cleaned surface can be varied at will by controlling the fluid pressure in the jet and selecting the nature and particle size of the abrasive substance. Bauxite is much used as an abrasive. The object undergoing shot blasting is kept inside a special enclosure to avoid dispersion of the abrasive powder.

Polishing

This is done by hand with the finer grades of abrasives such as emery-flour, rouge and diamantine. These are used either as powders or made up with tallow in paste form. Levigated alumina is a finishing abrasive by means of which a high polish can be obtained on metal that has been previously rubbed with a series of coarser grits. Burnishing is done either by using a cloth wheel on a buffing machine or in the case of fine work, a hand polishing stone, e.g., haematite; the so-called 'bloodstone'.

INTENSIVE WASHING AND DRYING

When an incrustation has grown upon metal, the metal underlying the incrustation is microporous and, when the incrustation is removed the surface layers of the metal will behave in the same way as a mass of capillary tubes and will retain a residue of chlorides. Still larger amounts of chlorides may be retained under a 'patina' which it may be desirable to preserve.

Intensive washing

In such cases the corrosive matter is not easy to remove, but it can be eliminated by prolonged soaking in changes of distilled water, provided there is alternating heating and cooling in order to ensure flushing of the capillaries.

Testing for chlorides

This intensive washing procedure must be continued until no chlorides can be detected in the water. The standard test for chloride is carried out by adding silver nitrate solution in presence of nitric acid. If a white flocculent precipitate forms which is soluble in concentrated ammonia, this indicates that chlorides are still present in the solution that is being tested.

In the final stages of washing, when testing is of the greatest importance, it is essential to be able to detect the presence of the merest traces of chloride remaining in the water. This can be accomplished by performing the chemical test under optimum conditions or by means of very accurate conductivity measurements.

Drying metal objects

Two methods are commonly employed for hastening the drying of metals: heating and desiccation. Heating in an oven at 105 °C is the simpler process: it is satisfactory for smooth and non-porous metallic surfaces. Porous metal, however, takes longer to dry, and base silver and copper alloys that are at all porous may acquire a disfiguring film of oxide in the oven. Although oxide films may be removed by glass brushing, this introduces another operation that can be avoided by using a desiccator charged with silica gel from which the air has been evacuated. Drying by this method can be accelerated by passing the object through a bath of acetone before placing it in the vacuum desiccator.

The vacuum desiccator is used not only to dry objects, but also to store them until such time as they can be lacquered or impregnated (Plenderleith, 1962, pp. 197-200; Organ, 1955).

IMPREGNATION

Wax impregnation

Ideally the object is washed in hot distilled water as described above, then removed from the hot water with tongs (it should not be handled until after waxing), shaken free from liquid, mopped dry with a soft, clean cloth, and placed in a bath of molten beeswax, or low-melting (49°C) paraffin wax (which has the merit of giving a less brittle film at room temperature). It is kept there for a few minutes at a temperature above 100°C to remove residual traces of moisture. It is withdrawn from the wax, again using the tongs, shaken and placed on blotting paper to drain. A domestic hair dryer is very useful for keeping wax molten on the objects so that any unnecessarily thick surface deposits may be wiped off. The thin film of wax that remains permeates the porous surface of the metal and acts as a protective coating (Plenderleith, 1962, pp. 250-261; Organ, 1961).

Varnish impregnation

After washing, the object is dried in 95 per cent alcohol as outlined above. A further immersion in xylene is desirable to improve penetration if an acrylic resin varnish is to be used. The object is then placed in a glass container and covered with the varnish solution (10-20 per cent solids); the glass beaker is transferred to a vacuum desiccator which in due course is evacuated. After the bubbling of air from the object has ceased, the vacuum is broken and the object retracted from the solution and placed on blotting paper to drain. When completely dry, impregnation may be repeated if necessary. When a vacuum pump is not available, the object is usually heated before being placed in the varnish solution, since in cooling it sucks in the impregnating solution, thus in some measure giving results similar to those obtained by using the more efficient vacuum technique.

Acrylic resins[1] are preferred for impregnation work since, of all the commoner water-clear synthetic resins, they possess the best ageing properties and toluene and/or xylene are best suited as solvents for solution and dilution of the synthetic resin.

SPECIAL METHODS USED IN TREATING METAL OBJECTS

In all the processes outlined below (Plenderleith, 1962, pp. 212-231) it should be clearly understood that objects treated with chemicals must always be washed very thoroughly afterwards with distilled water in order to remove the last traces of corrosive impurities.

SILVER AND ITS ALLOYS

Silver dip. Immersion in or application of a 5 per cent (w/v) thiourea solution in distilled water containing 1 per cent (w/v) of a non-ionic detergent (e.g., Lissapol).[2]

Temperature: ambient.

Dissolution of the tarnish may be accelerated by glass-brushing the surface.

Silver dip is recommended for removal of tarnish, light patinas and for the treatment of niellos (tarnished areas caused by the development of sulphur alloys).

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[1] See the Appendix, p. 303.

[2] Obtainable from Hopkins & Williams, Freshwater Road, Chadwell Heath, Essex (England).

Formic acid. Immersion in 30 per cent hot formic acid made by diluting the commercial acid with 2 volumes of distilled water.

Temperature: boiling point.

Vapours evolved are irritating.

This treatment is recommended for base silver objects (e.g., coins) encrusted with corrosion products of copper.

Other procedures.

1. Electrochemical reduction (see above) with aluminium powder and caustic soda.
2. Electrolytic reduction (see above) recommended for removal of horn silver incrustation.
3. Ammonium thiosulphate 15 per cent in distilled water containing 1 per cent Lissapol; this solution has a slightly more vigorous action than the silver dip.

COPPER AND ITS ALLOYS

Citric acid solution. Immersion in a hot 2-5 per cent (w/v) solution of citric acid in distilled water.

Temperature: 60-80°C.

Recommended for separating copper alloy objects joined by corrosion products. A coating of copper powder is usually found over the objects after treatment; it is removed by brushing. Citric acid is apt to strip off all the patina, so care must be taken if it is to be preserved.

Sodium hexametaphosphate. Soaking in a 5-15 per cent (w/v) solution of sodium hexametaphosphate (Calgon).

Temperature: ambient or 30-50°C.

Higher concentrations and temperatures hasten the solubilization of incrustations, but with some risk for the preservation of the patina.

At the higher concentration, Calgon is a stripping agent. It is recommended for cleaning bronzes covered with calcareous deposits (Farnsworth, 1940).

Silver oxide. Dry treatment of local outbursts of 'bronze disease' (corrosion by cuprous chloride) with silver oxide (Ag_2O) powder. Stages in the process (see Fig. 60) are as follows:

1. Excavation of the spots of 'disease'.
2. Local application of dry, salt-free silver oxide powder with a pointed match stick, using alcohol as a medium if required.
3. Deliberate exposure of the treated object to a relative humidity of 78 per cent for a period not exceeding twenty-four hours, both in order to mature a protective film of silver chloride and to detect any spots which have been inadequately treated (Organ, 1963*b*, 1963*c*).

Other procedures.

1. Electrochemical reduction (see above) with zinc and caustic soda. This involves the loss of green patina.
2. Electrolytic reduction (see above). Also in this case the green patina is lost.

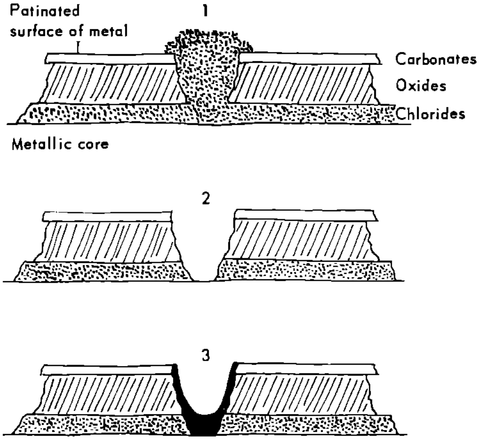

Fig. 60.

Silver oxide method of treating bronze disease (after R. M. Organ).

1. Disease spot.
2. The spot excavated.
3. Silver oxide added to form chemical seal.

3. Alkaline Rochelle salt followed by dilute sulphuric acid or alkaline Rochelle salt followed by hydrogen peroxide (Plenderleith, 1962, pp. 239-242); these are general cleaning procedures when patina can be sacrificed.
4. Sodium sesquicarbonate (alkali bath) does not remove green incrustations of patina, but extracts the chlorides (Plenderleith, 1962, p. 238; Organ, 1963*a*, p. 8).
5. Detarol (EDTA ethylene diamine triacetate) can act as a sequestering agent in a way analogous to Calgon (see 'Sodium hexametaphosphate' above).
6. Alkaline glycerol (120 g sodium hydroxide NaOH, 40 ml glycerine in 1 litre of water) can be used in place of alkaline Rochelle salt (Plenderleith, 1962, pp.232-257; Farnsworth, 1940; Organ, 1963*a*, 1963*b*; Jedrzejewska, 1963, 1964).

IRON

Electrochemical reduction (see above), zinc and caustic soda procedure. Preferred to electrolytic reduction if a metal core is present, but pitting of the surface is extensive.

Electrolytic reduction (see above). Recommended when a continuous core of metal remains and there are no inlays or nonmetallic attachments. If the surface is extensively pitted, electrochemical reduction is preferred, but there is little to choose between the two. Treatment is to be accompanied in each case by mechanical action and followed by intensive washing up to complete removal of chlorides, and finally impregnation or lacquering.

Rust removers and rust-preventive treatments. Certain commercial rust removers[1] are of special value for derusting objects (depending on their condition) that are either too heavy or too large for treatment by electrolytic methods. They have the added advantage of leaving a protective film[2] on the surface of the metal after treatment. Rust removers may be applied by brushing and when the solvent action has gone far enough, either the surface is wiped clean without washing, or in other cases any remaining chemicals are washed away. In using these commercial preparations the maker's instructions must be strictly followed.

After removing the rust the objects may be given a protective lacquer finish or not, according to conditions of future conservation.

Preservation of rust in completely mineralized objects. When iron is completely converted to massive oxide and no free metal remains, the specimen can be described as stable and no laboratory treatment is required for its preservation. When the rust is in a granular rather than a massive condition however, there is always the possibility of loss of shape and even disintegration due to a modification of the crystalline form of the salts that are present, and in this case the specimen will have to be washed free from soluble salts before its stability can be assured. A final impregnation of the rust with a synthetic resin (e.g., an acrylic) may be required in order to consolidate the granular surface.

Other procedures.

1. Caustic soda (sodium hydroxide). The fact that caustic soda is a rust inhibitor gives it an advantage over acid electrolytes in removal of rust. Treatment must be followed by intensive washing to eliminate chlorides.
2. Versenes (EDTA derivatives of ethylenediamine tetra-acetic) can have a solvent action over rust due to sequestering

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[1] For example, ACP Deoxidine no. 125, Imperial Chemical Industries Ltd., Paint Division, Slough, Bucks. (United Kingdom).

[2] The protective film is usually ferric phosphate formed by the phosphoric acid included in the formulation.

(complexing) of ferric ions in alkaline solutions. These versenes are sometimes used in mixtures with caustic soda and sodium hyposulphate.

3. Oxalic acid: 9 per cent solution in distilled water can be used as a rust remover (Plenderleith, 1962, pp.271-289; Pelikan, 1964).

LEAD

Electrochemical and electrolytic reduction (see above). Lead is slightly soluble in caustic soda (unless it is cathodically protected) and prolonged immersion may result in the loss of fine detail. Reduction is useful, nevertheless, for dealing with odd specimens where fine detail is absent, and especially with large objects that are heavily encrusted. Special care is required to wash away the last trace of soda from the metal, for if alkali is left in the porous surface or in cracks, the cleaned lead will eventually become white. An intensive washing procedure, based on accurate control of traces of caustic soda in the washing water by means of indicators, is described in Plenderleith (1962). A special spring retaining device for use in electrolytic cleaning developed by R. M. Organ allows handling of deeply split and fragile objects; the electrolytic process then resulting in metal rejoining over the fractures and in general reinforcement of the treated object (Organ, 1963*c*).

Hydrochloric acid and ammonium acetate—Caley's method.

1. Hydrochloric acid bath. Solution: 100 ml concentrated hydrochloric acid (analytical reagent, sp. gr. 1.19) in 1 litre of de-aerated distilled water.[1] Soak object in about fifty times its volume of acid till effervescence ceases (time: 1-2 hours or overnight). Drain off acid and place object for a few minutes in some hundred times its volume of *hot* distilled water. Decant and repeat the washing twice.
2. Ammonium acetate bath. Solution: 100 g ammonium acetate in 1 litre of distilled water. Soak washed object in about twenty-five times its volume of warm acetate solution till no more corrosion products are visible on the surface of lead. This should take about 1 hour and should not be prolonged beyond 2 hours at normal room temperature. Wash as follows: place object in about one hundred times its volume of *cold* freshly boiled distilled water. Time: 10 minutes. Decant and repeat the washing three times.
3. Dry at room temperature without heat, hastening the process by means of immersion in 95 per cent alcohol.
4. Impregnate with a wax or lacquer (Gettens, 1963).

Other procedures (Plenderleith, 1962, pp. 258-265, 267, 270).

1. Dilute nitric acid. Meretricious cleaning can be carried out using nitric acid. The immediate result may seem good, but it appears that after a lapse of several years, even when washing has been most carefully carried out, that lead so treated acquires a milky appearance; the method is no longer considered satisfactory.
2. Dilute acetic acid. Same observations as in the preceding paragraph but treatment is even less permanent.
3. Use of ion-exchange resins. Cation exchangers (such as Amberlite IR-120, Dowex 50, etc.) can effect a thorough cleaning of a corroded lead surface if the object is buried under the resin and covered with distilled water.

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[1] Normal distilled water contains carbon dioxide and this has a corrosive action on lead. When dealing with lead objects de-aerated distilled water must always be used. De-aeration is performed by boiling distilled water vigorously for a short time. De-aerated water should be kept in well-stoppered bottles or used at once as water re-dissolves carbon dioxide readily.

By the rational application of the methods outlined above, much good can ensue. The converse is unfortunately true, and those who are not versed in chemistry would be well advised to practise the various processes first of all on worthless metals before attempting to apply them to objects of cultural interest and value.

By this means confidence will be gained and interest stimulated. The pitfalls will become manifest and the hope is expressed that the reader will not be content until he has at least some nodding acquaintance with the basic literature wherein methods are described in greater detail than is possible in the present context.

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E. R. Beecher

The conservation of textiles

16

INTRODUCTION

The main characteristics of a woven textile fabric are toughness and flexibility. Though these vary in degree according to the nature of the fibres and the structure of the yarns and the web, they are the features by which its essential soundness may be judged. Deterioration of textile fibres is indicated by loss of tensile strength and of pliability.

The common causes of damage to textiles are light, oxygen and moisture; atmospheric pollution; insects and micro-organisms. Hence, conservation measures include:

1. Cleaning: the removal of soiling matter, discoloration and stains.
2. Sterilizing and mothproofing: to eliminate biological causes of damage and decay.
3. Protecting: from environmental dangers —visible and ultra-violet light and atmospheric impurities.
4. Reinforcing: to consolidate weakened material and to arrest disintegration.

As a preliminary to any technical treatment of a textile a photographic record of its condition should be made. Though this is an elementary matter it is easily forgotten when one is preoccupied with arranging for work to begin.

Such recording is important, not only as evidence of the nature and extent of existing damage, but in establishing the original position of fragments which may be held in place only by glue, mud, or a solitary yarn that subsequent operations are likely to break up.

IDENTIFICATION OF TEXTILES

Textile fabrics made of synthetic or reconstituted substances have been available since about 1890 when the production of man-made fibres was developed on a commercial scale. Examples are already included in some museum collections and their number will doubtless increase. At present the great majority of textiles represented are composed of natural fibres of animal or plant origin; mainly wool, silk, cotton and flax. Old lining and backing fabrics of hemp or jute are occasionally encountered. Dr. Rosenquist has recorded the use of nettle fibres in textiles found at Oseberg, woven *circa* A.D. 800.

The identity of the fibres composing a fabric should be known before specific treatment is given to it; particularly if stain removal is involved. Microscopic examination is a ready means of identifying fibres having marked visual characteristics. Familiarity with their appearance under magnification can be acquired by practice in comparing them with known examples. There are simple physical tests that may be applied to distinguish between animal (protein) fibres and vegetable (cellulose) fibres, e.g., animal fibres do not burn very readily, but if held in a flame they flare and shrivel into a residue of carbon, emitting the characteristic smell of singed hair. Vegetable fibres take fire easily and burn to a grey ash.

Staining tests are simple and satisfy normal needs for distinguishing between different kinds of fibres. The Shirlastains[1] have been developed for this purpose. A fibre is cleaned of all extraneous matter and placed in the Shirlastain liquid which stains it to a particular hue by which the fibre can be identified in accordance with a chart. Precise identification of closely related fibres is possible by more elaborate chemical methods. Tests covering all fibres used for textiles are described in a publication by the Textile Institute.

CLEANING OF TEXTILES

General discussion

The uneven, hairy surface of textiles woven from natural fibres renders them particularly susceptible to soiling. Dirt particles lodge in the innumerable interstices of the yarns and of the fabric and adhere by reason of the film of grease that envelopes most soiling matter. The amount of dirt entrapped by a fibre is influenced by its physical features, including the diameter of the fibre and the presence of striations, scales and indentations (Wagg, 1959).

Dirt on a fabric not only mars its appearance but can cause harm, particularly in tropical conditions of warmth and moisture that encourage the development of insects and the innumerable micro- and submicro-organisms that attack textiles. A soiled textile is more vulnerable to these than a clean one. Hence cleaning is an important early step in preservation.

Removing loose matter

Methods of cleaning woven fabrics are governed by the kind and condition of the material concerned and the nature of the soiling. Loose dirt and moths' eggs which, having no sticky surface-coating, are easily dislodged, are removed by brushing, shaking, or by suction with a hand vacuum cleaner. Quite frail fabric can be suction-cleaned with safety, if a piece of fine net is placed over it and held in firm, close contact while the nozzle of the cleaner is applied. Alternatively, a piece of muslin may be stretched over the nozzle of the cleaner and if this is placed gently on the weak fabric loose dirt will be transferred from it to the muslin, which should be changed from time to time. Carpets, rugs and other fabrics with a pile should be brushed in the direction of the pile towards a suction cleaner held just above the surface so that the dust is drawn away instead of falling back on the object. Brushes used on textiles should have white hairs of pure bristle: they should be kept white.

Washing

Water dissolves a greater number of substances than any other liquid and is the best solvent of ordinary dirt. For textiles that can be made wet without harm, washing is the simplest and most efficient method of cleaning. The water should be soft[2] for this is better for textile fibres, as well as being more effective in removing soiling matter, than water containing dissolved minerals and gases. The difference between washing with soft water in which soap will lather freely and hard water having dissolved calcium and magnesium compounds that cause soap to form an insoluble precipitate is a matter of common experience. This disadvantage of hard water can be overcome by using a synthetic detergent instead of soap.

The increase in the cleansing power of water obtained by the addition of alkali was well known in ancient times. Washing with 'nitre', a term then used for the natural

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[1] Shirlastains A and C for the identification of natural fibres, Shirley Developments Co. Ltd., Manchester (United Kingdom).

[2] A water softener or demineralization plant is needed in hard-water areas. Moderate hardness can be overcome by the use of a commercially available complex phosphate known as Calgon.

sodium carbonate found in the natron lakes of Egypt, is mentioned in Jeremiah, II, 22 in the Old Testament of the Bible. Ammonia, being volatile, is an appropriate alkali to add when washing museum textiles, especially when a neutral detergent is used in place of soap. Strengths should not exceed 1 per cent for fabrics woven of vegetable fibres, or 0.4 per cent for animal fibres. The temperature of washing solutions for wool and other protein fibres should not exceed blood heat.

Soaps and detergents. The function of soaps and synthetic detergents, technically described as wetting, or surface-active, agents, is to reduce the surface tension of water, causing it to spread and wet the fabric more effectively; to emulsify oils and fatty matter and envelop dirt particles; and to hold these in suspension until they are rinsed away.

The efficiency of neutral non-ionic detergents in low-temperature washing, particularly of wool, is a good reason for their use on museum textiles, usually at a concentration of about 1 per cent. Igepal, C.A. Extra and Lissapol N,[1] mentioned in Dr. Plenderleith's treatise, are well-tried examples. Howards B 30,[2] a liquid soap based on potassium oleate and containing Sextol, can be used for wet cleaning in addition to its purpose as a spirit soap. It is mildly alkaline and has been used with success on important tapestries as a 5 per cent solution in water.

Detergents sold in powder form for domestic use contain many additives, including optical bleach to make fabrics appear whiter. They are not suitable for museum fabrics. An ingenious and legitimate use of this colourless dye in textile repair work is described by J. Fusek. The material used for restoration to tapestries is impregnated with a 0.01 per cent solution of optical bleach. It is imperceptible except in ultra-violet light which reveals restored areas.

Apparatus. Adequate apparatus can make a significant contribution to safety as well as to efficiency during the handling and cleaning of textiles, and treatment of fragile or precious material should not be attempted without reasonable equipment. This need not be elaborate; common sense will be a guide to what is requisite. Any vessel of convenient size and shape can be used for washing, provided it is clean and of suitable material. A shallow vessel of ample area is preferable to a deep one. Metal, other than stainless steel, should be avoided. Enamelware must not be chipped: porcelain and polythene are excellent. During washing, textiles should be kept spread out and the water changed as often as necessary to prevent suspended soil from being redeposited on the fabric. A good arrangement to ensure this is to have the submerged textile resting upon a smooth, perforated support raised above the bottom of the reservoir *(Plate 37)*. As the fabric is gently pressed and released by the hands or with a broad sponge to expel the dirt, a gentle flow of water is introduced at one end of the reservoir, preferably near the surface, and the washing fluid is drained away at the other end from the bottom of the vessel, carrying suspended dirt with it (Anon., 1956). Drying should be reasonably rapid: a current of clean, dry air is the best means. Direct radiant heat is damaging.

Lightweight examples consisting of a single layer of tissue can be given a smooth finish without ironing by transferring them while wet to a glossy support, such as a piece of plate glass or sheet of polished plastics. The transfer from one support to another is accomplished by placing the fresh support face down on the textile so

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[1] Igepal is manufactured by I. G. Farben Industrie, Frankfurt A.M., C.A. Extra by General Dyestuff Corporation, New York, and Lissapol N, by Imperial Chemical Industries Ltd., London.

[2] Howards B 30 is manufactured by Howards Ltd., Ilford, Essex (United Kingdom).

that it is sandwiched between the two supports. These are held firmly together and turned over: the previous support is now uppermost and can be lifted away. If the textile is wet and tends to cling, a moist camel-hair brush is used to free it.

Solvent cleaning

For textiles that cannot be treated with water the main alternative is to clean them with organic solvent, sometimes called French cleaning, because it was first so used in Paris about the middle of the nineteenth century; though the principle was known earlier (Anon., 1964). According to tradition, a can of lamp fuel was accidentally spilled upon a gown and found to clean it.

The advantages of solvent cleaning are: (a) the solvent does not soften textile fibres as water does, therefore there is less risk of shrinkage and loss of shape; (b) dyes which are not fast in water may be undisturbed by solvent; (c) solvents are more efficient than water for dissolving grease; (d) in general solvents are volatile and dry quickly. The disadvantages include: (a) cost: all dry-cleaning solvents are more expensive than water; (b) inflammability: petroleum and aromatic types of solvent take fire easily, but chlorohydrocarbon solvents are not inflammable; (c) toxicity: in differing degrees the vapours of all cleaning solvents are harmful to health if inhaled.

For museum textiles the most appropriate of the chlorinated solvents is perchlorethylene; the most suitable of the petroleum solvents is white spirit. The former is quicker in action, more volatile and will remove some stains that are unaffected by white spirit. Its effect on dyestuffs is somewhat greater than that of the petroleum solvent and it is significantly more toxic but does not take fire. White spirit is inflammable but in all other respects it is the safest of all dry-cleaning solvents commonly used on textiles.

Spirit soap

As the cleaning efficiency of water is increased by soap, so the power of a cleansing solvent to remove dirt is increased by adding a dry-cleaning or spirit soap, which is a mixture of a detergent and a solvent. The potassium oleate soap, B 30 (Howards) which incorporates Sextol (methylcylohexanol), is particularly suitable for use with white spirit in concentrations up to 1 per cent. Spirit soaps are supplied as liquids or gels. The mechanical action in solvent cleaning is the same as in washing: movement of the fabric is necessary to dislodge and express dirt and to lift away dissolved grime. Very grease-stained fabric and objects of soft leather, such as kid gloves, are held on a hard, flat surface—traditionally a marble slab is used in commercial establishments—and brushed in one direction, away from the operator, with a soft-bristle brush that is continually dipped in the solvent solution, working towards the edge of the fabric. White spirit is less volatile than most other dry-cleaning solvents, hence a drying cabinet is desirable for objects cleaned with it.

Bleaching

Fabrics discoloured by age are unlikely to be restored to their original brightness by ordinary washing, which is largely a physical process for removing soiling matter. Dinginess not due to dirt can be altered only by bleaching, which is a chemical action. To what degree it should be applied to historical material is a matter of opinion. The bleaches most commonly used for textile fabrics are oxidizing bleaches, i.e., they release oxygen, in contrast to reducing bleaches which take up oxygen from the substances on which they act. Of the various oxidizing bleaches applicable to laundry work, hydrogen peroxide has the most points in its favour as a general bleaching agent for museum textiles. When it loses oxygen, as it does during its bleaching action, it changes into water. There is therefore no risk of subsequent chemical action, nor need of neutralizing treatment as with sodium hypochlorite. It can be used at ordinary room temperature on all fibres and its bleaching effect is permanent.

The strength of hydrogen peroxide solution is indicated by the number of volumes which represent the amount of oxygen gas produced by the decomposition of one volume of solution. Thus 1 litre of 5-volume hydrogen peroxide will produce 5 litres of gas. The rate of decomposition during bleaching can be controlled by adding a stabilizer to the solution. Sodium silicate is a good stabilizer and also provides desirable alkalinity.

A formula prepared by the British Launderers' Research Association for bleaching silk and wool fabrics in a cold solution of hydrogen peroxide comprises: 4 litres of soft water, 1 teaspoonful of sodium silicate dissolved in a teacupful of hot soft water, and 250 cm^3 of 20-volume hydrogen peroxide. This amount of solution is designed to treat 1 kg of fabric, which is immersed in the solution for 12 to 16 hours, with an occasional move round. Such prolonged soaking might be undesirable for much-weakened old fabrics: these should be soaked for a shorter time, allowed to dry, and treated again as necessary.

An attractive technique for bleaching with hydrogen peroxide has been tested on linen and cotton fabrics by Miss Poot of the Technical University at Delft, whose method eliminates a long period of immersion. The textile is submerged in water containing: 30 per cent 5-volume hydrogen peroxide, 2 per cent sodium silicate, 0.5 per cent sodium carbonate, and 0.5 per cent sodium hydroxide at a temperature of 20°C. After 5 minutes' soaking the fabric is taken out of the solution, drained and dabbed with filter paper to remove excess moisture, then wrapped or enclosed in plastics film. 'The bleaching proceeds in this condition until the degree of whiteness is reached; the material is then taken out of the plastic, rinsed for 2 minutes in cold water and dried in the air' (Poot, 1965). A significant degree of whitening takes place in 2½ hours: maximum bleaching effect, without harm to the fabric, in 6 hours.

The Dyers and Cleaners' Research Organization (Harrogate, United Kingdom) has originated a method of incorporating bleaching in the process of solvent cleaning. Hydrogen peroxide is mixed with dry-cleaning soap and a little ammonia and emulsified in white spirit. Fabric immersed in the solvent will selectively absorb the peroxide solution and it will break down and do its work. Hydrogen peroxide decomposes much more quickly in white spirit than in water.

Stain removal

The limits of what can properly be achieved in the removal of discolorations from museum textiles should be understood from the outset. Old stains may be so fixed that their alteration, even if possible, would involve too drastic action. Reasonable attempts at reduction are justified because stains are unsightly and may cause continuing damage to fibres. Treatment of local stains is termed 'spotting'. Stains dealt with in commercial practice are usually of recent origin, whereas those on museum textiles are likely to be old stains, difficult to identify, and often on weakened fabrics. Nevertheless, spotting methods based on scientific formulas are essentially the same for both. If the identity of a stain is known, even the inexperienced can consult a stain-removal handbook or chart and follow the directions (Moss, 1952; Cohen and Linton; 1961).[1] First attempts should be made on relatively unimportant

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[1] See also brochures issued by Skilbeck Bros., and by the British Launderers Research Association.

material until efficiency is gained. The underlying principles should also be understood.

Substances that cause staining are removed if they yield to solvent treatment. Action by chemical reagents does not remove them but alters their state so that they are made colourless. Enzymes or digesters are used on hardened protein stains to soften them and render them more easily soluble. Enzymes are usually obtained as composite proprietary products with directions for obtaining their maximum effect. Pepsin is a serviceable digester, prepared for use by mixing 1 g of pepsin in 25 cm^3 of warm water and adding two drops of hydrochloric acid. This mixture is spread on the built-up stain and kept moist until the stain becomes soft and can be removed with water.

About 90 per cent of all discolorations are water-soluble, hence an aqueous solution will first be used on stains of unknown composition. Equal amounts of water and Howards B 30, or Comprox A, (B.P. Detergents Ltd., London), or Trioctol (Skilbeck Bros., London), applied to the stain and left for a few hours will often loosen it so that it can be removed by flushing with water. A well-tried paste soap for removing stains is prepared as follows: (a) warm together 40 cm^3 of oleic acid and 130 cm^3 of water to a temperature of about 50°C; (b) mix 7 cm^3 of ammonia and 23 cm^3 of cold water. Add (b) to (a) while stirring: this will form an opalescent paste. When cool, brush it into the stain and allow to dry. Then rinse it away with white spirit. Alternatively warm water can be used.

STERILIZING AND MOTH PROOFING

Textiles are vulnerable to attacks by living organisms, particularly the grubs of the various clothes moths and beetles that attack keratin, and the micro-organisms that cause moulds. These thrive where there is darkness, warmth and absence of movement. Stagnant air, if it contains much moisture, is a major factor in the growth of fungi. A high proportion of moisture in the ambient atmosphere is a much greater danger to textiles than dryness. It is favourable to biological decay and intensifies the destructive action of light.

Control of humidity

The growth of moulds can be prevented by keeping the relative humidity of the atmosphere below 70 per cent at temperatures between 15° and 25°C. Instruments for measuring humidity are of various types. A recording hygrometer, or hygrograph, records the relative humidity on a chart: some instruments (thermo-hygrographs) record both the temperature and the relative humidity.

In tropical countries where the relative humidity is continually above 'mould formation point' (Coremans, 1960) infection by fungi is a constant danger. Air-conditioning, whereby rooms are virtually sealed from the outdoor atmosphere and supplied by means of fans and filters with air that has been freed from impurities and regulated to appropriate degrees of temperature and relative humidity, is the best method of overcoming all biological and atmospheric hazards to textiles. When air-conditioning is not available special attention must be given to ventilation, vacuum removal of dust and dirt, and the use of fungicides and insecticides.

The relative humidity of the air in display cases and in storage enclosures that are reasonably air-tight can be reduced by the use of silica gel, obtainable in the form of 'self-indicating' crystals that are blue when dry and turn pink when saturated with moisture. The moisture is removed by drying the crystals in an oven at 101°C, when they will revert to their blue colour and may be used again. This sequence can be repeated indefinitely. Crystals are placed in containers within the enclosures where their

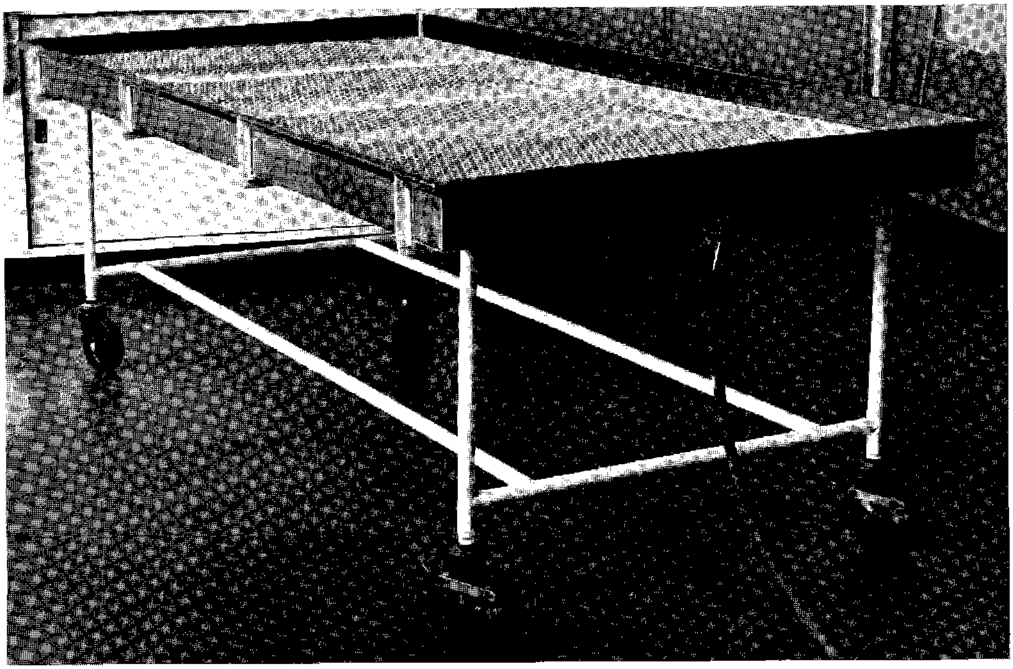

Plate 37

Mobile washing tank used for the cleaning of textiles. The submerged fabric rests on the removable screen. Water is introduced at one end, near the surface, and drained at the other end from the bottom, carrying the suspended dirt with it.

Plate 38

A type of light meter in which the selenium cell is mounted in an air-tight perspex hemisphere to measure foot-candles for light readings in museum galleries.
This has a high degree of cosine correction.

extraordinary powers as an absorbent are required. In humid conditions in Sydney (Australia), W. M. Boustead has found 3 kg of silica gel per cubic metre of drawer space containing prints will maintain a relative humidity of 55 per cent.

Fumigation

Institutions that have a gas chamber and follow the excellent practice of fumigating all objects susceptible to infestation immediately they are received, avoid introducing infection. Gases commonly used include: hydrocyanic acid gas, which is deadly to humans; carbon disulphide, which is explosive when mixed with air; ethylene oxide, which is also inflammable unless it is mixed with carbon dioxide; and methyl bromide. Methyl bromide (boiling point 3.6°C) is supplied as a colourless liquid. It readily vaporizes at room temperatures and is highly toxic to all stages of insects, but is not a quick-acting poison to humans. It has no noticeable odour except at high concentrations, so—as a safeguard against accidental inhalation—a lachrimatory indicator is sometimes added to it (Burns-Brown, 1959). It has greater penetration than hydrogen cyanide and evaporates from treated fabrics much more rapidly. Some users have reported residual odours after fumigating protein-containing substances with methyl bromide, but a report on a trial excercise by the Department of Scientific and Industrial Research Pest Infestation Laboratory states: 'no smell attributable to fumigation could be detected' (Anon., 1960). A concentration of 200 g/m^3 maintained for three hours will kill eggs, grubs and insects. Methyl bromide is heavier than air and therefore should enter the fumigation chamber from the top. An internal fan to circulate the gas is an advantage. A more recently developed fumigant, sulphuryl fluoride (Stewart, 1951; Gallo, 1963) marketed as Vikane (Dow Chemical Co., Michigan), has toxic and other properties similar to methyl bromide but possesses greater power of penetration.

Protective measures

Fumigation treatment eliminates existing infection but provides no safeguard against subsequent attack. Protective measures include the following.

Physical barriers, e.g., drawers, cupboards, boxes and bags. A newly hatched moth grub can pass through a 0.1 mm opening; therefore containers for vulnerable fabrics must close tightly or be sealed. If polythene bags are used the danger of moisture condensation within them, should a lowering of temperature occur, must be anticipated. It is of cardinal importance that textiles should be free from infestation before being enclosed, since these are the very conditions that favour the development of insects.

Aromatic protectants, as an additional safeguard. The belief that moths are kept away by the scent of certain substances is traditional and no doubt based on experience. Experiments indicate that their influence is toxic rather than repellent. Naphthalene and paradichlorobenzene are the most powerful

TABLE 1. Effect on mortality of 10 moth larvae of enclosing with garments and paradichlorobenzene in different packings (data from Herrick and Griswold, 1931)[1]

Form of sealing	Time (days)	No. dead	No. alive
Ordinary unsealed cupboard	8	1	9
Cupboard with all cracks filled and door sealed	8	9	1
Thin paper bag	7	1	9
Thick paper bag	10	6	4
Slaled thick paper bag	7	10	0

[1] Reproduced from *The Mothproofing of Wool.*

protectants of this sort. Their vapours when concentrated kill the eggs and grubs of clothes moths: therefore muslin bags of paradichlorobenzene crystals placed in receptacles containing textiles help to protect them.

The application of insecticides. This is the most effective method of protecting exposed textiles. Toxic chemicals that act as contact or stomach poisons to larvae (the larval stage is the only one when feeding takes place) are incorporated in a liquid carrier and applied to the textile by spraying or by immersion. The efficiency of the protection given by this treatment depends upon the permanence of the poison and the adequacy of its distribution. Insecticides should be evenly applied so that every fibre receives treatment.

For protection against carpet beetles, which are more resistant than moths, preparations containing dieldrin are recommended (Lehmann, 1964). One of these is Shell-tox, which is a wide-range insecticide containing 0.5 per cent dieldrin and other moth-proofing agents in an organic solvent.

Eulans are efficient larval poisons. The term Eulan is a trade name: Eulan U 33 is used with water and Eulan BLS with dry-cleaning solvents. These mothproofers have an affinity for wool fibres similar to that of a dyestuff. D. Lehmann has described their application to textiles in the West Berlin State Museums, and their property of inhibiting the growth of micro-organisms.

One of the most serviceable insecticides for textiles, which also has fungicidal properties and is suitable for protection against termite attacks, is Mystox LPLX[1] a grade of the series of preservatives based on LPL 100 per cent (pentachlorphenol laurate). It is normally supplied as a 5 per cent solution in white spirit which is sprayed liberally on the textile—thick or lined materials should be treated on both sides—to ensure a retention of 2 per cent of Mystox, calculated on the dry weight of the fabric.

Mystox LSE is an emulsion for use in aqueous solutions. It provides a convenient method for mothproofing textiles when they are washed. For efficient treatment the fabric should retain 4 per cent of its dry weight of Mystox LSE. To allow for dilution caused by the saturation of the textile during washing a 5 to 6 per cent solution is used for the dip.

Preparation of the bath. Make up the mothproofing solution by adding 250 cm^3 of Mystox LSE to 4 litres of water. The emulsion should be strained through gauze before entering the water. Then mix thoroughly.

Method of Treatment. When the textile has been rinsed after washing, steep it in the mothproofing solution, pressing and releasing the fabric manually to obtain maximum penetration of the fluid. When thoroughly impregnated, raise the textile from the bath (on a perforated support) and allow excess solution to drain back into it for the sake of economy. The textile should preferably remain on a horizontal plane while drying. If it has to be tilted or hung its position should be altered once or twice during drying to maintain an equal distribution of emulsion.

Ortho-phenylphenol is an efficient bactericide and fungicide. It is obtainable in the form of white, crystalline flakes that are soluble in most organic solvents (Imperial Chemical Industries Ltd.). A 0.5 per cent concentration is lethal to bacteria, fungal spores and surface mildews.

PROTECTION OF TEXTILES ON DISPLAY

Decay caused by light is the most general, insidious and irrevocable of all the forms of deterioration that menace textiles. Silks

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[1] Catamance Ltd., Welwyn Garden City, Herts. (United Kingdom).

are more readily weakened by light than other fabrics and wool is the most resistant of the natural textile materials, but all are vulnerable. The degree of decay is influenced by the kind and intensity of the light, the character of the fibres and of any dyes present, and the amount of moisture in the air surrounding them. Natural light is more damaging than ordinary forms of artificial illumination; of these, fluorescent lamps, because of their higher ultra-violet radiation, are more injurious than tungsten filament lamps. In general it is the shorter wavelengths of visible light, and ultra-violet light, that are most harmful. An important aspect of this, mentioned by G. Thomson, is that 'the more resistant a material is to deterioration by light, the more its eventual deterioration will be caused by ultra-violet rather than by visible light'. As ultra-violet rays do not contribute to visibility the best course is to exclude them. There are various commercial products that will do this. They are in the form of clear varnishes or plastics sheeting containing ultra-violet absorbing chemicals, hence they act as ultra-violet filters that can be applied to the inside surfaces of windows, or the glass of display cases that have external lighting. Thin plastics sheet is made in the form of sleeves that can be drawn over fluorescent light tubes. Whatever type of filter is used, it must be placed so that all light reaching vulnerable material first passes through the filter. In time this will need renewing. 'Most ultra-violet filters, whether sheet or varnish, may be expected to have about the length of life of a house paint, that is to say, at least five years and probably more under strong northern sunlight if protected from the weather by a layer of glass. Under tropical conditions the sun may be so strong as to destroy the filter in an uneconomically short time'.[1]

Ultra-violet filters do not, of course, reduce fading and deterioration caused by visible light, which is many times as great. It is plainly impossible to shield textiles from it and at the same time allow them to be seen. At present no expedient that would allow light-sensitive objects to be illuminated without injury has been developed, although it is known that fading is much diminished in the absence of oxygen and moisture. Hence textiles should be exposed to light as little as possible and the intensity of the light that is allowed to strike them should be no greater than is needed to view them properly. Comparatively low levels of illumination may be adequate if the eyes are not previously excited by stronger light. A level of 300 lux is regarded by some as suitable to museum textiles: a maximum recommended by G. Thomson is 50 lux. Appropriate levels cannot be fixed arbitrarily: they will vary according to the visual character of objects and their surroundings.

A light-meter is used to measure levels of illumination. There are various patterns of portable instruments. One in which a selenium photocell is enclosed in an airtight perspex hemisphere, ensuring a high degree of cosine correction, has been found serviceable for light readings in museum galleries *(Plate 38)*.

Sunlight is harmful but clear sky light of equal intensity is even more damaging and these effects are much increased by high relative humidity. Therefore measures for protecting textiles from damage by light must include attention to their atmospheric environment, as well as to the more obvious expedients of drawing blinds over windows, intercepting ultra-violet light and controlling artificial illumination.

REINFORCING TEXTILES

Weakened textiles can be reinforced by fastening the weak fabric to a stronger one, by impregnating the fibres with a solution that will set to a tough, flexible solid, and by a combination of both these methods in

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[1] See the Appendix, p. 303.

which the liquid also acts as an adhesive to attach the weakened fabric to a support.

Fastening a weak fabric to a stronger

Broadly speaking, this includes traditional sewing methods as well as contemporary techniques with adhesives. Well-tried methods of needlework are unlikely ever to be entirely superseded. For example, the efficiency of the method whereby weakened material is sewn to a supporting fabric and disintegrating areas are secured by 'couching' (loose or broken threads held in place by stretching filaments across them, anchored at intervals with small stitches) has been established by experience. In Sweden, old flags are skilfully placed between two layers of silk tissue (Crepeline) and secured by strategically arranged stitches, to give them supplementary support (Geiger).

In the past it was not unusual for fabrics to be stuck to card or linen with animal glue or flour paste. The result was bad because the fabric was made rigid and sometimes was stained by the glue. Nevertheless, the sustaining effect of such primitive reinforcement is significant: examples have been much preserved by it.

The development of man-made fibres and synthetic resins has made possible better techniques for securing weakened fabrics to supporting material. The advantages of an adhesive method include its intimate over-all contact, which is important for very weak tissues, its applicability to textiles too frangible for sewing, and its relative economy of time. In addition, by selecting modern materials, lightness, strength and flexibility are maintained. A procedure for this method of reinforcement is as follows.

Very lightweight nylon or, preferably, terylene net is stretched on a frame and coated with an internally plasticized vinyl acetate-vinyl caprate copolymer emulsion. Though this is a water emulsion the film it casts on drying is insoluble in water but soluble in industrial alcohol.[1]

It is important that the filaments should be coated without filling the openings. Adroit manipulation of the brush will achieve this, or a moderate jet of air directed on the mesh before the emulsion has dried will keep the network open.

A layer of non-stick paper, e.g., silicone impregnated vegetable parchment, is laid upon a table or working surface and the coated net, now dry, is placed on it. The fabric to be reinforced is laid in position on the net and moderate heat is applied (80°C), which will seal them together. The method of applying the heat and the area of fabric sealed at one time can be varied to suit the example being treated. An electric mounting iron is sufficient for small fragmentary specimens or may be applied here and there to a larger example to hold it in place or to secure the meeting edges of a tear, before using a domestic iron to seal down the main area.

Heat-sealed net reinforcement has been successfully applied to tapestries. Stronger net is, of course, required, and a heavier film of vinyl resin. If a picture-relining table is available its vacuum system can be used for sealing. The tapestry is laid face down on the table and prepared net is spread over the back of it. This is then covered by a sheet of Melinex (transparent polyethylene terephthalate), its edges are sealed to the table and the vacuum is applied. Atmospheric pressure is an ideal means of accommodating the net to the irregular surface of the textile. Radiant heat is then applied from above to seal them together. An infra-red lamp has been used for this; a hot-air gun might be better.

An important feature of the heat sealing technique is that no alien substance is introduced into the fibres or structure of the textile; its colours and texture therefore remain unaltered.

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[1] See the Appendix, p. 303.

Strengthening by impregnation

The method of strengthening a weakened textile by impregnating it with a solution that casts a flexible solid has been stimulated by the development of various synthetic resins. It is a method that should be approached with caution because once the resin has permeated the fibres it cannot be completely removed. Should it deteriorate, the textile would deteriorate as well. Nevertheless, impregnation with a suitable synthetic resin is a practical method of conserving decayed textiles that would disintegrate unless consolidated.

The strength of solutions used for reinforcing fabrics should be kept as low as possible, consistent with the fulfilment of their purpose, in order to preserve to the textile the maximum degree of flexibility and to minimize the change in surface appearance caused by the resin.

Because of their different structures and degrees of weakness, textiles needing to be consolidated cannot all be treated alike. A medium suitable for coarse flax may be inappropriate for fine silk. The following compounds are among those that have been used to impregnate weakened textile fabrics. They are applied as solutions that are brushed or sprayed on the fibres; or used as a bath in which the fabric is immersed. On evaporation of the solvents they cast clear, colourless films.

Polyvinyl alcohol (Rhodoviol BS 125). Supplied as a white powder soluble in water. Applied in concentrations of 0.5 to 2 per cent. Films moderately flexible; they become insoluble after some years (Société des Usines Chimiques Rhône Poulenc—SUCRP, Paris).

Ethyl-hydroxyethyl cellulose (Modocoll E.) Supplied as whitish granules soluble in water. A formula published by Dr. Geijer[1] consists of Modocoll E, 0.15 per cent, Polyglycol 400, 0.6 per cent, and Bonomold fungicide 0.2 per cent (SUCRP).

Polyvinyl butyral (Rhovinal B 10). Supplied as whitish granules soluble in ethyl alcohol. Applied in concentrations of 1 to 5 per cent. Remains soluble. Good flexibility (SUCRP).

Polymethacrylic ester (Bedacryl 122). Supplied as a clear, syrupy liquid, soluble in turpentine, acetone, etc. Concentrations of 1 part Bedacryl to 3-6 parts solvent. Good flexibility (Imperial Chemical Industries—ICI)

Soluble nylon (Maranyl C 109; Calaton C.A). Supplied as a white powder soluble in industrial methylated spirit. Concentration of 5 per cent. Very flexible and dries free from surface gloss. Nylon is vulnerable to sunlight (ICI).

Using the strengthening agent as an adhesive

A combined method (Richter) is sometimes used in which the weakened fabric is impregnated with resin which also sticks it to a supporting substrate, in the following manner. Fine nylon or terylene fabric is coated with resin and allowed to dry. The weak textile is then placed on it and additional resin solution is applied to the face: this saturates and penetrates the textile and softens the resin coating on the substrate, so that the two fabrics adhere. Adhesion is sometimes completed by pressing with an iron.

Until better substances and techniques are available such methods must be used to consolidate disintegrating textiles. Because the performance of the materials over a long period cannot yet be known they should only be applied to highly important objects when absolutely essential for their survival.

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[1] Museum of National Antiquities, Sweden.

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A. E. Werner

The conservation of leather, wood, bone and ivory, and archival materials

17

A. LEATHER

INTRODUCTION

From earliest times the skin of animals has been used for a variety of purposes by primitive peoples, and the wide extent of its application can be readily appreciated by studying the ethnographical collections in museums. Skin itself is not a permanent material as it is very susceptible to biological attack and is sensitive to moisture. These weaknesses can be overcome to a certain extent by treating the skin in various ways such as tawing (alum dressing), oil-dressing or tanning to give the product known as leather. The inherent defects of skin are not eliminated by these processes, and archaeological and museum objects made of leather or which include leather in their make-up are still susceptible to biological attack and are sensitive to the humidity conditions of the environment.

MOULD GROWTH

In ethnographical collections and in libraries where leather products are largely in evidence, control of environmental conditions is of paramount importance—particularly, in certain types of tropical climates, humidity control to keep the relative humidity of the atmosphere below the critical limit of 68 per cent. If the relative humidity rises above this value moulds will grow readily, causing staining of the leather and even physical deterioration. In countries where a high relative humidity persists for long periods of the year, it may not be a practical proposition—largely on economic grounds—to keep the relative humidity within safe limits, and the use of fungicides must be regarded as a necessity for the prevention of mould growth. Since it will be desirable to provide protection over a prolonged period, it will be necessary to use the fungicide in a relatively high concentration and to choose a fungicide which does not volatilize too readily, and which will not stain the leather. For these reasons preference is given to derivatives of pentachlorophenol, known commercially as Santobrite, or the sodium salt of *ortho*-phenyl-phenol, known commercially as Topane S, can be dissolved either in alcohol or water and used as a 2 per cent solution. Alternatively the lauryl ester of pentachlorophenol, available commercially as Mystol L.P. 100, can be used as a solution in white spirit or kerosene.

INSECT ATTACK

It is necessary in tropical countries to take special precautions to protect leather objects from attack by insects. 'Good housekeeping' is an essential factor here, as insects are attracted by dirt, etc. Leather objects should therefore be inspected at regular intervals and cleaned from time to time.

If these precautions are observed, infestation should be detected before it has assumed serious proportions. Such small outbreaks of insect attack can be effectively dealt with by removing any infected objects and spraying them in a special room or out of doors with a suitable insecticidal solution using an atomizer. Many effective commercial preparations are now available but these should be tested before use to ensure that the solution will not cause any staining of the leather or be harmful in any other way to the leather. Preparations of unknown composition should not be used. In many cases it may be more satisfactory and cheaper to prepare the insecticidal solutions oneself. Two preparations which can be recommended are the following:

Pyrethrum/DDT solution. 30 g of pyrethrum concentrate and 30 g of DDT powder are dissolved in 500 cm^3 of odourless paraffin distillate.

Lethane solution. 30 g of deodorized Lethane 384 is dissolved in 600 cm^3 of odourless paraffin distillate.

If the insect infestation is on a large scale, the only effective way of dealing with the problem is to carry out fumigation with hydrogen cyanide, methyl bromide or carbon disulphide. This fumigation will necessitate the use of special equipment as described in Section D of this chapter ('Archival Materials'). The chemicals used in fumigation do not confer any lasting protection, and it is therefore essential to examine the room from which the infested objects have been taken. If necessary, the room should be treated to ensure that reinfestation will not reoccur.

When leather objects which are known to be free from insects are being kept in store, it is a wise precaution to wrap them up in sealed polythene bags. This not only keeps the objects free from dust but also prevents access to insects. As an added precaution a few crystals of paradichlorobenzene may be placed in a perforated container inside the bag. The crystals should not be allowed to come into direct contact with the objects. Insecticidal lacquers, i.e., insecticides incorporated in solutions of resins, have been proposed for brushing or spraying on to leather to provide long-term protection, but this cannot be recommended. Such lacquers confer an unpleasant sheen on the leather and may even have an ultimate deleterious effect on it. If it is considered necessary to protect leather against possible insect attack, it is preferable to use an insecticidal wax preparation[1] rather than a lacquer. Such wax preparations have the advantage that the leather can be polished after application to give a pleasant appearance to the object. Insecticides can also be incorporated into other waxes which are used on leather.

In discussing the insecticides used to combat insect attack, no mention has been made of the chemicals such as mercuric chloride or sodium arsenite which are recommended and used in many tropical countries. Although these substances are undoubtedly very effective as insecticides, they suffer from the serious disadvantage of being extremely toxic to human beings. This means that great care has to be taken to prevent accidental poisoning, and it is preferable that their use should be abandoned in favour of the newer organic insecticides.

TREATMENT OF BRITTLE LEATHER

When leather is exposed in a museum for a prolonged period to a dry atmosphere, i.e., one in which the relative humidity is below about 40 per cent, it tends to lose its characteristic flexibility and becomes rather hard and brittle. Under such conditions some form of treatment will be necessary

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[1] A wax which contains both an insecticide and a fungicide is Cire 212; this has been developed by Mrs. F. Flieder of the Centre National de la Recherche Scientifique (CNRS) and it can be obtained from the Laboratoire de Cryptogamie, Museum National d'Histoire Naturelle, 12, rue Buffon, Paris-5e, France.

to restore flexibility to the leather. This is particularly necessary in the case of leather-bound books (or, indeed, any object in which the leather is flexed) because, if the leather on the hinge of a book is allowed to become hard and brittle, deterioration will soon become general. In practice this can be prevented by treating the leather with a suitable leather dressing based on lanolin and a wax; the lanolin dressing will be absorbed into the tissue of the leather and will serve as a lubricant for the fibres, whereas the wax will remain on the surface to consolidate the brittle leather—which may be in a powdery condition if deterioration has occurred. The actual dressing should be in the form of a liquid cream so that it can be applied without causing any physical strain on the leather.

The British Museum Leather Dressing

A preparation which meets the above requirements is the British Museum Leather Dressing, which has been used with success for a number of years. The ingredients and preparations are as follows: anhydrous lanolin, 200 g; cedarwood oil, 30 ml; beeswax, 15 g; petroleum ether B.P. 60-80°C, 330 ml. To prepare the dressing, the first three ingredients are mixed together and melted by heating carefully on an electric hot-plate; the molten mixture is then poured rapidly into the cold petroleum ether and allowed to cool with stirring, so that a yellowish emulsion is produced. The mixture is highly inflammable and no naked flames should be present in the room during the preparation of the dressing or during its application. The dressing should be applied sparingly and rubbed well into the leather with swabs of cotton wool. After two days the leather is polished with a soft cloth.

In hot climates it may be found that the particular grade of petroleum ether is too volatile; if so, a petroleum ether B.P. 80-100°C may be used instead. Also, if so desired, 3 g of DDT may be incorporated in the above mixture to act as an insecticide.[1] It must be emphasized that, although the use of a leather dressing will prolong the life of leather, it does not offer any protection against chemical decay. This question will be discussed in Section D below.

Leather objects in desertic climates

Leather objects which have been exposed to a very dry environment for a prolonged period of time and then excavated will be found to have become so desiccated that they are extremely hard and brittle. It will then be necessary to restore flexibility before such an object can either be unfolded or re-shaped. In the past this was usually done by impregnating the brittle leather with a material such as Turkey-red oil. However, this is not an entirely satisfactory procedure, and an improved and simpler method is to use one of the grades of the polyethylene glycol waxes as the impregnating material. The particular grade which has proved suitable is the material which is a blend of equal parts of the solid wax 1540 and the liquid polyethylene glycol 300; at room temperature this has the consistency of vaseline and melts at about 40°C. This is known as grade 1500 by producers of polyethylene glycol waxes, except for the firm Mo och Domsjö (Sweden) who market it as grade 1500/300. For carrying out the treatment the brittle leather object is immersed in the molten polyethylene glycol wax at a temperature of 50°C. When the impregnation has been completed—usually

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[1] The British Museum Leather Dressing can be obtained from Hopkin & Williams Ltd., Freshwater Road, Chadwell Heath, Essex (United Kingdom). A similar preparation is also available under the trade name Pliantine from Arthur Rich & Partners Ltd., Unity Works, Belper, Derbyshire (United Kingdom). References to other recipes for leather dressings will be found in Leaflet No. 318 of the United States Department of Agriculture, Washington, D.C.

after a few days—and the leather has become flexible, the object is removed from the bath of molten wax, any excess of wax on the surface is washed off with water and the leather allowed to dry. The object can then be unfolded or re-shaped as necessary. It should be noted that this grade of polyethylene glycol wax is slightly hygroscopic, being in fact about 30 per cent as hygroscopic as glycerol. Under normal museum conditions the treated leather will remain unchanged, but if exposed to humid conditions the leather may become slightly moist. To guard against this the leather should be treated with the hydrophobic wax preparation consisting of a hard wax of the polythene type dispersed in a microcrystalline wax which has been recommended for wood (see formulation, page 271). This wax preparation is also very convenient for the removal of ingrained dirt from leather objects; this is due to the good dispersion properties inherent in microcrystalline waxes. For this purpose, it should be rubbed into the leather on swabs of cotton wool until all the ingrained dirt has been removed, and then the leather given a final polish with a soft clean cloth.

B. WOOD

ADHESIVES AND CONSOLIDANTS

The agencies which are likely to cause the deterioration of objects made of wood have already been discussed in some detail in Chapters 3 and 4. Under tropical conditions one may expect to find that wooden objects which have been exposed to uncontrolled atmospheric environment may suffer major damage due to action of fungi or attack by insects. As a result the conservator is often faced with the problem of the treatment of wooden objects, which may have suffered such severe damage that they have lost most of their normal mechanical strength. The question must therefore arise as to the best method to be adopted for the consolidation of wooden objects which have been reduced to a fragile condition. This will involve the use of adhesives for joining parts of an object, liquid consolidants for impregnation of wood weakened by insect attack, and solid consolidants to make good the wood which may have been completely eaten away.

This naturally leads one to consider the important question as to how one is to decide what type of material should be chosen for carrying out the necessary treatment. In the past one's choice was limited to various materials of natural origin such as animal glues, beeswax and natural resins such as shellac. None of these materials is really satisfactory even in a temperate climate, and under tropical conditions they would be even less satisfactory. However, nowadays there are available a number of synthetic materials which are superior in many respects to the natural materials. The number of these new synthetic materials at the disposal of the conservator is now so great that he may well become confused in trying to select the most suitable material, and also he may be rather bewildered by the different trade names, often used to describe materials of essentially the same nature. It is therefore important to discuss first of all certain fundamental properties of the materials used as adhesives and consolidants, and to consider later the factors which govern the choice of a particular material for a given job.[1]

Shrinkage

One factor of paramount importance as regards the use of adhesives and consolidants in the conservation of fragile wooden antiquities is the question of the amount of

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[1] See also discussion in the Appendix, p. 319.

shrinkage which may occur when an adhesive or consolidant sets from the liquid to the solid state. If there is considerable shrinkage, this will result in the development of contractile forces which are likely to cause serious distortion of a fragile object. A simple method for testing the behaviour of certain materials used as adhesives or consolidants as regards the development of contractile forces is shown in *Plate 39*. The material under test is poured in the liquid state into a cut-out recess in a plywood frame, and allowed to set. It was found that two of these materials—ordinary rabbit-skin glue and the synthetic resin resorcinol-formaldehyde—caused serious immediate distortion on setting: and this has become progressively worse with time. This was due to the fact that shrinkage occurred during the setting reaction on account of the loss of volatile material (water) and that the resulting set film was tough, so that the strains were transmitted to the framework, causing it to distort. In the case of the material called soluble nylon, shrinkage also occurred during the setting reaction due to evaporation of the solvent (ethyl alcohol), but the contractile forces were released in the film itself which underwent reticulation, so that no distortion of the framework took place. Finally, in the case of the epoxy resin, the chemical reaction involved in the setting is such that no volatile material is evolved and therefore there is no appreciable shrinkage and consequently no distortion (this particular test was carried out fourteen years ago and the sample still shows no sign of any distortion). A similar result was also obtained when the polyester type of resin was tested in the same way, since these resins also set without undergoing appreciable shrinkage.

Penetration

It is thus clear that these particular types of synthetic resins—epoxy and the polyesters—are potentially of great value as adhesives and consolidants in the treatment of fragile wooden antiquities. Furthermore these materials offer a new approach to the problem of the consolidation of wooden objects which are in such a decayed state that they require to be impregnated with a material which will confer upon them the necessary mechanical strength so that they can be handled with safety. In this type of work it is essential that the material to be used for the consolidation should be capable of thoroughly penetrating the object. When solutions of synthetic resins are used for this purpose, they suffer from the disadvantage that they can be used only as relatively dilute solutions, at the most about 10 per cent, so that repeated applications are necessary in order to get an adequate amount of the resin to enter the wood. Also, owing to the fact that the solvent has to evaporate from the wood, it is difficult to achieve a degree of penetration which is sufficient to ensure that an adequate amount of the consolidant is actually deposited throughout the thickness of the object and is not merely deposited only in the surface layers. Similarly when molten waxes are used as consolidants, adequate penetration will be difficult to achieve if they are merely brushed on to the object. Thorough soaking of the object in a bath of molten wax will be essential, and this means that special equipment, e.g., electrically heated baths, lifting tackle for raising and lowering heavy objects, will be necessary, thus adding considerably to the cost of the treatment (Unesco, 1960, plate 6). On the other hand the epoxy and the polyester resins can be used in the form of non-solvent systems. This means that they can be applied as mobile liquids (the resin plus the appropriate hardener) which can readily penetrate throughout the wood where they solidify *in situ* at room temperature. They are thus easy to apply, and furthermore another very important advantage of these non-solvent resin systems is that they are very versatile, so that conditions can be altered to suit the particular requirements of the work in hand; thus the setting time can be varied within wide limits by suitable choice of the hardener and accelerator, the physical properties of the solid set resin can be varied either by the addition of a plasticizer or by the choice of a particular resin, and also the viscosity of the resin-hardener system in its pre-set form can be adjusted as desired.

Epoxy resin impregnation—an example

As a specific example of the use of an epoxy resin for the consolidation of a fragile wooden object, we may consider the case of a ceremonial double-faced four-horned mask for use in the *Ikem* play, which was carved about 1900 by an Ibo artist at Oziutem (South-East Nigeria) *(Plate 40)*. When this was received in the British Museum Research Laboratory, it had been so thoroughly attacked by insects that the bulk of the mask was reduced to a mere shell and the nose and one ear were almost detached. Consolidation leading to restoration of mechanical strength was readily achieved by impregnating the mask with a formulation consisting of the following: Araldite CY 219, 50 parts; hardener HY 219, 25 parts; accelerator DY 219, 1 part; dibutyl phthalate, 10 parts. Subsequently this particular formulation has been successfully used for the consolidation of many wooden objects in a fragile condition. As well as being used as liquid systems for impregnation, these epoxy and polyester resins can be mixed with powdered inert materials and made available as pastes which, when mixed with a liquid hardener, set at room temperature to a hard solid; in this form they can be used for making good parts of a wooden object which may be missing, as they can be readily shaped with ordinary wood-working tools. Thus in the case of the Nigerian mask referred to above, holes and gaps where the wood had been completely eaten away were made good with the epoxy resin Araldite AV 121. A convenient polyester paste which has also been used for the same purpose is the material available commercially under the trade name Bondafiller from Bondaglas of Croydon (United Kingdom).

Effects of humidity on adhesives and consolidants

Another point which must be borne in mind in connexion with the repair of wooden objects in a tropical climate is the susceptibility of adhesives and consolidants to either excessive dryness or excessive humidity. As a general rule it will be found that adhesives based on natural materials, such as glue, starch, etc., will be more sensitive than the synthetic resin glues. The former are largely hygroscopic in character. This means that they maintain reasonably good adhesive properties under average conditions of relative humidity, say about 50-70 per cent. If, however, the relative humidity falls too low, the adhesive film will tend to dry out and become brittle with consequent loss of adhesive power. Conversely, if the relative humidity gets too high the adhesive film will tend to absorb water and become so liquid that it completely loses its adhesive power. On the other hand, the synthetic resin adhesives are on the whole non-hygroscopic and are therefore less susceptible to variations in the relative humidity of the environment. The polyester and epoxy resins are particularly good in this respect and are therefore to be strongly recommended as permanent adhesives for use under tropical conditions.

PROTECTIVE SURFACE COATINGS

Another problem which the conservator has to deal with arises in connexion with the use of surface coatings which may be applied to wooden objects to protect a friable surface or to confer a pleasant sheen on a wooden object which has become dull in appearance. In the past it was often customary to apply drying oils, such as linseed oil, or waxes such as beeswax. The former suffer from the disadvantage that they tend to yellow with age—a tendency which will be accentuated under tropical conditions—and the latter often leave the surface of the wood slightly sticky so that dust will tend to collect, particularly in the crevices in the wood, thus creating conditions favourable for the laying of eggs by wood-boring insects. Waxes may, on the whole, be considered suitable as protective surface coatings if care is taken to ensure that a suitable wax mixture is chosen which leaves a relatively hard, non-sticky surface finish. It is possible to prepare such a wax mixture using some of the new synthetic waxes which are now commercially available. One particular formulation which has proved successful in this respect has been made by incorporating a microcrystalline wax with a polyethylene wax. Several varieties of these waxes are available and the sheen of the resultant wax film can be varied by altering the grades and the proportions of the waxes used. The following basic recipe may be taken as one which has been found to be generally satisfactory: 100 g of Cosmolloid 80 Hard (microcrystalline wax)[1] and 25 g of A Wax (polyethylene wax)[2] are melted together and well stirred to ensure thorough mixing of the two waxes.[3] The molten mixture is poured quickly into 300 ml of white spirit, and, while cooling, is constantly stirred so that a smooth paste is obtained.

The above preparation not only provides a protective coating of pleasant appearance but also serves to remove ingrained dirt from the wood on account of the high dispersive power of the microcrystalline wax. Furthermore, for use in tropical conditions, an insecticide such as lauryl pentachlorophenate can be added to the wax mixture so that the waxed object will be protected to a certain extent against attack by insects. Lauryl pentachlorophenate is a suitable insecticide to choose, because it can be readily dissolved in the white spirit used to prepare the wax paste, and it can be expected to have a fairly long-lasting effect, because of its relatively low volatility.[4] An alternative liquid insecticide which may also be used is β-chloronaphthalene.[5]

WATERLOGGED WOOD

When wooden objects have remained buried for prolonged periods in wet soil, they suffer serious deterioration because the cellulosic components of the cell walls undergo biological degradation. If the waterlogged object is exposed to the air so that the excess of water is allowed to evaporate, the surface tension forces involved will bring about the collapse of the weakened cell walls. This means in practice that the wooden object will suffer considerable shrinkage and distortion. Precautions must therefore be taken to ensure that such an object is not exposed any longer than is necessary. It should be immediately wrapped in polythene sheeting until it can be taken to the laboratory for treatment. The actual physical state of a waterlogged object will depend upon the degree of deterioration which has taken place. This will vary with the period of burial and the conditions of the environment; in many cases it will be found that the wood has become very soft and has almost the consistency of cheese and must be handled with great care when it is removed from the ground. The conservation of waterlogged wood is a twofold problem; it

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1. Available from Astor Boisellier and Laurence, 9 Savoy Street, London W.C.2.
2. Available from BASF, Ludwigshaven-am-Rhein (Federal Republic of Germany).
3. See also the Appendix, p. 303.
4. This material is available from Catamance Limited, Welwyn Garden City, Herts. (United Kingdom).
5. Available under the trade name of Xylamon from Desowag A.G. Düsseldorf (Federal Republic of Germany).

involves, firstly, the removal of the large excess of water by a method which will prevent any shrinkage or distortion, and, secondly, the incorporation into the wood of a material which will act as a consolidant and confer mechanical strength to the wood. Many methods for the treatment of waterlogged wood have been tried in the past with varying degrees of success. Those which have aroused most interest and which seem to offer the best chance of success are the following.

Treatment of small- to medium-sized objects

Alum method. The principle underlying this method is based on the fact that alum (potassium aluminium sulphate, $K_2SO_4Al_2(SO_4)_3.24H_2O$) is a salt which has a much greater solubility in hot water than in cold water; it will in fact dissolve in its own water of crystallization at 96°C. This means that if the excess of water in the wood is replaced by a solution of alum at an elevated temperature, then on cooling the alum will crystallize out inside the wood and will stabilize the weakened cell-walls. In practice, the waterlogged object is immersed in a saturated solution of alum maintained at a temperature of 92°-96°C. It is left totally immersed in this hot solution for a sufficient period of time to ensure adequate impregnation. An average time is at least ten hours, but a longer period will be necessary if the wooden object is bulky or if the wood has a close grain. The object is then removed from the alum bath, washed quickly with warm water and set aside to cool. Any residual white deposit of alum which crystallizes out on the surface is brushed off when the object is dried. This method was the earliest used for the treatment of waterlogged wood, and it has a fair record of success. It is, however, rather a drastic method, and sometimes fails unpredictably. If this should happen there is nothing that can be done to repair the damage, and it has now been largely abandoned.

Alcohol-ether method. This method is essentially similar to the routine used for the drying out of biological specimens. The waterlogged wooden object is first immersed in successive baths of ethyl alcohol (industrial methylated spirits can also be used) until all the water has been replaced by alcohol, the progress being followed by measuring the specific gravity of each bath. When all the water has been replaced by alcohol, the object is then immersed in successive baths of diethyl ether, so as to replace the alcohol by the ether. When this has been accomplished, the object is dried very quickly by placing it in a vessel which can be rapidly evacuated so that rapid volatilization of the ether occurs. Ether was chosen because it has a very low surface tension (0.17 dyne/cm compared with 0.72 dyne/cm for water). This means that when the ether evaporates, the surface tension forces are too low to cause any appreciable collapse of the weakened cell walls. If necessary, dammar resin can be dissolved in the final bath of ether so that the dammar will be deposited in the pores of the wood to act as a consolidant. This method has proved to be very successful, but it is only economically practicable for the treatment of relatively small objects. Also alcohol and ether—particularly the latter—are highly inflammable materials, so that extreme precautions have to be taken to guard against fire risks. Furthermore, the low boiling point of ether (35°C) would be an additional problem militating against the use of this method in tropical countries.

Arigal-C method. This method depends upon the use of a special melamine-formaldehyde resin used to impregnate the waterlogged wood. The object to be treated is first washed in water to remove the acidic substances which are present in the wood as the result of the degradation which has taken place. After this preliminary washing the object is immersed in a 25 per cent aqueous solution of the melamine-formaldehyde resin.[1] The object is left immersed in this solution until the excess of water has been replaced by the resin solution and thorough impregnation of the wood has been achieved—a process which, in the case of bulky objects, may take many weeks. Then the object is removed from the bath, to which a special hardener (catalyst) is added. The wooden object is replaced in the bath, which is placed in a vacuum container and the pressure reduced to 80 mm of mercury. After about 35-40 hours the liquid resin is converted to a solid which consolidates the cell walls and thereby confers mechanical strength on the wooden object. Further experimental details and the results achieved by this method will be found in the publication of H. Müller-Beck and A. Haas (1960), who introduced this method for the treatment of specimens of prehistoric wooden objects excavated from waterlogged neolithic strata.

Polyethylene glycol wax method. The polyethylene glycols are synthetic materials which have the generalized formula: $HOCH_2.(CH_2OCH_2)n.CH_2OH$. The early members of the polymeric series are liquids, the intermediate members are semi-liquids of the consistency of vaseline, and the higher members with value of *n* greater than 35 are wax-like materials. Although these materials have the physical properties of waxes, they are distinguished from other waxes by the fact that they are freely soluble in water. The particular material having suitable properties for the treatment of waterlogged wood is the polyethylene glycol wax of grade 4000, which is a hard, white, non-hygroscopic solid with a melting point of 53°-55°C. Using this material it was possible to develop a reliable method, which was also simple to carry out since the removal of the water in the waterlogged wood and the consolidation of the wood could be achieved in one operation (Fig. 61). The waterlogged object is cleaned to remove all dirt on the surface and placed in a container with a close-fitting lid which is filled with a 12 per cent solution of the wax at room temperature. The container is placed in a ventilated oven and the temperature is gradually increased until after a period of weeks it has reached 60°C. During this time the wax slowly diffuses into the wood, displacing the water in the wood, and the supernatant solution slowly evaporates through the slight space between the lid and the container, so that at the end of the operation the wooden object is just covered with molten wax. The object is then removed and allowed to cool. When cold, the wax on the surface of the object is removed by brushing with hot toluene. In carrying out this method it is important that the dimensions of the container should be such that the actual quantity of wax present will be more than enough to cover the object at the end of the process. Polyethylene glycol waxes are commercially available under a number of different trade names; the following are among the best known:

Carbowax: from Union Carbide Corporation, 30 East 42nd Street, New York 17, N.Y. (U.S.A.).
P.E.G.: from Shell Chemical Co., 50 West 50th Street, New York 20, N.Y. (U.S.A.).
Polywachs: from Farbwerke Hoechst A.G., Frankfurt am Main (Federal Republic of Germany).
Modopeg: from Mo och Domsjö, Strandvägen 1, Stockholm (Sweden).

Treatment of large wooden objects

The above methods for the treatment of wooden objects in a waterlogged condition involve the use of fairly elaborate equipment. This may present a difficult problem when large wooden objects such as boats and

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[1] This is produced under the trade name Arigal C by Ciba Ltd. of Basle (Switzerland). See also the Appendix, pp. 322-323.

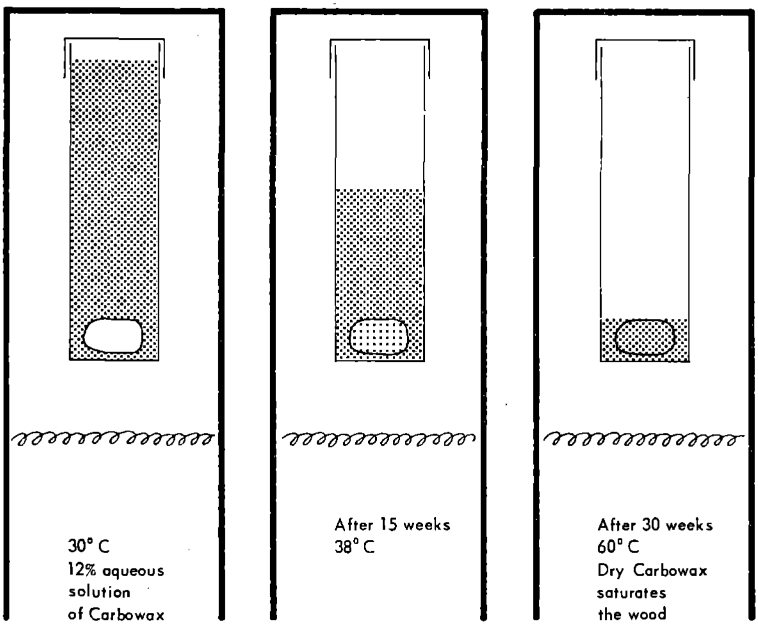

Fig. 61.

Diagram showing the treatment of waterlogged wood with Carbowax 4000 (polyethylene glycol wax). Slow diffusion of water out of the waterlogged wood is controlled by raising the temperature of a hot-air bath.

canoes have to be treated. The very size of such objects may well preclude the use of any of the above impregnation methods because of the cost of constructing a suitable-sized container and of acquiring the large quantity of materials required. However, large objects of this type will usually be found in such a state that they still possess a reasonable degree of mechanical strength. For this reason it is possible to consider an alternative method of treatment which does not involve the use of elaborate equipment or large quantities of chemicals. Immediately after excavation the object is wrapped in damp sacking, placed in a cool cellar, and allowed to dry out slowly—the sacking being damped periodically as required. This slow-drying process is allowed to proceed for at least a year, and, if properly carried out, there will be no undue warping or shrinkage of the wood. When the wood has dried out, the object can be stabilized by brushing on a material which will penetrate the wood to an extent sufficient to ensure consolidation. For this purpose an epoxy resin has proved suitable; the actual formulation to be used is the same as that given above (p. 270) for the consolidation of the Nigerian ceremonial mask. This is a mobile fluid which is readily absorbed by the wood and solidifies *in situ* at ordinary room temperature. Successive coats should be applied until there is no further absorption of the resin preparation.

PAINTED WOODEN OBJECTS

The consolidation of painted wooden objects which are in a fragile condition is complicated by the fact that precautions must be taken to avoid any damage to the painted surface. This means in practice that the reagents used for the consolidation must not be allowed to come into direct contact with the painted surface. If the paint is in a sound condition, it can be protected temporarily by the application of tissue paper, using an adhesive such as gelatine or polyvinyl alcohol—a method analogous to the facing of a panel painting prior to the

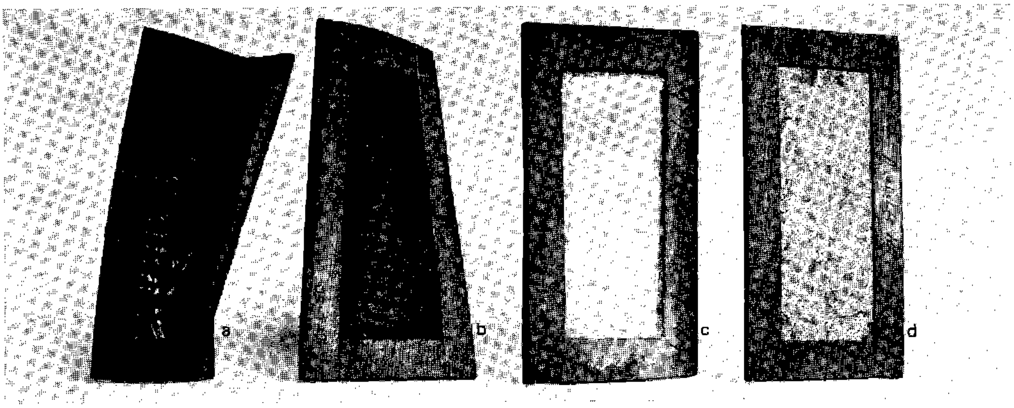

Plate 39

Method used to show the contractile forces of different types of adhesive on setting (photo: British Museum).

- *a* Resorcinol formaldehyde.
- *b* Rabbit-skin glue.
- *c* Nylon polymer C 109/P.
- *d* Araldite 101 (epoxy resin).

Plate 40

Ceremonial mask from South-Eastern Nigeria after consolidation with Araldite epoxy resin (photo: British Museum).

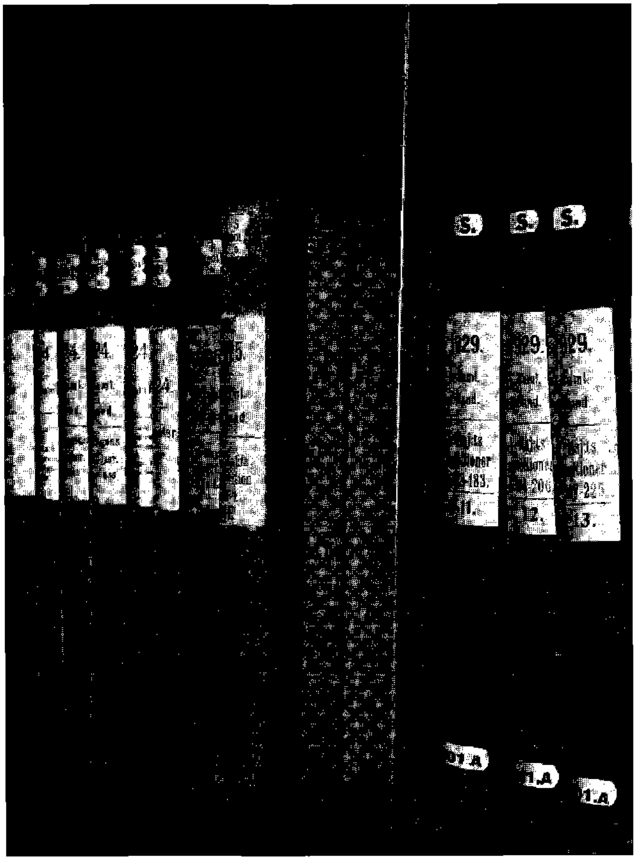

Plate 41

Pattern of mould growth on books caused by the high relative humidity of stagnant air within metal shelving (photo: British Museum).

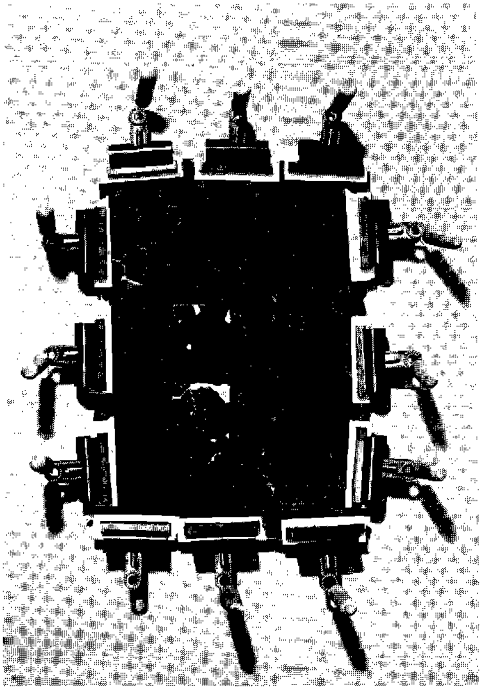

Plate 42

A sheet of parchment being stretched after it had been relaxed with moisture.
The sheet is pulled flat with clips which are held in position by pegs (photo: British Museum Research Laboratory).

treatment of the decayed wood of the panel. The facing of tissue paper is removed when the necessary treatment, either consolidation or application of an insecticidal solution has been completed.

Protection of the painted surface

If the painted surface itself is in a friable condition or if it is tending to flake away from the wood, consolidation of the paint will clearly be an essential first step in the treatment. Such consolidation and reattachment can be achieved by the application of an adhesive, but as mentioned above (p. 268) the important criteria of the adhesive to be used are the degree of shrinkage and the toughness of the adhesive film. If the film is tough and shrinkage occurs when it sets, contractile forces will eventually be developed which may cause subsequent flaking of the painted surface. This behaviour has, for example, been found to occur with adhesives such as nitrocellulose or shellac—two materials which were often used in the past for this purpose. A new synthetic material which does not suffer from these disadvantages and which has been found to be suitable for the consolidation of friable paint and for the reattachment of flaking paint is soluble nylon. This material is made by treating ordinary nylon with formaldehyde.[1] This soluble nylon is a white powder which dissolves in methyl alcohol, ethyl alcohol or industrial methylated spirits; it is normally used as a 5 per cent solution in one of these solvents. The solution may tend to gel in cooling to room temperature, but can be readily reliquefied by warming to about 40°C.

The protective film which is formed on the surface of friable paint has the following desirable properties: it is fairly flexible and therefore does not exert any undue contractile force on the painted surface, and it has a matt appearance so that it does not confer an undesired sheen on the treated areas of the painting.

The soluble nylon also possesses good adhesive properties and can be used for the reattachment of flaking paint. It is merely necessary to brush the warm 5 per cent solution over the flaking paint and to apply gentle pressure. The alcoholic solution has a much lower surface tension than an aqueous adhesive would have, and it therefore readily flows underneath the flakes of detached paint, drawing them back into position and forming a secure bond with the underlying ground.

Removal of dirt

Another problem which is often met with in painted wooden objects is the removal of ingrained surface dirt. If the painted surface is in a reasonably sound condition, i.e., is firmly attached to the support and is not friable, the surface dirt can be cleaned off using swabs of cotton wool moistened with a cleaning fluid. Since the paint will normally be on a ground consisting of a white inert material (such as chalk or gypsum) in a glue medium, it is desirable to avoid the use of aqueous solutions, since there is a risk that these may soften the ground, particularly if they are used carelessly, as the liquid may penetrate fine cracks in the paint. For this reason non-aqueous cleaning fluids should be used. One such cleaning fluid which has been used with success is Soap B30 available from Howards (Ilford, Essex, United Kingdom). This material is soluble in white spirit (also known as turpentine substitute) or trichloroethylene, and is used as a 2 per cent solution in either of these solvents, the former being preferred if there is any risk that the trichloroethylene might have a solvent action on the paint.

If it should happen that the painted surface is in a delicate condition, i.e., is either tending to flake or is in a friable

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[1] See the Appendix, p. 309, for a discussion of thermoplastic adhesives.

state, it may not be possible to subject the painted surface to even the slight rubbing involved in washing with swabs of cotton wool moistened with a cleaning fluid. The removal of ingrained surface dirt presents a difficult problem in such cases, but there is a possible solution which has proved successful in the cleaning of wooden Egyptian painted steles. The cleaning material used is a silicone rubber called 'bouncing putty'. This material has—as the name implies—the consistency of putty and it has a slight tackiness; if this material is gently rolled over the dirty painted surface, the ingrained dirt will be taken up by the putty without risk of physical damage to the painted surface itself. Small areas are treated at a time, the dirty putty being repeatedly kneaded between the hands between each application so as to present a fresh clean surface. When the friable painted surface has been cleaned, it should then be consolidated (as described above) with a solution of the soluble nylon.

C. BONE AND IVORY

INTRODUCTION

From earliest times, objects of various kinds have been fashioned from bone and ivory; in general, the former was used for utilitarian objects, such as tools and implements, whereas the latter was used for producing objects of a decorative nature, such as statuettes, plaques and carved reliefs.

The particular problems which arise in connexion with the conservation of bone and ivory objects are associated with the physical structure and the chemical composition of these materials. Firstly, bone and ivory are anisotropic, i.e., they have different physical properties in different directions, and for this reason they will, for example, tend to warp when exposed to changes in the relative humidity of the environment. Secondly, the organic component—the so-called protein ossein—is decomposed by prolonged exposure to moist conditions, so that objects excavated from damp soil will tend to be in a fragile condition. Also, the inorganic component, mainly calcium phosphate associated with some calcium carbonate and fluoride, is readily attacked by acids. Furthermore, ivory and bone are porous materials so that they are easily stained and readily absorb salts if they are buried in a salty ground. For these reasons, the state of preservation of excavated bone and ivory objects can vary greatly depending upon the nature of the soil in which they have been buried. Thus, objects from a chalky soil may be brittle owing to loss of the organic matrix, whereas objects from a salty soil may be in a fragile condition owing to absorption of soluble salts, and bone and ivory from a wet soil may tend to be soft.

FIELD METHODS OF CONSOLIDATION

It may be that the bone or ivory is found in such a poor state of preservation that it cannot be safely removed from the ground without risk of damage. In such cases, it will be necessary to use a consolidant to give the object the necessary mechanical strength to enable it to be removed from the ground and transferred to the museum laboratory for further preservative treatment. Since this laboratory treatment may necessitate the subsequent removal of the consolidant, it is essential that the material used as a temporary consolidant in the field should be one which can be readily dissolved. Solutions of synthetic resins are, in general, the most useful consolidants for this purpose. If the bone or ivory is excavated from a relatively dry environment, a 10 per cent solution of polyvinyl-acetate dissolved in toluene may conveniently be used. There are various grades of polyvinyl-acetate commercially available which differ in their degree of polymerization and, consequently, in their physical properties. The grade which is most suitable for use as a consolidant is one having a degree of polymerization of approximately 1200 (see the Appendix).

If the bone or ivory is being excavated from a wet environment it will be necessary to use an aqueous emulsion of a synthetic resin such as polyvinyl-acetate or polymethacrylate. There are a large number of commercially available emulsions which can be recommended and are cited in the Appendix. These emulsions are convenient to use in tropical countries because they can be transported as a concentrate for field work and diluted with water to the required consistency before use.

It is important to note that only the minimum amount of consolidant should be used to give the object just sufficient mechanical strength so that it can be removed from the ground. If too much is used, it may lead to difficulties in carrying out subsequent treatment in the museum laboratory. The idea is to achieve surface consolidation and not complete impregnation of the object.

TREATMENT OF BONE AND IVORY IN THE LABORATORY

If the object has been treated in the field with a consolidant, the first step may well involve the removal of the synthetic resin used for the consolidation so that the necessary further treatment can be carried out. If the materials recommended above have been used, thay can be readily removed by washing the objects with toluene which will dissolve the synthetic resin used.

The subsequent treatment in the laboratory will depend upon the condition of the object. The usual processes which will probably be necessary may be conveniently considered under the following headings.

Removal of soil

Any soil which is loosely adhering to the objects can be removed by scraping it off with a pointed implement, e.g., a plastics knitting needle or a wooden stick sharpened at the end. In some cases it may be necessary to vary this procedure by wrapping a small swab of cotton moistened with water around the end of the implement. This preliminary cleaning can then be followed by careful brushing with a soft tooth brush. When doing this kind of mechanical cleaning, care should be taken to ensure that the object is supported on a soft material, such as foam rubber, so that it can withstand the mechanical stresses involved. If necessary, the supporting material should be wrapped round the object. As a general rule, metal tools should not be used for removing soil, as there is a risk that the object may be scratched.

Removal of soluble salts

If the ivory or bone object has been recovered from a salty environment it will be saturated with soluble salts which will tend to crystallize out on the surface, causing disintegration of the object. Objects in this condition require washing in distilled water to remove the salts, the washing being repeated until no further salt efflorescence occurs on drying. Care must be exercised while proceeding with this treatment, as if the objects are in a relatively poor state of preservation, repeated washing may cause their disintegration. Hence, consolidation of the object by brushing on a 5 per cent solution of the soluble nylon is an advisable precaution prior to washing. This material forms a consolidating film which is water permeable and therefore does not interfere with the washing out of the soluble salts.

Removal of insoluble salts

The treatment of bone and ivory objects which are covered with an incrustation of calcium carbonate (chalk) poses a difficult problem. The use of an acid is essential to dissolve the calcium carbonate, but this involves decomposition of the calcium carbonate with the evolution of carbon dioxide gas. The effervescence thus caused would, if uncontrolled, result in the disintegration of a fragile bone or ivory object. This risk can be overcome by applying the acid locally to small areas at a time. The objects should therefore be cleaned under a stereoscopic microscope at about 10 diameters magnification, using a 1 per cent solution of hydrochloric acid applied with a small paint brush. When the evolution of carbon dioxide gas ceases, the excess of liquid is removed with small pieces of blotting paper held in a forceps. Care should be taken to ensure that the acid solution used is in quantities just sufficient to soften the incrustation of calcium carbonate, which should then be removed mechanically with a needle. Any traces of acid which might remain should be removed by washing the treated object in several baths of distilled water, and then drying by immersion in two or three successive baths of ethyl alcohol or industrial methylated spirits.

Another type of insoluble incrustation which may occasionally be found in an ivory or bone object is calcium sulphate. This material can be distinguished from the more normal calcium carbonate incrustation by the fact that it is not decomposed by acids; it is, in fact, so insoluble that it cannot be removed by any chemical method. The only means which can be adopted for removing an incrustation of calcium sulphate is to attempt to remove it mechanically by the use of dental equipment. However, this procedure can only be undertaken if the object is in a sound condition and is capable of resisting the mechanical stresses involved.

Consolidation

If the object is in a dry, powdery condition it can be readily consolidated by impregnation with a suitable transparent synthetic resin; solutions, about 5 per cent w/v, of polyvinylacetate or polymethacrylates in toluene have been found to give satisfactory results. Alternatively, these resins can be used in the form of aqueous emulsions. If only surface impregnation is necessary, the materials mentioned above can be applied by brushing. It will probably be found that two or more coats will be necessary for consolidation: care should be taken to ensure that each coat is allowed to dry out before the next coat is applied. If these solutions are carefully applied, the object should not have an unpleasant sheen. Where, for aesthetic reasons, it is essential to produce a very mat appearance, it is advisable to use a 5 per cent w/v solution of soluble nylon in alcohol as the consolidant. This material is characterized by the extremely mat appearance of the film which it forms.

If an ivory object is in a very fragile condition, it will be necessary to secure a thorough penetration by the consolidant in order to confer adequate mechanical strength on the object. This can be achieved by carrying out the impregnation under vacuum. For this purpose the object is placed in a container filled with one of the impregnating solutions described above, and this container is placed inside a vacuum vessel which is attached to an ordinary laboratory water pump. When the pressure inside the vacuum vessel is lowered, air in the interstices of the object will escape and the consolidating solution will readily penetrate the object. When no further air bubbles escape from the object, the vacuum is slowly released by opening a tap on the vacuum vessel. The object is then taken out of the solution and allowed to drain on a wire frame.

Surface cleaning

It is often found that a delicately carved ivory object may be covered with ingrained dirt and will, therefore, be in need of surface cleaning. Owing to the sensitivity of ivory—particularly if it is of some age—to moisture, it is advisable to avoid the use of aqueous detergent solutions. It is much safer to use a detergent which can be dissolved in an organic solvent. One such detergent which can be successfully used for the surface cleaning of ivories is Soap B30 (see above). This material is used as a 2 per cent solution in white spirit (a petroleum distillate). Small swabs of cotton wool are moistened with this solution and used to clean the ivory. After cleaning, the ivory should be washed in white spirit to remove any traces of the Soap B30 which might remain on the ivory. If the grime proves obstinate and is not readily removed by this solution, a little powdered whiting made into a paste with methylated spirits may be gently applied on a small swab of cotton wool. This treatment may also reduce the dark appearance of cracks and crevices that cannot be properly cleaned out, as residues of whiting will tend to fill up the cracks and cause them to harmonize better with the surrounding ivory. When the surface cleaning has been completed, the ivory object should be dried with a soft absorbent cloth.

Ivory and bone objects tend to attain a yellowish tone which may be regarded as a natural patination that is conferred on them by time. No attempt should be made to bleach ivory or bone in this condition. However, these materials are porous and may possibly become stained in an unsightly manner so that an attempt at bleaching may be considered desirable to improve the appearance of the object. The best way to bleach ivory or bone objects is to coat them uniformly with a stiff paste made up of whiting and 20-volume hydrogen peroxide. The coating is left on the object for a few hours, and then washed off with a swab of cotton wool moistened with water. The object is then immediately dried with a soft cloth. If necessary, the treatment is repeated until the stain has been reduced to the required extent.

Repairing broken ivory

A suitable adhesive which can be recommended for the repair of broken ivory objects is nitrocellulose. This possesses the following advantages: ease of application, reliable adhesive properties, and ease of removal. This last property is particularly important because it means that adjustments can readily be made in the course of the repair work if this should prove necessary. This type of adhesive is certainly preferable to aqueous adhesives, such as glue or isinglass, which cannot stand up to the humid conditions which are likely to be met with in the tropics and which may lead to loss of strength in the adhesive joint.

Another point which must be borne in mind in repairing ivory or horn objects—particularly if they consist of thin pieces—is that the individual fragments should be kept under controlled conditions of relative humidity whilst the repairs are being carried out, otherwise it may be found that the separate fragments have responded to differential shrinkage and will not fit together properly. The separate fragments should therefore be kept in containers inside which the relative humidity is kept constant by the use of a suitable chemical reagent.

D. ARCHIVAL MATERIALS

INTRODUCTION

The materials of which archives are composed, namely paper, parchment, palm leaves, birchbark, and leather and adhesives used in bookbindings, are susceptible to two main forms of deterioration. One is biological deterioration caused by insect attack and/or fungal growth, and the other is deterioration caused by adverse environmental conditions, e.g., presence of dirt, dust, etc., extremes of dryness or dampness, or wide fluctuations in relative humidity, associated with the large variations in day and night temperatures which occur in certain tropical countries. These two forms of deterioration are interconnected because humid conditions will favour the growth of fungi (moulds) and accumulations of dirt, dust, etc., will attract insects.

In general, it may be said that the potential deterioration of archival material can be largely combated by adopting principles of good housekeeping involving regular inspection of material on exhibition and in storage, and the controlling of climatic conditions within prescribed limits.

METHODS FOR CONTROLLING INSECT PESTS

In recent years a considerable amount of work has been done in developing methods for protecting archival material against attack by insects by the use of different insecticides. However, the indiscriminate use of insecticides must be avoided, and it must be stressed that no single method is likely to be universally effective in exterminating all kinds of insects. Details about the various kinds of insects and appropriate methods of control will be found in Chapter 4.

Another factor also to be considered is the extent of the infestation as this will be important in deciding upon the measures to be adopted. Insecticides may be used either in the form of gases or vapours, i.e., fumigation, or in the form of insecticidal solutions which can either be sprayed or brushed on the infected material.

Fumigation

If the infestation has assumed severe proportions and is likely to be a constantly recurring problem, large-scale fumigation in a special chamber using one of the fumigants mentioned in Chapter 4 will be necessary. Such fumigation should only be carried out by suitably qualified people who realize the hazards involved in the handling of these fumigants and are aware of the necessary safety precautions to be taken. Hydrogen cyanide and methyl bromide are highly toxic to humans, and ethylene oxide forms an explosive mixture with air; for this reason it is normally supplied as a mixture with carbon dioxide, known commercially as Carboxide, or as a mixture with Freons (fluorine hydrocarbons) known as Cryoxide.

If it is necessary to fumigate only a few books, a simple method is fumigation with *para*-dichlorobenzene—which must not, however, be allowed to come into direct contact with the books—for at least a fortnight. The quantity of *para*-dichlorobenzene should be about 1 kg to every cubic metre of air space. A similar method of fumigation can also be carried out using either chloroform or a mixture of 3 parts of ethylene dichloride and 1 part of carbon tetrachloride at a concentration of about 500 ml for every cubic metre of air space. The above-mentioned fumigants will kill insects and their larvae, but the eggs are resistant. It is therefore advisable to keep the treated books under observation for at least a year; if insects do reappear, fumigation should be repeated.

Insecticidal solutions

As an alternative to fumigation, insecticides can be applied as liquids which can be brushed on or sprayed as a fine mist from an atomizer. Attention should be paid not only to the books and documents themselves, but also to the shelves and bookcases. Insecticidal solutions which may be regarded as satisfactory include the following:

1. DDT dissolved in kerosene in the proportion of 40 g per litre.
2. Lethane 384 (a solution of an aliphatic thiocyanate in petroleum spirit). This is diluted with petroleum spirit or kerosene to a concentration of 50 g per litre.
3. Dieldrin 15: a commercial preparation containing dieldrin available from Shell Chemical Company.
4. Gammexane (gamma-isomer of benzene hexachloride 'lindane'), dissolved in kerosene in the proportion of 20 g per litre.
5. Shirlan: a proprietary preparation containing salicylanilide.

A number of formulations of insecticidal solutions which have been used by various institutions in tropical countries are mentioned by W. J. Plumbe (1964). In these, great emphasis is laid on the use of mercuric chloride dissolved in methylated spirits in a concentration of about 50 g in 1 litre. Mercuric chloride is undoubtedly a powerful and effective insecticide, but it must be remembered that this chemical is also extremely toxic to human beings. Stringent precautions should, therefore, be taken in the application of solutions of mercuric chloride. Also, if books treated with this solution are being constantly handled, there is a risk that the chemical may be absorbed in the hands. It is, therefore, advisable to avoid the use of mercuric chloride as an insecticide, except under exceptional conditions, and to use instead one of the commercial preparations mentioned above.

When applying insecticidal solutions, particular care should be taken to treat the space between the binding and the spine of the book. It should be noted that these insecticidal solutions may not necessarily kill eggs, so that treated books should be inspected periodically, and treatment repeated if necessary.

A note of warning is also required when insecticidal solutions are applied by spraying. It is essential to ensure that a proper mist which will just moisten the books should be produced, and care must be taken that a stream of liquid droplets is not delivered from the orifice of the atomizer.

For the treatment of shelves the most convenient method to adopt is to use an insecticidal lacquer which can be brushed on to the shelves. One such lacquer which has proved effective and is being used in certain libraries and museums in tropical countries is the commercial preparation known as Insecta-Lac, which contains dieldrin as the active principle.[1] An alternative preparation is Xylamon-BN clear of which the active principle is chloronaphthalene.[2]

These lacquers should be thoroughly applied to the bookshelves, taking care to cover all areas such as cracks, crevices and the underside of the shelves, where insects may be expected to be found. They can either be applied with a soft brush, or sprayed from an atomizer or an aerosol press-button sprayer.

Although insecticidal lacquers or varnishes have been frequently recommended for the protection of leather book-bindings, care is necessary in their use. If injudiciously applied they may leave an unpleasant gloss on the leather, and those containing resins such as shellac and resin may produce acidic products on ageing which may have harmful effects on the leather.

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[1] Manufactured by Sorex Ltd., 105 Tonbridge Road, Maidstone, Kent (United Kingdom).

[2] Manufactured by Desowag-Deutsche Solvay A.G., 83-85 Bismarckstrasse, Düsseldorf (Federal Republic of Germany). See also Appendix of Chapter 4.

If it is considered necessary to protect books by the application of an insecticidal preparation, then wax preparations which have been properly formulated are to be preferred. The previously mentioned mixture (p. 271) of a microcrystalline and a polyethylene wax containing lauryl pentachlorophenate is one which can safely be used. Another preparation is the special wax known as Cire 212 (see p. 266). This wax preparation which contains both an insecticide and a fungicide is available in six colours—white, blue, maroon, black, red and green. The book-binding can be polished after application so that a pleasant appearance can be produced.

MOULD GROWTH (FUNGI)

Fungi or moulds will tend to grow on book covers and documents if the relative humidity of the surrounding air exceeds a level of about 70 per cent and the ambient temperature lies between 18° and 25°C, and the rate of growth will increase as the relative humidity rises. Such conditions are particularly liable to develop if there is poor air circulation so that pockets of humid stagnant air build up *(Plate 41)*. It is clear, therefore, that mould growth is liable to be a troublesome problem throughout the humid tropics and will demand more attention than is the case in more temperate regions where the trouble is only intermittent. Furthermore, the spores of these micro-organisms remain suspended in the air and can be carried over long distances until they find suitable conditions for their growth.

The growth of fungi (often also referred to as mildew) is revealed by the formation of whitish patches on book covers and documents, which later may become brownish or greenish in colour. It is a common experience to find that this mould growth occurs more readily on books which are tightly packed one against another; this is due to the fact that a thin, stagnant pocket of moist air is formed which favours mould growth. If books are loose on the shelves there will be adequate air circulation which will tend to reduce the formation of mildew.

In general, there are two principal methods which can be employed to retard the growth of fungi on archival material. These are: control of the relative humidity of the ambient air; and the application of suitable fungicides.

Control of relative humidity

The most obvious way to control the relative humidity is by air-conditioning, which aims to maintain an air temperature of 21°-25°C and a relative humidity of a little below 55 per cent. However, the installation and operation of full-scale conventional air-conditioning units for libraries is an expensive business, which may well be beyond the financial resources of small institutions. It is, therefore, necessary to consider alternative, cheaper methods for the partial control of humidity. One simple, but relatively effective, method which can be used to control the relative humidity in glass-fronted cases containing books and documents is to dry the air by installing a source of moderate heat in the bottom of the case so that the warmed air will rise up through the case. Another method is to install dehumidification units in the room. A simple home-made unit can be constructed by making holders out of wire-netting and filling these with the desicant, silica gel. In calculating the amount of silica gel required it may be assumed that 4 kg will be sufficient to dehumidify about 30 m^3 of air. When the silica gel is exhausted—indicated by a colour change from blue to pink—it can be reactivated by heating in an oven to 100°C. Another convenient dehumidifier is made by Rotaire Driers Ltd.[1] This is a rotatory

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[1] Broadway Chambers, Ilford, Essex (United Kingdom).

machine in which a special desiccant is incorporated in an absorption bed in the form of a drum having a honeycomb structure; this drum slowly rotates and the air to be dried is allowed to pass through it. There is also a special arrangement whereby the exhausted desiccant is automatically regenerated, so that the operation of the dehumidifier is continuous. The machine is produced in models of varying drying capacities, and, if the size of machine is chosen in proper relation to the volume of air to be dried, it will be possible to ensure steady and continuous conditions of relative humidity in a given space.

No matter what form of air-conditioning is employed, it will be necessary to have some method of recording the relative humidity, so that due warning can be given of any undesirable changes in the relative humidity in a controlled area. The best instrument for this purpose is a thermohydrograph which gives a continuous record of both relative humidity and temperature. Another well-known type of instrument is the hair hygrometer, which is available in many forms. The great value of these instruments is that they are cheap, they indicate the relative humidity directly on a scale, and they can be placed in suitable positions either in sealed cases or on bookshelves.

However, it should be borne in mind that these recording instruments will need periodic checking with a sling or whirling psychrometer. This is an instrument which depends upon first principles—the relative humidity being measured directly as a function of the difference between the temperature of a wet-bulb and a dry-bulb thermometer. The actual relative humidity is read from hygrometric tables provided with the instrument. This instrument also has the advantage that it can be used to take readings in different parts of a room; it is thus possible to detect the presence of any local air-pockets in which an undesirably high relative humidity may tend to build up. This instrument should in fact be regarded as an essential item of equipment for all those who are concerned with the care of archival material.

Further details about the essential factors involved in the control and measurement of relative humidity will be found in the publication *Climatology and Conservation in Museums* (Rome Centre, 1960). Yet another method of controlling the relative humidity in a room is to install an electric heater with a fan so that the temperature can be raised and the heated air circulated through the room. This method has actually been used in Ceylon to protect military stores from damage by mildew. In some parts of Ceylon conditions of 90 per cent relative humidity at 30°C persist during a considerable part of the year. By raising the temperature to 35°C the relative humidity can be reduced to 70 per cent.

Fungicides

If none of these methods of controlling the atmospheric relative humidity can be adopted for practical reasons, then the premises must be disinfected using fungicidal sprays, as described in Chapter 3. Infected archival material can also be treated directly. Two fungicides which can be safely applied to book covers or documents are dilute (approx. 5 per cent) solutions of pentachlorophenol or *ortho*-phenyl-phenol in ethyl alcohol or methylated spirits. These should be brushed thinly and allowed to dry thoroughly before the books or documents are replaced. An alternative technique which will give more permanent protection because the fungicide is less volatile is to impregnate tissue paper with the sodium salt of pentachlorophenol or *ortho*-phenylphenol and to use this impregnated paper for interleaving books and for wrapping round loose documents. This protective paper can be prepared by passing the tissue paper through a 10 per cent aqueous solution of the above salts, and then allowing it to dry. The sodium salt of pentachlorophenol is available commercially under the trade name Santobrite.[1] And the sodium salt of *ortho*-phenyl-phenol under the trade name of Topane WS.[2] This latter material is to be preferred, because it is easier to handle than the Santobrite (which is an irritating sternutatory powder) and also it is potentially more stable; under mildly alkaline conditions Santobrite is liable to decompose. The use of these protective papers provides a valuable means of protecting archival material against mould growth.

If archival material is found to have become infected by mould growth, measures must be taken immediately to deal with the outbreak. The infected material should be removed into the open air and the adherent mould growth brushed off. The material is then disinfected as described in Chapter 3.

PRACTICAL METHODS OF TREATMENT

Although the repair and restoration of damaged archival material (including books, and documents) may in many cases present problems which can only be successfully tackled by experts in this specialized field of work, there are a number of simple treatments which can safely be undertaken by conservators with an average degree of manual dexterity. It is, therefore, proposed to consider briefly certain simple operations which may be regarded as first-aid treatment. The usual problems which are likely to arise may be conveniently discussed under the following headings.

Brittle parchment

When parchment documents are kept under conditions that are too dry, say at 45 per cent relative humidity or lower, they tend to cockle and to become rather rigid. This condition can, however, be reversed, because it is possible to restore flexibility by exposing the parchment to moisture. The first thing to do is to find out if the ink itself is susceptible to moisture. This can be simply done by taking a piece of moist blotting paper and pressing it on the writing for a few minutes. If the ink shows no tendency to off-set on to the blotting paper, it may be assumed that the ink is not sensitive to moisture. The parchment document can then be conveniently relaxed by sandwiching it between several sheets of damp white blotting paper between two plates of glass and setting it aside for a few hours. If necessary, the procedure should be repeated until the parchment has regained its normal flexibility. It is important that no attempt should be made to speed up the process by making the blotting paper too damp; it is safer to use only moist blotting paper and to allow time for a slow process of humidification to take place. If the test described above shows that the ink is sensitive to water— as may be expected in the case of documents written in unfixed carbon ink—then the documents should not be exposed to the direct action of liquid water. The humidification of the parchment necessary to relax it can then be achieved by hanging the documents in a closed container above a dish of water. In this way the parchment will gradually take up water vapour and regain flexibility. It must be emphasized that no attempt should be made to straighten out or stretch parchment documents in a dry, brittle condition until they have been relaxed by one of the processes just described, otherwise serious damage may be caused; ink may easily flake off and, if illuminations are present, they may suffer in the same way *(Plate 42)*.

When the brittle parchment has been relaxed it can be flattened as follows. Place the document on a sheet of dry blotting paper which is resting on a sheet of glass, cover it with another sheet of dry blotting paper and then place over this a sheet of glass held down with a weight.

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[1] Manufactured by Monsanto Chemicals Ltd.

[2] Manufactured by Imperial Chemical Industries, Ltd.

It should be noted that documents of papyrus or birchbark which also become very brittle in the dry state can be relaxed by moisture in a manner similar to that used for parchment. Greater care will, however, be necessary in handling these materials, since they are not so robust as parchment, and tend to be very brittle in the dry condition.

Resizing of paper

When paper has been weakened by the decay of the sizing material as the result of the action of mould growth, it becomes limp and loses its characteristic quality. In this condition it is very easily damaged by careless handling and also readily stained. Paper in such condition will require to be resized; this can be most conveniently done by brushing on to the paper a good gelatine size, made by dissolving about 1.5 of good-quality gelatine in 1 litre of water, to which 0.5 g of a fungicide such as Topane WS is added. The best-quality gelatine is the photographic grade, which is entirely free from undesirable sulphur compounds. It is recommended that the size solution should be freshly made immediately before use, because this solution is a very good medium for mould growth, and it would be rather difficult to preserve it for any appreciable period of time in tropical countries without the addition of an undesirably high concentration of fungicide. In the case of thin paper, the size solution should be brushed lightly over the paper, but thick papers may be sized by immersing them in the size solution and then hanging them up to dry away from radiators and draughts.

If the paper is in such a condition that it becomes too weak to handle easily when wet, or if it is suspected that the ink may be sensitive to water, an alternative method of sizing can be adopted which avoids the use of an aqueous solution. The material to be used as the size is a modified form of nylon, known as methyl methoxynylon, which is soluble in methyl alcohol, ethyl alcohol or denatured spirit (industrial methylated spirits). This material is manufactured by Imperial Chemical Industries Ltd. under the trade name Maranyl soluble nylon C109/P—grade DV55 or Calaton C.B. For sizing, a 2 per cent solution in one of the above solvents is used, and this can either be sprayed or brushed on to the paper.

Repair of documents

Removal of creases. If the paper is not too badly creased, the creases should be lightly damped and ironed out with a warm iron. In the case of very bad creases, the document should be laid down on a glass plate and covered with a piece of moist blotting paper and set aside to dry slowly. The contraction of the paper against the glass as it dries should remove the creases.

Tears in documents. If the tears are extensive and if lacunae have to be made good by the insertion of patching paper, the treatment is best left to the expert. Simple tears can, however, be mended by the use of self-adhesive tapes, provided that the right kind of tape is chosen. When these tapes first became available they were of poor stability and there was a marked tendency for the plastic film to darken and shrink and for the adhesive to bleed out from under the film with disastrous results. Nowadays, however, there are self-adhesive tapes available which are much more permanent and which can, therefore, be used for repairing tears in documents. One such tape is Scotch Magic tape 810 made by the Minnesota Mining and Manufacturing Co. When applied this tape is virtually invisible because the plastic film has a mat finish.

As an alternative to the use of this self-adhesive tape one can use strips of tissue paper impregnated with polyvinyl acetate. This impregnated tissue paper is prepared as follows. Take 1 part of an emulsion of an internally plasticized polyvinyl acetate[1] such as Texicote VJC 555, dilute with 1 part of water and add 1 part of ethyl alcohol or denatured spirit and mix quickly. Lay a sheet of fine tissue paper on glass, spray or brush on the above emulsion, drain off any excess, and allow to dry on the glass. When thoroughly dry, immerse the glass with the sheet on it in water and in a few minutes the impregnated tissue can be peeled off and hung up to dry. To repair a document, tear off a suitable sized strip of this tissue, lay it on the area to be mended, cover it with a piece of silicone-impregnated release paper and press firmly with a warm iron. This softens the adhesive and attaches the tissue paper firmly to the document.

Cleaning

Dirty marks and stains on documents may in some cases be removed by the careful use of a fine, soft eraser or, preferably, powdered art gum which is sold commercially under the name Draft Clean Powder.[2] A small quantity of this material is sprinkled on the paper and rubbed over the dirty areas with the fingers tips. If this dry method of cleaning is not successful, it will be necessary to wash the paper. This can, of course, only be done if the ink is not sensitive to water. In the case of unfixed carbon inks, these should be first protected by carefully brushing on a 5 per cent solution of the above-mentioned soluble nylon. The document to be cleaned is then soaked in cold water for about an hour supported on a net made of nylon or terylene. It should then be floated on to a bath of very hot water and left until no more dirt comes off. The document should then be removed, allowed to dry and resized as described above.

In the case of stains which are not removed by washing in water, the use of organic solvents such as acetone, carbon tetrachloride, etc., may be tried. Tests should be carried out to ensure that the ink will not be affected, as some modern inks are readily soluble in such organic solvents.

Bleaching processes

Stains that cannot be removed by ordinary washing will require the use of bleaching agents. The most important general rule to observe in connexion with the use of bleaching agents is that they must be applied under strict control and for the minimum period of time necessary to achieve the desired results. Also, preliminary tests should be carried out to ensure that the bleaching agent has no deleterious effect on the ink.

Four bleaching processes which can be recommended as being most suitable are described below.

Ethereal solution of hydrogen peroxide. This is a mild bleaching agent which is suitable for local application for removal of stains. The solution is prepared as follows. Equal parts of hydrogen peroxide (20 vols. solution) and ether are shaken together in a glass-stoppered bottle, and the two immiscible layers are allowed to settle out. The ether layer on the top contains sufficient hydrogen peroxide for bleaching purposes. A swab of cotton wool on the end of a thin piece of wood is dipped into this top layer and applied to the stained area to be bleached.

Chloramine-T. This is a relatively mild bleaching agent which has a slow action. It is obtainable commercially in the form of a fine white powder moderately soluble in water. If it is kept in a well-stoppered bottle it is reasonably stable, but solutions are unstable and must be prepared immediately before use. These are readily prepared by dissolving 2 g of the powder in 100 cm^3 of water. Local stains, such as fox marks, may be treated by applying the solution with a camel-hair brush or a small swab of cotton wool. The action is mild and treatment should be repeated until a satisfactory result

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[1] See the Appendix, p. 311.

[2] Made by Keuffel and Esser Co.

is achieved. If the document is extensively stained, it can be immersed in a sufficient quantity of solution to cover it. The progress of the bleaching action is carefully observed, and when it has proceeded far enough, the document is removed and washed thoroughly in running water. It is then placed between two sheets of blotting paper to remove excess water, and allowed to dry between two more sheets of blotting paper under a sheet of glass.

Halazone. This material is chemically similar to chloramine-T and has a similar kind of mild bleaching action. It can be obtained conveniently in the form of tablets produced by Boots Chemicals Ltd., Nottingham (United Kingdom). A bleaching solution of suitable strength can be made up by dissolving 5 tablets in 100 cm^3 of water. The procedure for bleaching is similar to that used for chloramine-T.

Sodium chlorine (chlorine dioxide). This has an effective bleaching action which is more rapid than chloramine-T. Owing to the unpleasant smell of the chlorine dioxide gas which is the active bleaching agent the operation must be carried out in a fume cupboard. The bleaching solution is prepared by adding 25 cm^3 of formalin (40 per cent formaldehyde solution) to 1 litre of a 2 per cent aqueous solution of sodium chlorite in an enamel photographic tray of suitable size. The solution will become yellow after a few minutes owing to the formation of the chlorine dioxide. The document, supported on stiff nylon or terylene net, is immersed in the solution until the stains are removed. The time involved will depend upon the nature of the stains; usually a period of about 15 minutes is sufficient, but it can be safely prolonged in exceptional cases because chlorine dioxide is known to have no effect on cellulose. The actual concentration of the bleaching solution is not critical; it may be used either stronger or weaker as desired. When bleaching is finished, the document can be given a brief rinse in water and dried in the usual manner. Prolonged washing is not necessary because no traces of the bleaching agent remain in the paper.

Deacidification of paper

The presence of acid impurities in paper causes it to become brittle due to degradation of the cellulose. This insidious process of degradation will continue unless the paper is treated so as to remove the acid impurities. A simple practical method for the deacidification of brittle paper was devised by Barrow. The document is first immersed in a saturated solution of calcium hydroxide (lime water) which neutralizes the acid. Any excess of calcium hydroxide is removed by subsequent immersion of the document in a dilute (about 0.15 per cent) solution of calcium bicarbonate, which is prepared by passing carbon dioxide gas through a suspension of calcium carbonate in water. During immersion in these two solutions the documents must be supported on strong nylon or terylene net so that they can be safely handled. This aqueous method of deacidification cannot be used for documents written in ink which is sensitive to water. In such cases a non-aqueous method of deacidification must be used. For this purpose prepare a dilute solution of barium hydroxide in methyl alcohol by dissolving 18.6 g of crystalline barium hydroxide hydrate, $Ba(OH)_2.8H_2O$, in 1 litre of methyl alcohol. The document to be deacidified is then immersed in this solution which neutralizes the acid impurities. The treated documents are hung up to dry in the air, when atmospheric carbon dioxide converts any excess of barium hydroxide into barium carbonate which is deposited in the fibres of the paper. In connexion with the deterioration of paper caused by small amounts of acidic impurities, it should be noted that documents should only be mounted on good-quality non-acid board, otherwise there is the danger that acidic impurities in the board will migrate into the paper. Furthermore, this migration, which is known to occur even in a temperate climate, is more likely to occur under tropical conditions.

Lamination of fragile documents

This is a process for conferring mechanical strength on documents which are fragile and brittle due to degradation and consists in sandwiching the document between two sheets of a suitable transparent supporting material. The classical method of lamination is that of 'silking'—a process in which both sides of the document are covered with fine silk chiffon having an open weave that is attached by an adhesive such as starch paste or dextrin. Under tropical conditions this technique suffers from the disadvantage that the silk is liable to deteriorate in time and the adhesive is subject to mould growth unless conditions of storage of the documents are carefully controlled.

Methods of lamination using plastics films as the supporting material have been introduced recently which have advantages under tropical conditions, because the materials are more stable. Many of these techniques, such as the well-known process devised by Barrow, involve the use of complicated and expensive equipment, which can be carried out only in well equipped archival workshops. There is, however, one method of lamination which is of particular interest, as it can be carried out simply without the use of any expensive equipment. This process was developed in the National Archives of India. It is carried out as follows. The document is first covered on one side with a film of cellulose acetate, over which is placed a sheet of tissue paper. The surface is then rubbed over with a swab of cotton wool moistened with acetone, using slight manual pressure. The acetone has a solvent action on the cellulose acetate film, which is softened just enough to cause the tissue paper to adhere firmly to the document. The document, laminated on one side, is now turned over and the same process is repeated on the other side. This is an attractive process for the small archival workshop as it is so simple to carry out. However, attention must be drawn to two points. Acetone vapour is rather toxic, and a mixture of air and acetone vapour can become explosive. This means that this process of lamination must always be carried out in a well ventilated room in which no naked flames are present.

Another process which is also worth considering because it can be readily carried out with simple equipment has been developed by the Morane Plastic Co. Ltd. of Ashford, Middlesex (United Kingdom). This firm has produced a plastics film based on cellulose triacetate which has a semi-mat finish and is acceptable for the lamination of archival material. The process of lamination is carried out by placing the document between two sheets of the plastics film and applying pressure at about 80°C. Only slight pressure is required to bond the film securely to the document, and this can be easily achieved, using either an ordinary photographic dry-mounting press or an electrically heated hand iron which is passed over the plastics film.

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Lighting, air-conditioning, exhibition, storage, handling and packing

18

INTRODUCTION

The main causes of deterioration, and the methods used to repair damage due to unfavourable environmental conditions or incorrect earlier treatment have been described in previous chapters. The conservation of objects in a more direct sense of the term, their display, storage and handling in conditions likely to inhibit further deterioration is the subject of this chapter. At the same time, it cannot be assumed that all objects will have been treated by the methods described in this manual, since few museums have sufficient staff to keep their collections in perfect repair.

The conservation of objects in tropical museums does not differ in principle from conservation in temperate climates as far as the objects themselves are concerned. The difference lies in the fact that, in the absence of environmental control, light, temperature, humidity and other factors may be outside the normal safety margins for adequate preservation. Specifically, throughout the tropical zone the light is stronger, and in many parts a combination of high temperature and high humidity favours rapid mould growth.

From the point of view of preservation, the subjects of this chapter as listed in the heading are interrelated. The normal functions of the museum, primarily exhibition and secondly storage, with accessibility of secondary and research material, must be reconciled with the prevention of deterioration. Light is necessary if the objects are to be seen yet it may be a major source of deterioration (for which reason it will be considered in detail in the following pages). The comfort of the museum visitor must be assured, though it may conflict with the best conditions of conservation. The starting point, however, must be the safety of the objects, and it is necessary here to recapitulate some of the causes of deterioration and their relevance to tropical museum conditions.

The types of tropical climate have been dealt with in detail in Chapter 2. It will be sufficient in this context to typify two main climates, the hot-dry and the warm-humid, with an intermediate type in which dry and wet seasons alternate (the monsoon regions).

The basic causes of deterioration in museum objects, reflecting storage and exhibition conditions can be classified as follows:

1. Light.
2. Adverse atmospheric conditions:
   (a) contamination from solid particles;
   (b) relative humidity (i.e., when too high, too low or too variable). Temperature considered independently of relative humidity.
3. Biological factors: (a) vegetable growths; (b) insect pests.

LIGHT AND ITS EFFECTS ON SENSITIVE CULTURAL PROPERTY

This will be considered first, since (apart from the promotion or discouragement of some factors of biological decay) light can, to a large extent, be regarded as independent of other factors. It can be accepted that the effect of light is in general more marked the greater the relative humidity, and this is particularly the case in some specific examples of dyed textiles. There is insufficient evidence, however, so far, to justify lowering the relative humidity in particular cases to reduce light damage.

The types of material, forming parts of museum objects, that are subject to damage by light are: (a) pigments and dyestuffs (including inks); (b) textile fibres, natural and artificial; (c) paper and similar cellulose materials; (d) thin films of organic materials, such as proteins, resins and gums (both natural and artificial) used as paint vehicles, varnishes and adhesives; (e) various other organic materials.

Many inorganic materials are unaffected by light, e.g., metals and minerals, including jewellery, ceramics and the different forms of stone. Glass (including fired and painted specimens) and vitreous enamel can be included in this category, though there have been reports, from time to time, of slight changes in colour attributable to light.

Pigments and dyestuffs

Water-colours. The fading of pigments occurs most noticeably in thin-layer paintings such as water-colours. In such cases the pigment particles are often scattered in a single layer with very little binding medium. The fading of a single layer of pigment particles might not be observed in an oil painting, but it is very noticeable in a water-colour. Also, since the protective binding medium is so thin the penetration of radiation and possibly of oxygen is much greater. Some of the pigments which have always been popular with water-colour artists such as van dyke brown, sepia, indigo, carmine and gamboge are particularly vulnerable and fade rapidly when exposed. If a water-colour painting fades uniformly over its surface the loss in brilliancy would be deplorable but the essential aesthetic quality of the painting could still be appreciated. Unfortunately, however, colours fade selectively, some disappearing while others remain unchanged, which means that the colour relationships of a painting can be grossly distorted. Most water-colour artists use mixtures of various colours for particular effects. With exposure the fugitive components of a mixture will fade, leaving a colour completely different from the original, and the usual effect of these changes is to leave the painting harsher and less subtle. It has to be accepted that water-colour paintings are 'consumable goods'; from a conservation point of view they should not be exhibited unless they are invulnerable to light. Those paintings such as gouache and oriental miniatures in which part of the control of tonal values is by admixture of the colours with white will normally be less sensitive than water-colours composed of thin washes; with some exceptional pigment mixtures, however, the reverse may be the case.

Oil paintings. In oil paintings the protection of the pigment by the medium, and possibly also the complex chemical interaction of pigment and medium, in some cases leads to a much greater resistance to the effects of light. Fading and colour changes are not strikingly obvious, and it is only when parts of a painting have been covered over (by repaint or by the rebate of a frame) for a long period, that comparisons can be made. Changes are then seen to be considerable in transparent glazes of pigments of the 'lake' type, in which vegetable dyestuffs such as carmine, madder and quercitron are mordanted on aluminium hydroxide or chalk. The change in the transparent copper resinate from a bright emerald green to a dark opaque chocolate brown is probably the most aesthetically damaging form of deterioration in the entire museum field; this material was extensively used in Europe from the late mediaeval period until the eighteenth century.

Dyes in textiles. The fading of the dyestuffs of textiles such as embroideries and tapestries can easily be seen by comparing the front with the unexposed back. Fading of costumes is revealed by comparing the prominent parts of folds, pleats and lapels with the inward parts and by examining unexposed material under seams. The specialist curator of costumes is probably the most light-conscious of museum officials, since he will certainly have encountered cases in which the almost unused costumes of the eighteenth century have been stored in dark cupboards until presented to the museum by the owner's descendants; fading under museum lighting may then be so rapid that it will be apparent within months of exhibition.

Woods. Some woods bleach under the action of light, e.g., mahogany and walnut, some 'yellow', e.g., oak, rosewood and sycamore, and some darken, e.g., teak. Woods such as boxwood, holly, maple, spruce, beech, birch, elm, pine and sycamore are substantially protected, however, by merely eliminating the ultra-violet component.

Non-European woods will be similarly variable in their response to light. Since there are materials whose response to light is much greater than that of wood, its slight alteration does not arouse much attention. However, if the essential aesthetic or ethnographical interest of a wooden object lies in the particular features of its natural colour or dye, light is a factor to be taken into account.

Natural history and ethnographical exhibits. The materials and dyestuffs of natural history exhibits, such as hair and feathers, and botanical and entomological materials, together with the ethnographical objects which include them, must be considered. In the absence of specific data the dyestuffs must always be regarded as fugitive and these materials must be placed in the top category of light vulnerability.

Textile fibres

Cellulose and protein molecules, which are the main constituents of the vegetable and animal fibres of cotton, linen, wool and silk, are colourless and not rapidly affected by light. These fibres are never pure, however, since they contain dyes, mordants, sizes, pigments and dirt. Under the influence of light a complex series of reactions occurs, resulting in the weakening or tendering of the fibres by the breaking of the long molecules to which they owe their strength. Also, coloured decomposition products may stain the fibres. This degradation increases the sensitivity of cellulose fibres to damage by the weakly alkaline solutions often used for washing.

Tendering is particularly noticeable in textiles in which wool and silk are combined. The wool is generally found to be in a reasonable state of preservation, whereas the silk will often be so decayed that it falls to a powder when it is touched. The decay of silk flags and banners under the action of light is a current international problem. Materials composed of artificial fibres are now present in museums, both as exhibits and as visible structurally necessary parts of restored objects, especially in costumes, and in the material of military museums and also in special displays such as dioramas. It should be noted that some of these artificial materials are more or less light-sensitive. The cellulose range of synthetics have similar characteristics to cotton. Some materials such as nylons, polyvinyl chloride, polyvinylidene chloride, are known to be light sensitive.

Paper and other cellulose material in sheet form

The embrittlement and discoloration of paper is closely similar to that of cotton. Stability decreases from new rag paper to sulphite paper and finally newsprint. A single morning's exposure to sunlight for instance, even in temperate climates, will visibly discolour a newspaper.

Paint media, varnishes and adhesives

The effect of light upon protein media such as egg and glue is not sufficiently striking for the practical conservator to regard it as a problem at present. Light plays a part in the chemistry of the drying oils and almost certainly contributes to their final decay, but these are matters for further research. It is only in the field of natural and synthetic resin varnishes that the deleterious effects are obtrusive. The natural resin varnishes used on paintings and furniture are all subject to discoloration. In the case of shellac, used in furniture probably earlier than the nineteenth century, but certainly extensively from then onwards, the discoloration is not very significant. The hard resins dissolved in oil and the spirit-soluble resins are all more or less unstable and the effect of light is not only to discolour them, but also to accelerate deterioration. The discoloration of furniture varnishes (other than shellac) has not been extensively investigated and little is known about it. It is believed that oriental lacquers may be 'moderately' sensitive to light. European lacquers which include 'japanning' and *vernis martin* have entirely different media from oriental lacquers. These may be shellac (or other spirit-soluble resins) or combinations of oils and fossil resins and are therefore covered by the above comments. The pigments of both oriental and European lacquers are generally but not always permanent.

In painting, the discoloration is of vital importance, since beyond a certain point the varnish becomes too coloured to be tolerable and must be removed—a task requiring skill, and subject to some risk to the painting. The vast majority of paintings have been varnished with mastic or dammar, sometimes mixed with drying oils. These can be seen clearly to have yellowed within five years of application. It is important to protect these varnishes from the effects of strong light, not because they are intrinsically valuable or satisfactory as varnishes, but to defer as long as possible the moment when they are so discoloured as to demand removal. Of the synthetic resin varnishes now used as substitutes, all are more light stable than the natural resins, but only one, polyvinyl acetate, is almost completely so. Polyvinyl acetate cannot be used invariably for certain technical reasons. The problem of protection against the effects of light is therefore still present, even when synthetic resin varnishes are used.

Other organic materials

The light stability of other materials such as leather does not appear to have been studied systematically under museum conditions, and in the case of leather particularly, observation is complicated by the large variety of tanning and dyeing treatments. The dyes may of course be subject to fading.

In the absence of positive information, it can be generally assumed that any material of biological origin is likely to be damaged by light. The exceptions to this rule are few.

METHODS OF REDUCING LIGHT DAMAGE

There are two useful ways of reducing light damage. These are, first, a reduction in the actual amount of light falling on the object to the minimum required for efficient viewing and lively museum display, and secondly, a control of the spectral quality of the light to eliminate the more harmful rays of the spectrum without unduly distorting the colour rendering of the object. Considering the second factor, the shorter wave-lengths of the spectrum (towards the blue end) are normally the more harmful. Generally speaking, therefore, the warmer light sources are to be preferred. The invisible ultra-violet component of sunlight, daylight and fluoresent lighting is relatively the most harmful of all, and being useless for viewing should be eliminated. The methods of achieving this are discussed in the Appendix.[1] In both temperate and tropical conditions the easiest method of securing control of both quantity and quality of light is by eliminating daylight and using artificial lighting in those parts of the museum in which vulnerable objects are exhibited. This introduces design problems, and air-conditioning would be desirable in the tropics.

The recommended maximum illumination values are as follows:

Objects insensitive to light, such as metal, stone, glass and ceramics, stained glass, jewellery, enamel, bones:
  Unlimited illumination, though in practice subject to display and radiant heat considerations.
Objects moderately sensitive to light, but in which colour changes are not of great importance, e.g., wood:
  Unlimited illumination, as above.
Oil and tempera painting, undyed leather, horn, oriental lacquer:
  Maximum illumination 150 lux.
Objects specially sensitive to light, such as textiles, costumes, water-colours, tapestries, prints and drawings, manuscripts, miniatures, paintings in distemper media, wallpapers, gouache, dyed leather; most natural history exhibits, including botanical specimens, such as coloured fur and feathers:
  Maximum illumination 50 lux.

From the visitor's point of view these low levels of lighting can be unpleasant and monotonous. Careful planning is needed, especially in the tropics where daylight levels can greatly exceed those in temperate regions, to ensure that the transition from brightly lighted areas to those subject to control is arranged to take account of the adaptation properties of the eye.

In situations where it is not possible to remove daylight completely from rooms with vulnerable objects, the standard methods employed in tropical architecture for eliminating both sun and glare from the sky become particularly important. The sun is a problem with both humid and dry tropical climates and the orientation of the building and the siting of windows will have to be considered from this point of view. Needless to say, direct sunlight must be entirely excluded from rooms with vulnerable objects by the use on north and south sides of overhanging eaves or horizontal projections, and on east and west sides by vertical shades. In the humid tropics, cloud produces bright diffused radiation from the sky and sun-breakers are only partially effective. It is important in these circumstances to cut off a direct view of the sky from the interior, both to reduce the amount of light on the object and to eliminate fenestration glare from the museum visitor's point of view. This can be done with louvres and blinds as in temperate regions. Reflections from nearby buildings can be controlled by choice of paints on facing exterior walls. In the dry tropics windows are kept to a minimum for general comfort and, with the sun obscured by appropriate design, the light from the clear sky has a lower brightness than in the humid tropics and is more easily controlled. Here again, control of reflections from the nearby buildings and from the ground is important. Basically, control (i.e., reduction) of the amount of light falling on the objects is the same in both climates. The important principle, however, in museum practice, which distinguishes it from normal practice in tropical lighting is that, in the latter, the aim of architectural design is to secure the comfort of the inhabitants by eliminating solar heat-gain and reducing glare, though

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[1] See p. 324

the amount of light properly distributed can be high (at least 1,000 lux). Museum practice requires comfort and absence of glare *but also* a reduction of light level to 50-150 lux. In the absence of air-conditioning, the requirements for conservation are merely an intensification of the normal procedures. However, in the humid zone, the ventilation system must be carefully designed both to ensure the comfort of visitors during opening hours and also to discourage mould growth at all times.

ADVERSE ATMOSPHERIC CONDITIONS

Atmospheric contamination

The principal agent of decay, oxygen, is an essential constituent of the atmosphere and must be accepted. Water vapour, which plays an essential part in most processes of deterioration, is also inevitably present. It should be noted that the deleterious effect of the gaseous and solid atmospheric contaminants may be somewhat reduced, at any rate in dyed textiles, by a reduction in relative humidity. These contaminants are therefore less important in hot-dry tropics than in the warm-humid zones. The effect of contaminants is at its greatest when the air is at saturation point and condensation of moisture occurs on the objects. The proportions of solid and gaseous contaminants vary according to weather and proximity to towns, industrial installations and the sea. Sulphur dioxide (with its oxidation product, sulphuric acid) is one of the most potent sources of damage. Chlorides, partly from industrial atmospheres but mainly from the sea, may be an additional major cause of the deterioration of some material. Solid particles in the atmosphere may contain tarry material and free carbon, together with salts and siliceous material. The effect of a deposit of dust on an object is twofold. First, if there are active agents of deterioration present, a deposit, especially in the presence of moisture, can act as an actively corrosive poultice. Secondly, the dirt may spoil the appearance of an object so much that the layer has to be removed, a process requiring special skills to avoid damage.

Almost all museum objects can be damaged by atmospheric impurities. It is convenient to divide their component materials into three categories, namely, materials of organic origin, metals, and stone-like materials of siliceous and calcareous composition.

Material of organic origin. This category includes animal skin products such as leather, parchment and fur; textile fibres, cellulosic and proteinic, such as wool, silk, cotton and linen, together with the various artificial fibres; wood and other cellulosic materials of vegetable origin such as basketry; artefacts in which cellulose fibres such as paper products form the support; bone, ivory and horn.

All these materials are likely to be soiled and stained by solid particles of carbon, tarry matter and other solid contaminants. Sand can damage textiles and paper, especially when they are handled. In coastal regions hygroscopic saline particles attract moisture which can not only accelerate decay but also attract further deposits of grime.

Probably the worse atmospheric contaminants for this group of materials are sulphurous and sulphuric acids resulting from the combustion of fuels and from other industrial processes. The effects are particularly severe with cellulosic materials such as paper, cotton and linen and with leather. Protein textiles such as wool and silk are somewhat less affected, though the dyestuffs of all four categories of textile, depending on their composition, may be slightly or seriously faded. The loss of strength of cotton fibres as a result of contamination from sulphur acids may in some circumstances be of the same order as the loss of strength due to light. There is a close correlation between the loss of strength of paper and its acidity resulting from sulphuric acid contamination.

Metals. Oxygen, sulphur gases and saline impurities in the atmosphere, in the presence of moisture on metals, particularly alloys of iron and copper, have powerful corrosive effects. The higher the humidity the greater the corrosive effect.

Siliceous and calcareous materials. As with textiles, the chief hazards here are the deposition of dust containing carbon and tarry matter, combined with a gradual attack of the surfaces by sulphur acids with the conversion of the calcium carbonate into calcium sulphate. The effect is, of course, not as severe under indoor museum conditions as with exterior stone but the damage may range from unpleasant staining resulting from the combined effects of carbon deposition and chemical action to the acceleration of incipient scaling.

Control of contamination. Where it is possible to install a filtration system (see under 'Air-Conditioning' below) most of the contaminants can be reduced or eliminated. Usually the finer particles cannot be completely eliminated by ordinary physical filtration systems and a residual proportion of particles varying in size up to 5 microns remains. Sulphur gases can be removed almost completely by washing the incoming air, especially if slightly alkaline water is used. This is normally only praticable if the air-conditioning system incorporates refrigeration. Reduction in the contents of sulphur gases down to 30 microgramme/m^3 could be regarded as satisfactory.

Relative humidity

Physico-chemical effects. Whilst water vapour or actual moisture plays an important part in most chemical processes of deterioration, its effect on the dimensional stability and physical properties of some materials is even more important. The materials concerned are those of organic origin and of fibrous or cellular structure, such as paper, parchment, papyrus, textile fibres, wood, ivory and leather. These more or less hygroscopic materials swell and shrink with an increase or decrease in the relative humidity of the atmosphere and may change in strength and flexibility.

Wood and ivory, especially in composite structures such as furniture, may warp and crack if the relative humidity is raised or lowered. Normally the wood of furniture is seasoned so that its moisture content is in equilibrium with a particular humidity range. Changes to very much lower or higher values (particularly the former) will introduce severe strains leading to warping and cracking. With composite layers, as in marquetry or veneered furniture, unequal strains will lead to pronounced warping and loosening of the layers. There is a similar situation with paintings on wood, and with lacquer and gesso on furniture, where the applied layers cannot follow the expansion, contraction and distortion of the wood as the relative humidity changes, and cleavages are likely to occur. These effects are likely to be most marked in a hot-dry climate where there will not only be pronounced shrinkage of wood, but also embrittlement of adhesives and such material as paint films, decayed paper, bookbindings and textiles. As an additional hazard there will be a pronounced diurnal swing of relative humidity owing to changes in temperature which can vary from 55 °C by day to 10°C by night.

In warm-damp (including monsoon) climates some distortion is possible in wooden objects seasoned in climates of lower average relative humidity. Failure of the traditional aqueous glues may occur, together with some reduction in strength of glue-gesso layers, thick aqueous paints and textile fibres. Wooden objects acclimatized to warm-humid conditions without serious apparent deterioration may be subject to special risk when transported to drier climates, apart from the shock of change in humidity conditions, since some permanent compression-shrinkage effects may be present.

Recommended levels of relative humidity. Recommended values of relative humidity, assuming that control by some form of air-conditioning is possible, depend considerably upon the composition, condition and construction of the objects. The values recommended for mixed collections in temperate climates, i.e., averages in the region of 50-60 per cent with a variation of about ± 3 per cent can only be taken as a general guide. There is a clear upper limit of about 65 per cent above which mould growth is possible (see Chapter 3) There is no fixed natural lower limit. For wooden objects of a composite nature, one of the determining factors would be the moisture content of the wood when the objects were constructed. Wood seasoned to a high moisture content for use in the humid tropics would shrink and crack in conditions of moderately low humidity which furniture seasoned for a temperate climate might easily tolerate. Taking such exceptions into account, a lower limit of about 40 per cent might be regarded as reasonable.

Effects of temperature

Temperature can hardly be considered independently of humidity. Thermal expansion and contraction are negligible factors in conservation. Some materials of art objects soften at the higher temperatures, but this has never been a significant problem. Mould growths have optimum temperatures for maximum activity, but humidity is usually a predominating factor. The well-known chemical axiom that reaction rate is doubled with every 10°C rise in temperature does *not* apply, since in museums chemical change is normally started, not by heat, but by light or by the arrival of some active chemical. The common assumption that deterioration proceeds more rapidly in hot countries cannot, on present knowledge, be justified on the grounds of temperature alone.

AIR-CONDITIONING

The problems defined above can best be solved by some form of control of air temperature, humidity, and purity, but this is expensive, and methods of planning to reduce the cost while still achieving conditions beneficial to the objects must be considered. However, the initial and maintenance costs of air-conditioning are offset by the reduction both in the high professional expenses of restoration and in losses on the capital value of the objects.

Refrigeration

In the humid tropics refrigeration is an essential part of the air-conditioning equipment. In exceptional cases in the dry tropics this can be dispensed with by using water sprays which increase the relative humidity. For example in Baghdad the period of lowest relative humidity (15-17 per cent) coincides with the period of highest temperature (32°-34°C) and such a system would be practicable. Generally, however, refrigeration is essential. The museum problem is unique, in that the comfort of the visitors, though important, is secondary to the specific requirements for the preservation of the objects. Moreover, apart from resident staff and research workers, visitors are present only for an hour or two. Also the building is closed to visitors for two-thirds of the day, though during the opening hours the number of visitors present may fluctuate considerably as when, for example, special exhibitions are held.

Fortunately, the design problems for

comfort do not clash seriously with those for conservation. In the tropics the interior temperature must be higher than in the temperate regions, and an important factor is the 'effective temperature'. This is an experimentally determined subjective index of the sensation of temperature as controlled by the actual temperature (dry bulb), the relative humidity and the air flow. In the warm-humid tropics the effective temperature should be about 22°C, though up to 24°C can be tolerated owing to the transient nature of museum occupancy. With proper air distribution without draughts an effective temperature of 21°C would correspond to 24°C dry bulb and 55 per cent relative humidity. In the dry tropics a similar figure would be suitable, with possibly a lower humidity of about 45 per cent. In particular locations, costs can be reduced by departing somewhat from these figures, always bearing in mind the technical background of preservation as described above. The same is true of the limits of tolerance of variation in temperature and humidity permissible.

Filtration

Filtration and the degree of recirculation of air depend respectively on local atmospheric conditions and on the average number of visitors. Electrostatic precipitation, the most efficient method of filtration, must be entirely avoided for museums, owing to the production of ozone, a powerfully damaging gas for many museum materials. For this reason, fabric or oil filters are recommended. In the dry tropics, unless special dust separators are incorporated, the filters will clog when dust storms occur. This is not a serious problem in a museum where the percentage of recirculated air will be high.

The elimination of sulphur gases, where required, in industrial areas can be achieved by incorporating a water spray chamber, preferably with slightly alkaline water or by the use of activated carbon. Periodic checks of sulphur dioxide content are advisable.

Design elements

The question of the design of buildings, their insulation, orientation and shape, to reduce the heat gain and air-conditioning load is outside the scope of these notes. Double glazing of windows with external shading and internal blinds, insulation of walls and, especially, roofs will be adopted in appropriate circumstances whether air-conditioning is used or not.

It is worth noting that, for a given ground area, a compact structure without wings or courtyard, and with inner rooms artificially lit, suits the requirements both of air-conditioning economy and of the conservation of light-sensitive objects.

Unit air-conditioning plants for single rooms are being progressively improved in various countries and may be the solution for small museums in the humid tropics where the chief conservation hazard is mould growth which accompanies high relative humidity.

Absence of air-conditioning

In the absence of air-conditioning, conditions are more favourable to conservation in the dry tropics than in the humid regions. Provided that the interior light is kept at a low level, the chief hazards are dust and sand, which can be kept down by control of apertures and general cleaning. Exhibition under glass in cases and frames may be found to be generally necessary. The desiccation of materials is unavoidable in the worst conditions, and wooden objects seasoned for temperature climates will certainly suffer damage. Portable humidifiers should be used in rooms in which these objects are concentrated. Humidification, a much less expensive process than dehumidification, is always worth attempting, even if close control is not possible.

In the humid tropics the chief hazard in the absence of air-conditioning is mould growth. This can only be kept under control by adequate ventilation, regular inspection and the use of fungicides. Control is easier to achieve with objects on display than with those in storage. For comfort in the humid tropics an adequate air flow is essential, and objects on open display will therefore normally receive adequate ventilation. If maintenance is adequate, exhibition cases can be equipped with a desiccant such as silica gel. In storage, however, especially of prints, drawings, etc., and textiles, more vigilance is needed. First, objects should not be packed so closely that adequate ventilation is impeded, and particularly should not be pressed against each other. Shelves and racks should be designed to allow the free flow of air and to avoid pockets of stationary air. Artificial lighting should be installed, and since it will be used only intermittently it can be of a much higher level than the permitted maximum for exhibition, to enable a more searching inspection to be made. Secondly, regular inspection of every object should be a routine. Thirdly, in severe conditions treatment of objects as a prophylactic measure as well as after attack may be carried out. Details of such treatment and of the use of fumigants for insect pests have been given in earlier chapters.

PACKING FOR TRANSPORT

Here we shall discuss only matters of environmental conservation during transport, and not protection against physical damage[1] which is a problem common to all countries and climates. Considerable progress towards the basic principles of the packaging of museum objects has been made. The transport of objects from one continent to another has, unfortunately, increased considerably in recent years and will probably continue. The problem is therefore that of the packing and transport of objects under all conceivable types and combinations of climatic conditions. In so far as the matter is specifically related to tropical conditions, we shall have to consider primarily movement from temperate regions to hot-dry or warm-humid zones, and the reverse, or movement from one tropical zone to another.

Dangers due to variations in humidity

The most important hazard from the point of view of conservation lies in the changes in relative humidity in the package as a result of movement through or into regions in which temperature and humidity differ from those in which the object is first packed. It has been stated above that objects of organic origin should generally be retained in an atmosphere of reasonably constant relative humidity and that this should be below 65 per cent to avoid mould growth but above 40 per cent to avoid embrittlement of some objects. In addition, some inorganic materials, e.g., metal and stone, are liable in certain circumstances to be damaged by a high relative humidity. Thus it may be said in general that the humidity should be maintained at some point within the above range, with as little variation as possible.

Packing cases and materials

A closed empty case will normally be intermediate between two extremes; a well ventilated case will follow variations in external relative humidity with little time lag, whereas in a completely sealed case made of non-absorbent material, such as metal, the relative humidity will vary with the external *temperature!* A rise in temperature will produce a drop in the relative humidity and a fall in temperature will lead to a rise in relative humidity. The latter will lead to

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[1] This subject is dealt with at some length in the Unesco publication *Temporary and Travelling Exhibitions*, Paris, 1963 (Museums and Monuments series, No. X).

condensation if it reaches 100 per cent. For example, if a package containing no water-absorbent material is sealed at 25°C and 70 per cent relative humidity (not an unusual situation for the humid tropics) it would require a fall in temperature of only 5°C to produce condensation. Material of organic origin enclosed in such a package would be susceptible to mould growth from the start, and increasingly so as the temperature fell and the humidity rose.

A ventilated case has obvious disadvantages since, even if precautions are taken against the ingress of contaminants, the object is not protected from relative humidity changes in transit. On the other hand, a sealed case (or a sealed bag of metal foil or moisture-resistant plastics) may lead to condensation or create conditions favourable for mould growth.

This problem can be solved by using a sealed case, for example of wood with an inner seal of polythene, but with an interior ballast of moisture-absorbent material such as fibre board. Any fibrous cellulosic material which can be close packed but which presents a large surface area within its interstices, such as cotton, hessian, etc., may be used. Its temperature-insulating properties are also valuable. Other buffering agents are under investigation. In a closed case, using quantities of packing wood (Excelsior) greater than about 100 g per 100 litres of air, the change in relative humidity will not exceed about one-third of the temperature change in Centigrade degrees and will be in the same direction. For example, if the temperature falls from 30° to 20°C on leaving the tropics the relative humidity will fall about 3 per cent and vice versa.

Obviously if the object itself consists of hygroscopic material such as wood or textile fabrics, these will contribute to the buffering action.

Precautions in packing

The above considerations provide a basis for transport to and through any climate provided that the passage is not prolonged, since moisture barriers such as polythene are not complete seals, and even 'complete' seals are usually subject to leakage. There are, however, some subsidiary factors of importance in tropical countries. The package material and contents must be sterilized at the time of packing, preferably by fumigation with such materials as methyl bromide or ethylene oxide, and should in addition be sprayed with insecticides and mould deterrents (usually the chlorinated hydrocarbons) (see above, Chapters 3 and 4). Packing should take place in conditions which bear reference to the future history of the consignment, so that there is no sudden change in conditions on arrival, a particularly important consideration for wooden objects. In warm-humid climates this may be difficult to achieve unless an air-conditioned room can be obtained for packing. If such a room is available objects and packing materials should be retained at the chosen relative humidity for some time before packing. In monsoon regions packing should be done during the dry season if possible.

Synthetic materials used in the conservation of cultural property

Appendix

Originally published in 1963 by the
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The text has been revised and brought up
to date by Mr. Toracca and is reprinted
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At the General Conference of the International Council of Museums (ICOM) held in Stockholm in 1959, it was felt that the techniques of preserving and restoring works of art were in process of being profoundly affected by the use of synthetic materials that are becoming increasingly available today and it was agreed that special reports should be prepared on this subject by Messrs. G. Thomson (National Gallery, London) and A. E. Werner (British Museum, London).

Mr. R. L. Feller (Mellon Institute, Pittsburgh) has since co-operated, forming a working party under the chairmanship of Dr. A. Van Schendel (Rijksmuseum, Amsterdam) so that in the intervening period those studies have been kept up to date.

The present communication forms the substance of the latest report to the joint meeting of the ICOM Committee of Museum Laboratories and the ICOM Commission for the Care of Paintings and is published by the Rome Centre partly with the help of a grant from ICOM which is gratefully acknowledged.

Rome, September 1963

Introduction

GENERAL

During the past few decades, advances in organic chemistry have resulted in the appearance on the market of a wide range of new synthetic materials, commonly referred to as plastics, certain of which are of potential value in conservation. The enterprising conservator chooses from among all the materials available those best suited to his needs, and it is the purpose of this report to survey the various kinds of synthetic materials which have already been used in conservation or appear to have proved their worth.

This report will consider substances that are intended to remain in contact with museum objects over long periods of time from one occasion for conservation to the next. Materials such as picture varnishes, adhesives, consolidants, and permanent supports are in mind, in contrast to materials that might be used for the temporary support or treatment of an object.

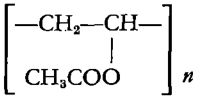
It is first of all necessary to realize that these synthetic materials are not to be regarded as mere substitutes for materials of natural origin: many of the synthetics possess a combination of physical and chemical properties which is not to be found in any natural material. Thus, for example, there is now available a wide range of wax-like materials (which, as a class, might conveniently be referred to as ceramers) that show a combination of properties not known in any of the naturally occurring waxes. For this reason, synthetic materials afford the opportunity to develop improved and more reliable methods of conservation.

However, the number of synthetic materials now at the disposal of the enquiring conservator is so large that he may well become confused in his attempt to select the most suitable type for his particular needs, and be bewildered by the large number of trade names used to describe materials of essentially the same type. It cannot, therefore, be too strongly emphasized that no synthetic material should be used in conservation unless its properties are reasonably well known. This implies that the composition of a synthetic material—as indeed also of a natural material—must be known in all essential details so that its permanence and properties can be accurately assessed.

It is not sufficient to rely on the class of polymer, e.g., polyacrylate, polyvinyl, or even on the type, e.g., polymethyl methacrylate, because other unspecified ingredients may have been added to some products which may have potentially undesirable properties from the point of view of their use in conservation. The position in this respect is improving, however, and most manufacturers now provide sufficient details as to composition, so that products of proven quality can be selected.

CHEMICAL STRUCTURE OF SYNTHETIC RESINS

From the chemical point of view, most of the synthetic materials described in this report have a so-called *polymeric* structure, i.e., they are made up of long chains or networks of simple repeating units (monomers). Thus, for example, in the case of polyvinyl acetate—one of the simplest of such polymers—the repeating unit consists of molecules of vinyl acetate ($CH_3COO\,CH = CH_2$) which are joined together in a long chain, which may contain as many as 20,000 such units. This is expressed by writing the essential chemical formula for polyvinyl acetate as:



$$\left[\begin{array}{l}-CH_2-\underset{\displaystyle CH_3COO}{\underset{|}{CH}}-\end{array}\right]_n$$

where *n* specifies the number of monomer units in the chain. The physical properties of individual polymers will depend upon the average number of monomer units in the chain; this is often designated as the *degree of polymerization (DP = n).*

Synthetic resins may be divided into two main groups, namely, the thermoplastic and the thermosetting, which are fundamentally different in structure. In the case of *thermoplastics,* the monomeric units are linked together so as to form two-dimensional linear chains, with the result that the material is soluble in an appropriate solvent or range of solvents and remains permanently fusible.

Thermosetting resins, on the other hand, are characterized by the fact that the monomeric units are linked together by chemical bonds to form a three-dimensional network; such materials are infusible and insoluble in all solvents, although they may swell to form a gel with certain solvents, or be chemically broken down by certain reagents to form soluble products. Thermosetting resins were originally so called because they were only formed under the influence of heat as the result of a chemical change. It should, however, be noted that some of the new resins in this category can be produced without the application of heat; these are usually referred to as *cold-setting resins* since their production is induced by the use of special hardeners and catalysts at room temperature. Also, it should be noted in this connexion that, under certain conditions, linear thermoplastic resins may be converted into infusible insoluble resins. The phenomenon is referred to as cross-linking, because chemical bonds or links are formed between the linear chains, which are thereby converted into insoluble three-dimensional networks.

PLASTICIZERS

Plasticizers are materials which are often added to synthetic resins in order to modify their physical properties, and in particular to confer added flexibility to a resin which may be too brittle.

There are fundamentally two types of plasticizers. One classification calls them *primary* and *secondary.* The primary plasticizer is a true solvent for the resinous material being plasticized. The secondary plasticizers are only partially miscible with the original substance and require a third component to make them compatible. Another method of classifying plasticizers is to designate them as *volatile* and *non-volatile.*

A plasticizer must remain in the film long enough to keep it flexible throughout a useful lifetime. In many industrial applications, a relatively volatile material such as dioctyl phthalate will remain in the film for a sufficient length of time to be of practical value. A limitation to the use of such materials in conservation is that the relatively volatile plasticizers eventually leave the film either by evaporation or migration. The use of volatile plasticizers in picture varnishes, for example, is avoided because of the possibility that the plasticizer might migrate into the paint, softening or otherwise altering its properties.

The non-volatile polymeric plasticizers are generally in the molecular weight range 850 to 8000. Their greatest limitation is their low compatibility. Such large molecules are not easily miscible with materials. The third component necessary for miscibility may be relatively volatile. Incompatible materials often separate: a secondary plasticizer often oozes out of a coating in time.

Bearing the general term in mind, one can see that 'plasticizers' are certainly necessary and traditionally used in conservation. Gum elemi, Venice turpentine and honey perhaps might be considered to be plasticizers. The use of the modern plasticizers described above has not, however, been widely employed in conservation. The reasons for avoiding the volatile type of plasticizer are clear. But the possibility of applying certain of the polymeric types remains an intriguing one, and requires further study.

Certain polymers are said to be 'internally plasticized'. This is not a particularly suitable designation, but it implies that the flexibility of the resinous material has been built into it or is inherent in its particular molecular structure. The flexibility that it possesses will not vary, because there is no added component which might evaporate or change with age. Many of the newer materials that have been used in conservation are of this type, for it is considered that the flexibility will last much longer if it is an inherent property and not one that depends on additives.

AVAILABILITY OF SYNTHETIC RESINS

The forms under which synthetic resins are available for use in conservation may be conveniently considered under the following headings.

Solutions. All thermoplastic resins can be prepared as solid powders or lumps which can be dissolved in an appropriate solvent ready for use for any particular purpose. In the majority of cases, the solvent is of an organic nature; but a few synthetic resins will dissolve in water. Such solutions can be applied in conservation to produce a protective film on an object, to act as an adhesive or to impregnate an object.

Emulsions. Many synthetic resins which do not dissolve in water can be produced as aqueous emulsions, i.e., stabilized dispersions of finely divided particles of the resins in water; these are often made by a special process of emulsion-polymerization, in which the monomer is dispersed in the aqueous phase prior to polymerization.

There is now available a wide range of such emulsions, and care must be exercised in their choice, since various additives are present which may have an influence on their ultimate use. In choosing an emulsion attention should be given to the following factors, namely, nature of material added to stabilize the emulsion, the pH of the emulsion, and possible presence of thickening agent used to increase the viscosity of the emulsion. Any emulsion containing such thickening agent should be viewed with reserve by the conservator. In most cases, the detailed composition of an emulsion will not be disclosed by its manufacturer. Unless the composition of all the additives is known, emulsions should be treated with a certain amount of reserve.

Two-system types. These systems are characteristic of thermosetting resins which are generally supplied as a viscous liquid or paste (the resin component) to which a so-called hardener has to be added. This hardener may be in the form of a mobile liquid or a fine powder. In certain cases it may also be necessary to add a catalyst in order to increase and control the rate of the reaction.

REVERSIBILITY

Reversibility is a principle upon which the conservator should be explicit. The term is used here in the sense that a conservation method can be reversed if anything unexpected should happen, so that the object can be recovered in its original state undamaged. This principle is paramount when any material, whether natural or synthetic, is applied to a very valuable object, e.g., a painting, and in such cases applies absolutely. However, in the conservation of many archaeological objects, particularly where consolidation is necessary, it may be considered permissible to carry out an irreversible process using materials which have been thoroughly tested on trial objects.

TRADE NAMES; PRODUCERS AND MANUFACTURERS

The question of trade names is a most difficult problem in the field of synthetic materials. Thus, the same basic trade name may be used to cover a wide variety of chemically distinct resins, and it may also happen that a trade name is retained while the composition of the resin is altered without notice. In the present report an attempt has been made to collect together the trade names of the most important producers of the synthetic materials discussed and to indicate, where possible, the chemical nature of the material.

A distinction should be drawn between producers and manufacturers. The former are the primary makers of the synthetic materials, whereas the latter form the synthetic materials into sheets, rods, or finished articles. This report lists only the main producers.

A NOTE ON SOURCES

The greater part of the information in these tables has been compiled from producers, technical leaflets and booklets, and where possible confirmed by independent sources. The authors have, of course, also made extensive use of their own published and unpublished material. Much useful information is to be found in *IIC Abstracts* and *Studies in Conservation.*

For general information on properties of plastics see the following:

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DOOLITTLE, Arthur K. *Technology of solvents and plasticizers.* New York, London, John Wiley, 1954.

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LEE, H.; NEVILLE, K. *Epoxy resins.* New York, Toronto, London, McGraw Hill, 1957.

LÜDECKE, C.; IVANOVSZKY, L. *Taschenbuch für die Wachsindustrie.* Stuttgart, Wissenschaftliche Verlagsgesellschaft, 1958.

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SCHILDKNECHT, C. E. *Vinyl and related polymers.* New York, Wiley, 1952.

STANNETT, Vivian. *Cellulose acetate plastics.* London, Temple Press, 1950.

WANDEBERG, E. *Kunststoffe.* Berlin, Springer Verlag, 1959.

WARTH, A. H. *Chemistry and technology of waxes,* 2nd ed. New York, Reinhold, 1956; London, Chapman & Hall.

Note. All figures for degree of polymerization are taken from molecular weights given in *A Handbook of Adhesives,* ed. Irving Skeist, New York, Reinhold, 1962. Glass temperatures (T_g) for vinyl polymers are also taken from this book. Glass temperatures for the polymethacrylates are from H. BURRELL, *Official Digest,* 34 (1962), p. 133.

Thermoplastic varnishes

I

INTRODUCTION

The materials in the lists below are all thermoplastic polymers of good general durability which have found uses in conservation, primarily as varnishes, but also as adhesives, retouching media, etc. Polyvinyl acetate and the polymethacrylates are the two groups of thermoplastics generally considered the most durable under outdoor exposure tests.

No material, of course, is absolutely permanent, and it should be emphasized that inclusion in these lists does not imply a recommendation for indiscriminate use. All the materials discussed below can be obtained in solid form without additives. Polymers whose stability could perhaps be made satisfactory by the addition of stabilizers, and polymers that require plasticizers for good performance are not included.

A protective coating must have reasonable toughness in order to be successful. That is, it must possess a certain minimum strength and it must be able to stretch somewhat without cracking. It is known that, up to a certain point, increasing the average molecular weight of a polymer will increase the strength of the films and give them greater ability to elongate. Therefore, the characterization of polymers through some measurement that indicates the average molecular weight is an important specification. The viscosity of a solution of resin at 20 per cent solids concentration in toluene has been taken as a rough indication of the average molecular weight and has been designated the 'viscosity grade' of the resin. Other arbitrarily chosen concentrations are just as useful, such as the 8.6 per cent solution of polyvinyl acetate in benzene, or the 4 per cent solution of polyvinyl alcohol in water that will be found in tables below.

Thermoplastic polymers can usually be alternatively graded according to *degree of polymerization,* that is to say, according to the number of monomer units that go to make up an average chain. In general, the *higher* the *degree of polymerization* the more viscous the solution at a given concentration, the higher the softening point, the slower the *rate* of solution, and the tougher the film.

Polymers of any one type are, however, as stated above, more conveniently graded by their viscosity under standard conditions. A low viscosity grade indicates a low degree of polymerization. It is often difficult to ascertain with certainty the degree of polymerization, so that only approximate figures, extrapolated from a few known figures, can be given below. *These should not be accepted as final* but have been included because they give some idea of the length of the molecule chains with which we are concerned.

APPEARANCE OF VARNISHES

As experience has continued to grow in the handling of a number of new materials, the evidence has become quite clear that practically every solvent-type varnish, containing simply a resin and solvent, can be handled in such a way as to give a range of gloss. This may be accomplished either by the addition of matting agents, by spraying techniques, or by other methods. Hence, for the widest versatility, a varnish should be capable of the highest gloss likely to be required. It could then be made as matt as desired in any particular application.

The appearance of a varnish and its handling qualities are also controlled to a considerable degree by the formulation of the solvent. As in many areas of craftsmanship, considerable experience is necessary in the proper selection of solvents for coatings and in the proper application by spraying. These subjects are more extensive than can be treated here, but attention is called to them to indicate that these two factors, which are not inherent properties of a varnish or resin, nevertheless have considerable influence upon their appearance.

Our opinion of the appearance of a surface is strongly influenced by its gloss. One can say that it is generally easier to get a higher gloss with a resin of low degree of polymerization (DP). Polymers of high DP become resistant to flow at an earlier stage in the drying. Thereafter, because of shrinking (through the continued loss of solvent) and the lack of mobility of semi-dry varnish, the roughness of the paint surface tends to be reproduced in the varnish surface. Thus, if the paint is matt, a varnish with a high degree of polymerization will tend to be matt. In extreme cases, it will also look as though it had 'sunk in'. (This does not apply to emulsions, which dry by a somewhat different mechanism.) If the surface of an old painting is very porous and it is desirable to 'bring out the colours' most effectively, coatings based on resins of low molecular weight seem to penetrate and wet the porous paint more effectively than those based on resins of high molecular weight.

The appearance of a varnish should remain unchanged for as long a period as possible. *Wrinkling* of a film and *bloom* are defects that may show up at an early stage in films of dammar, mastic, and resins AW2 and MS2. These defects are far less likely to be encountered in coatings of the other synthetic resins listed below.

Certain coatings have a tendency to collect *dust*. Many synthetic resins attract dust by acquiring a static electrical charge, but there are various ways of minimizing this and it has not proved to be unduly troublesome. Much more important is the capacity of certain resins to hold fast, and even to imbibe, dust that falls on them. The property that affords the best indication of this tendency is known as the 'second-order transition temperature' or 'glass temperature', T_g, of the material. Resinous materials do not exhibit sharp melting points but a more gradual 'second-order transition'. If the T_g of a resin is above the temperature of the room, the resin will be in a rather hard, glassy state. If, on the other hand, the T_g of the resin is much below the temperature of the surroundings, the material will be in the rubbery or highly viscous liquid state: materials tend to stick to it. For example the T_g of poly-*n*-butyl methacrylate is about 22°C, and films of this material have a tendency to imbibe dirt at temperatures found in many rooms. An indication that a resin has a T_g value much below room temperature is the fact that the lumps of resins in the container flow together or conglomerate after long storage. As a rule of thumb, such resins are to be avoided for protective coatings. Occasionally, when thin coatings of this type are applied, a second coat of harder material can be applied on top.

The synthetic resins listed below are colourless as film. They are also highly resistant to discoloration. The natural-resin varnishes, on the other hand, have a tendency to discolour. In the criticism and evaluation of varnishes, it is possible that the complete absence of colour in the varnish film might influence the opinion of a minority.

A failure of adhesion can affect the appearance of the coating through light being reflected by cracks and fissures. An outstanding case is polyvinyl alcohol which has been found, in experimental tests, to have insufficient adhesion on most kinds of paints.

It is sometimes stated that the refractive index (RI) of a varnish is an important property. The RI is a measure of the extent to which light is bent when it enters a material from the air. Theoretically, the RI of a varnish can affect the appearance of a painting in three ways:

1. The higher the RI, the more light is reflected from the top surface.
2. The higher the RI, the less the light gets out of the coating into the air again, because of total internal reflection.
3. The higher the RI, within reason, the less light will be reflected at the varnish-oil interface.

The effect of variations in the refractive indices of different varnishes is often much smaller than the differences in gloss owing to the relative smoothness and roughness of the upper surface of the varnish. Yet, if any of the factors above are important, it is perhaps the first.[1]

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[1] Effect 1 can be demonstrated where the illumination is diffuse, i.e., comes from many directions, which is a common situation. In such a case the darks of a picture varnished with polyvinyl acetate (RI = 1.46) will be rendered darker than with other varnishes likely to be encountered. This RI effect is small, so that varnishes must be compared under similar conditions of gloss, etc. —G. THOMPSON

SUMMARY

Loss of gloss through too high a degree of polymerization. Avoid high-molecular-weight resins, e.g., polyvinyl acetate of viscosity greater than about 25 (see Table 1 below). No trouble with MS2A or acrylic emulsions.

Loss of gloss due to bloom and wrinkling. Only a consideration with AW2 and MS2, which may lose gloss unevenly in the first few months. MS2A, which does not have this defect unless applied thickly, should be chosen in preference.

Dust collection. Lumps which fuse together or conglomerate in storage indicate a resin with a low T_g. Such a resin may collect and hold dust, particularly in hot climates. Trouble will be found with poly-*n*-butyl methacrylate (but not poly-methyl and ethyl methacrylate), and with the very low viscosity polyvinyl acetates (viscosity 2.5 and less).

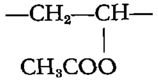
Refractive index. Not a major consideration.

Adhesion. Polyvinyl alcohol has poor adhesion to smooth surfaces.

LIST OF MATERIALS

Polyvinyl acetate

Chemical formula. The molecular chains are composed of the following unit:



$$-CH_2-\underset{\displaystyle CH_3COO}{\underset{|}{CH}}-$$

Properties.

Stability. Good stability to light. Severe exposure may increase sensitivity to water but does not cause yellowing, and evidence available suggests that the polymer remains fully soluble (not cross-linked).

Solubility. Can be dissolved, on the one hand in toluene and the aromatic solvents, on the other hand in the lower alcohols with small additions of water. Also soluble in esters and ketones. Relatively unaffected by aliphatic hydrocarbons. Slightly swollen in water, especially the lowest viscosity grades (see Table 1).

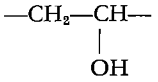
Mechanical properties. Grades of low degree of polymerization (on left in tables below) give soft films with a tendency to cold-flow under stress. Highly polymerized grades are tough and horny.

Softening point. From 60°C to over 200°C with increasing degree of polymerization (for T_g see Table 1).

Viscosity for varnishes. For single-coat varnishes, avoid high viscosity on the one hand and too soft a resin on the other; a viscosity is best chosen between about 4 and 15 (see Table 1).

Polyvinyl alcohol

Chemical formula. This resin is produced by the partial or complete hydrolysis of polyvinyl acetate to form units of the formula



$$-CH_2-\underset{\displaystyle OH}{\underset{|}{CH}}-$$

Various grades are available (see Tables 2, 3, 4), depending on the degree of hydrolysis and the degree of polymerization required.

Properties.

Stability. Good stability to light. According to one manufacturer prolonged exposure results in slight loss of strength (e.g., chain breaking) rather than loss of solubility (due to cross-linking). However, in strong light and dry conditions slight cross-linking will also occur. Yellowing and insolubility result from heating above 100°C.

Solubility. Water is the only practical solvent. Consequently the polymer is very resistant to petroleum solvents, oils, and fats. Contrary to what might be expected, grades of high acetate content dissolve most readily in cold water, while completely hydrolysed grades require some heating (85°-90°C). Low-viscosity grades dissolve more quickly. Weak solutions with no disinfectant may be subject to mould growth. To combat this, low concentrations of chlorinated phenols may be added.

Softening point. Can be heat-sealed at 120°-150°C. The glass transition temperature (T_g) of high-viscosity grades is about 85°C.

Mechanical properties. Good strength and flexibility for all grades, though strength is greater for grades of high degree of polymerization. Strength depends on humidity, but medium acetate grades will remain coherent

TABLE 1. Polyvinyl acetates

Trade name	Viscosity[1]													
	1.5	2.5		4	7		15		25		60		100	800
Lemac (Borden)					7	12	15						150	1 000
Gelva (Shawinigan)	V 1.5	V 2.5			V 7		V 15		V 25		V 60		V 100	V 800
Mowilith (Hoechst)		20	25	30	40		50		60		70		90	
Rhodopas (Rhône-Poulenc)	BB	B		M					H		HH		HV1	HV2
Vinnapas (Wacker)		B 1.5	B 5	B17	B60	B100 B500	UW1	B1 000	UW4	UW10	UW30	UW100	UW200	UW10 000
Vinavil (Montecatini)		K 25		K 40			K 50		K 60		K 70		K 90	
Vinylite (Bakelite, Union Carbide)	AYAC	AYAB			AYAA		AYAF		AYAT		AYAW			
Approx. DP	150	240			600		1 200		1 900		4 000		7 000	20 000
Tg (°C)	16	17			21		24		26		27		28	29

[1] Viscosity is quoted in centipoises as that of an 8.6 per cent solution in benzene. Note that the producers of Gelva use this as their designation.

TABLE 2. Polyvinyl alcohols: low acetate (97.5-100 per cent hydrolysis)

Trade name	Viscosity[1]									
	2-3	5	10	15	20	25	30	40	50	60
Alcotex (Revertex)		99-05	99-10		99-20					
Elvanol (Du Pont)		70-05				71-24	71-30		72-51	72-60
Gelvatol (Shawinigan)		1-30				3-60	1-60		3-90	1-90
Gohsenol (Nippon Syn. Chem. Tokyo)		NL-05			NM-14				NH-22	
Lemol (Borden)		5-98		16-98		24-98	30-98		51-98	60-98
Mowiol (Hoechst)		30-98	50-98		70-98				90-98	
Polyviol (Wacker)	VO 3-20	MO 5-20		M1 3-20			W28-20		W48-20	
Poval (Kurashiki)							PVA-117			
Rhodoviol (Rhône-Poulenc)		BS-10					HS-10			
Vinavilol (Montecatini)	2-98		10-98A		20-98A	20-98		42-98		

[1] Viscosity in centipoises of a 4 per cent solution in water at 20°C.

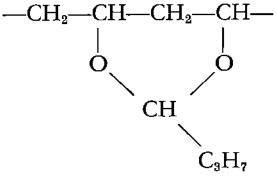
and tack-free up to about 90 per cent relative humidity. Polyvinyl alcohol has an unusually low permeability to those atmospheric gases which are not very soluble in water, notably oxygen.

Estimated approximate degree of polymerization related to the viscosities in Tables 2 to 4.

Viscosity	5	25	50
DP	200	2 000	2 600

Polyvinyl formal, acetal, and butyral

Chemical formula. These are thermoplastic polymers obtained from polyvinyl alcohols by partly reacting with formaldehyde, acetaldehyde, and butyraldehyde respectively. For example, the formula of polyvinyl butyral is:



Properties.

Stability. Stability to light very good. As with polyvinyl alcohols, heating above 100°C may cause some insolubility.

Solubility. The formals dissolve only in limited strong solvents, the acetals and butyrals in alcohols, acetone, and aromatic hydrocarbons.

Mechanical properties. All form tough films, the formals the hardest, the butyrals similar to polyvinyl acetate. The butyrals have been suggested as picture varnishes, but are not widely used for this purpose.

Producers.

Polyvinyl formals: Formvar (Shawinigan); Mowital F (Hoechst); Rhovinal B (Rhône-Poulenc).

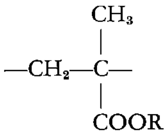
Polyvinyl acetals: Alvar (Shawinigan); Rhovinal A (Rhône-Poulenc).

Polyvinyl butyrals: Butvar (Shawinigan); Mowital B (Hoechst); Rhovinal B (Rhône-Poulenc); Vinylite XYSG and XYHL (Bakelite); Pioloform (Wacker).

Most of the above products are available in various grades, according to degree of polymerization (ranging from 200 to 2000) and polyvinyl alcohol and acetate contents.

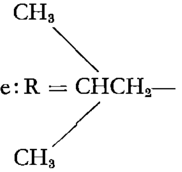
Polymethacrylates

Chemical formula. The molecular chains are composed of the following unit:



$$-CH_2-\overset{\displaystyle CH_3}{\underset{\displaystyle COOR}{C}}-$$

polymethyl methacrylate: R = CH_3—
polyethyl methacrylate: R = CH_3CH_2—
Poly-*n*-butyl methacrylate: R = $CH_3CH_2CH_2CH_2$—
poly-iso-butyl methacrylate: R =



Properties.

Stability. Good stability to light. Stable up to melting points. A tendency to become insoluble due to cross-linking through the action of light without any change in appearance has been noted in certain polymethacrylates, particularly iso-butyl, (but not in the case of methyl).

Solvents. The poly-butyl methacrylates can be dissolved in aromatic hydrocarbons such as toluene, and even in turpentine, and in petroleum solvents having about 25 to 35 per cent aromatic content. Polymethyl methacrylate is more difficult to dissolve, but will give a relatively low viscosity solution in an 80/20 mixture of toluene and methyl alcohol.

Mechanical properties. Tough and glass-clear films. Methyl methacrylate is the hardest, *n*-butyl methacrylate the most elastic. Poly-*n*-butyl methacrylate has a pronounced tendency to hold dust (see p. 310).

Glass temperature (T_g). Methyl, 105°C; ethyl, 65°; *n*-butyl, 22°.

Producers. A wide range of producers will supply solutions and emulsions of methacrylate and acrylate polymers. Polymethyl methacrylate is most common in sheet form (see p. 316).

The following producers supply in solid form with no additives:

Du Pont Polychemical Department:[1]	*Viscosity*[2]
Elvacite 2008, 2009, 2010 and 2041 polymethyl methacrylate	0.20-1.20
Elvacite 2042 polyethyl methacrylate	0.91
Elvacite 2044 poly-*n*-butyl methacrylate	0.53
Elvacite 2045 poly-iso-butyl methacrylate	0.66
Elvacite 2046 50/50 copolymer of *n*-butyl and iso-butyl methacrylate	0.61
Elvacite 20/3 Methyl/*n*-butyl methacrylate copolymer	0.20
Elvacite 20/4 Methyl methacrylate copolymer	0.45
Rohm and Haas (U.S.A.):	
Acryloid B-72 Methyl acrylate ethyl methacrylate copolymer	29[3]

A NOTE ON ACRYLIC EMULSIONS

Emulsions of undisclosed compositions have not been included in this section on thermoplastic varnishes. However, studies at Mellon Institute indicate that Rhoplex AC-33 (Rohm & Haas, U.S.A.) is highly resistant to cross-linking, and forms a glossy transparent film. Rhoplex AC-33 may be based on an acrylate-methacrylate copolymer similar to Acryloid B-72, although of higher molecular weight. It has a non-ionic dispersant, and has successfully

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[1] Polymethacrylates supplied by Du Pont were previously known as Hypalon or Lucite.

[2] Viscosity: inherent viscosity of 0.25 g of the polymer in 50 ml chloroform at 25°C measured in a number 50 Cannon-Fenske viscometer.

[3] 20 per cent solution in toluene at 21.1°C, in centipoise.

TABLE 3. Polyviynl alcohols: medium acetate (85-90 per cent hydrolysis)

Trade name	Viscosity[1]									
	2-3	5	10	15	20	25	30	40	50	60
Alcotex		88-05	88-10		88-20		88-32			
Elvanol		51-05			52-22	71-24	70-30	50-42	72-51	72-60
Gelvatol		20-30			20-60			20-90		
Gohsenol		GL-05		GM-14						
Lemol		5-88			22-88			42-88		
Mowiol		30-88	50-88	70-88						
Polyviol		M05-140		M13-140		W25-140				
						PVA-217				
Rhodoviol						HS-100				
Vinavilol		4-88								
		4-92[2]		20-88				42-88		

[1] Viscosity in centipoises of a 4 per cent solution in water at 20°C.

[2] 92 per cent hydrolysis.

TABLE 4. Polyvinyl alcohols: high acetate (75-80 per cent hydrolysis)

Trade name	Viscosity			
	1.3-2	2-3	5	15
Alcotex			75.L 78.L	
Gelvatol	40-10	40-20		
Rhodoviol			BS-125	MS-135

undergone seven years of outdoor exposure as an emulsion paint medium.

Acryloids (Rohm and Haas, U.S.A.) are known as Paraloids in Europe, and Rhoplexes are known as Primals. The numbers and letters remain the same, e.g., Acryloid B-72 = Paraloid B-72; Rhoplex AC-33 = Primal AC-33.

Rohm and Haas (U.S.A.) is not connected with Röhm and Haas (Federal Republic of Germany).

RESINS AW2, MS2, MS2A

These resins have found favour as picture varnishes because they are similar in handling qualities and mechanical properties to the natural resins, dammar and mastic. They are, however, more resistant to yellowing and oxidation, and of the three MS2A is the most permanent.

Also like dammar and mastic, though soluble in white spirit when fresh, the films require stronger (more polar) solvents for removal as time goes on. Eventually a proportion of ethyl alcohol or similar solvent will be required, though this stage will be reached very much later with MS2A than with AW2 or MS2.

AW2, MS2, and MS2A are all as brittle as the natural resins, and this is their main shortcoming. Commercial varnishes using these resins contain plasticizers.

According to tests carried out at the National Gallery, London, AW2 and MS2 do not bloom so readily as the natural resins, but lose gloss through wrinkling just as badly, though they may take longer. Resin MS2A, unless applied thickly, is most unlikely to wrinkle or bloom.

Chemical nature. AW2 and MS2 are composed of cyclohexanone and methyl cyclohexanone units, linked by reaction with formaldehyde with an average of about seven units per chain.

MS2A is made from MS2 by chemically reducing the ketone groups to hydroxyl groups, thereby increasing the stability.

Properties.

Solubility. All can be dissolved in low-aromatic petroleum spirit, but are affected by most organic solvents, including alcohols.

Mechanical properties. Brittle and easily reduced to powder by abrasion, when fully dried.

Softening point. 80-90°C.

Producers.

AW2: Badische Anilin und Soda Fabrik, Ludwigshafen/Rhein (Fed. Rep. of Germany).

MS2 and MS2A: Howards of Ilford (United Kingdom); Howards and Sons Ltd., P.O. Box 995, Cornwall, Ontario (Canada), Canadian distributors.

PROTECTIVE COATINGS FOR ANTIQUITIES

In the case of certain metallic antiquities it is often necessary to apply surface coatings either to prevent tarnishing or to limit the ingress of moisture vapour which is liable to activate salts that may cause corrosion. To prevent tarnishing, the surface coating must be relatively impermeable to such gases as hydrogen sulphide, and at the same time it must not confer an unpleasant sheen on the object. Specially formulated lacquers known as Ercalene and Frigelene based on cellulose nitrate have long proved satisfactory for bronze and silver objects in the British Museum. In the case of iron objects which must be protected against moisture vapour, microcrystalline waxes such as Cosmolloid have been found to be effective (see below, 'Synthetic waxes'). These synthetic waxes are preferable to either the beeswax or paraffin waxes previously used.

Objects which tend to flake or have a friable surface also need to be protected against possible damage due to careless handling, etc. For this purpose the application of emulsions of polyvinyl acetate or polymethacrylates or of a solution of soluble nylon (see below) has proved satisfactory, because they do not exert undue contractile forces and can be made to have a pleasant mat appearance.

II Transparent sheets

INTRODUCTION

Thin, transparent, flexible sheets have been used as supports, on one or both sides, for thin, delicate material, such as textiles, parchment or paper. Thicker sheets, which can be moulded to shape, act as unobtrusive supports for fragile or fragmentary material, such as corroded metal.

Apart from their use on the objects themselves, synthetic sheets have many uses in the laboratory, studio or workshop.

The two types of sheet in commonest use are *polyethylene* (polythene), and *cellulose*, regenerated or acetylated (regenerated: Cellophane; acetylated: cellulose acetate, safety film). These are so common in most countries that they can be bought in shops or stores. Their manufacturers are therefore not given in the list below.

Polyethylene cannot be regarded as a highly stable material, since it becomes yellow and more brittle with age. The addition of a filler such as carbon black greatly increases its durability, but reduces its usefulness to the conservator. At the time of writing, most of the polyethylene on the market is considered to be low-density polyethylene. A high-density polyethylene is now being produced, which is stiffer, has a higher softening point, and is slightly more transparent.

Polypropylene, in the form now available, carries these same properties a little further.

High-density polythene can now be obtained as a permeable sheet, known as Vyon, from Porous Plastics Ltd., Dagenham Dock, Essex (United Kingdom).

Regenerated cellulose and cellulose acetate are perfectly clear flexible films commonly used for wrapping. They are only moderately stable to light, and become brittle in course of time due to loss of plasticizer. Where a more durable film of this type is required, cellulose acetate-butyrate (CAB) is to be recommended, though here the addition of plasticizer is necessary for the purposes of manufacture, and this may be leached out or migrate. *Nitrocellulose* sheet (celluloid) is *not* recommended for conservation, since it is highly inflammable, and darkens on exposure to light. Paper objects, stored in unstabilized nitrocellulose envelopes have been destroyed by the products of decomposition, principally nitric acid.

Two synthetic sheet materials of excellent durability and toughness are *polymethyl methacrylate* and *polyethylene terephthalate.*

Polymethyl methacrylate is one of the acrylics (polyacrylates and polymethacrylates), most of which have good stability to light. It is highly transparent, but as a substitute for glass it has the disadvantage of being easily scratched and of storing an electric charge which attracts dust. This latter defect can be remedied by applying a polish supplied by the manufacturers; it is, incidentally, one from which most plastics materials suffer because of their good electrical insulating properties. The earlier forms of polymethyl methacrylate tended to craze in sunlight. The addition of a stabilizer has greatly reduced this tendency.

Polyethylene terephthalate is better known as the synthetic fibre Terylene (Dacron). It is also available in sheets as thin as 6 microns, and has found use as a non-adhesive film in hot-table relining. It is exceptionally strong.

Among the vinyl polymers, the commonest in sheet form are *polyvinyl chloride* (PVC), *polyvinylidene chloride* (PVDC Saran), and *polystyrene.* Though satisfactory for many short-term uses in the studio and laboratory, they are none of them sufficiently stable to merit their inclusion in this list of conservation material.

All the above polymers are thermoplastics, that is to say they are softened by heat, and can be dissolved, though sometimes with difficulty.

There are no highly flexible sheets among the thermosetting (insoluble) resins. There resins are now common in the form of rigid sheets known as laminates. They are made from melamine-formaldehyde, urea-formaldehyde, or phenol-formaldehyde (though this last tends to darken), and are widely used as tough surfacing materials (Formica, Wareite, Bakelite, Tufnol: note that these trade names may also be used to describe other materials). They have little direct application to conservation processes, except as supporting and structural materials in museum display.

FILMS FOR LAMINATION

For documents which have become brittle and are too fragile to be handled without risk of damage, a special process of strengthening has been devised in which the document is laminated between plastic films. Films based on polyvinyl chloride are not recommended for the permanent lamination of valuable archival material, since there is the possible risk that, under unfavourable conditions of storage, degradation of the film may occur with the formation of chlorine-containing compounds which might damage paper documents. Films of plasticized cellulose acetate have been successfully used for lamination of documents for a number of years, and these may be considered reasonably safe, if the specifications drawn up by the United States National Bureau of Standards (NBS Monograph No. 5) for the cellulose acetate and plasticizers are adhered to.

If adhesives are used for attaching the lamination film to the document, it is essential that the adhesive should be one which is soluble in an organic solvent, so that the process of lamination can be reversed if necessary.

In cases where pressure-sensitive adhesive tapes are used for the repair of documents, care should be taken to ensure that the adhesive used will not tend to exude in the course of time from the tape. Many of the self-adhesive tapes are only intended for temporary use, but special 'permanent' tapes are now available commercially in which a specially formulated adhesive is used which shows no tendency to exude.

LIST OF MATERIALS

Polymethyl methacrylate (see Table 5)

TABLE 5.

Trade name	Producer	Thicknesses (mm)
Plexiglas[1] (colourless)	Rohm & Haas (U.S.A.). Röhm & Haas (Fed. Rep. Germany).	1.5-25
Perspex[2]	ICI (United Kingdom).	1.0-25
Terplet (unplasticized)	Terps Kemiske, Himmelev, Roskilde (Denmark).	1.5-25
Soltrans	Productos Canfe, Cordella de Llobregat, Barcelona (Spain).	1.0-30
Acrylite	Mitsubishi Rayon Co., Tokyo (Japan).	

1. Light-diffusing, corrugated, and flame-resistant forms are available. For UV absorbers see p. 325.
2. Diffusing and corrugated forms available.

Properties.

Stability. General stability is good, and resistance to sunlight is also satisfactory.

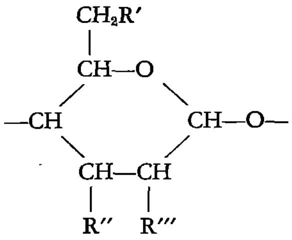
Solubility. Soluble in aromatic and chlorinated hydrocarbons (benzene, chloroform), esters (butyl acetate), 80/20 toluene/methyl alcohol, acetone. Relatively unaffected by the lower alcohols, aliphatic hydrocarbons, and water.

Softening point. 100°C. Can be bent to shape at 120°C.

Cellulose derivatives

Cellulose acetate butyrate (CAB) (see Table 6).

Chemical formula.



where R′, R″, R‴ = hydroxyl, acetate, or butyrate.

Table 6.

Trade name	Producer	Thicknesses (mm)
Rhonax II	M and B Plastics, 23/25 Eastcastle Street, London W.1 (United Kingdom). *and* Cipso, 106, boulevard Haussmann, Paris-8e (France).	1 and 2
Kodacel	Eastman Kodak.	

The above sheets are manufactured from Eastman Kodak CAB.

Degree of polymerization. 200 to 300 units.

For the manufacture of sheets, a low viscosity CAB, having acetate 6-13 per cent of theoretical maximum, butyrate 48-37 per cent, would be chosen.

Properties.

Stability. Superior to cellulose acetate or regenerated cellulose; comparable to acrylics; moisture resistant; contains plasticizer for manufacturing purposes.

Solubility. Soluble in ketones (acetone), esters, 80/20 toluene/ethanol. Relatively unaffected by aliphatic hydrocarbons, water.

Softening point. In the region of 120°C.

Polyethylene terephthalate (see Table 7)

Table 7.

Trade name	Producer	Thicknesses (microns)
Mylar	Dupont	6-250
Melinex[1]	ICI	9-254
Hostaphan[2]	Farbwerke Hoechst (Fed. Rep. Germany.)	10-50
Terphane	Cipso 24, avenue Montaigne, Paris-8e (France).	
Diafoil	Mitsubishi Kasei. Kogyo Co., Tokyo (Japan).	
Luminar	Rayon Co., Tokyo (Japan).	

1. Type S has been treated to reduce static charge, is very slightly milky.
2. Available as double film with polyethylene—Type PE.

Properties.

Chemically similar to Dacron or Terylene (see below under 'Textiles').

Exceptionally high strength, and consequently available in very thin sheets.

Unsuitable for outdoor exposure, due to some sensitivity to ultra-violet light.

Very high softening temperature: melts at about 250°C, and can be used up to about 200°C. Cannot be heat-sealed at all easily.

Normally contains no additives.

Note. A large range of cross-linking polyesters can be obtained in liquid form for varnishes, paints, adhesives, and glass-fibre reinforced plastics. Some of these can easily be cast into sheets. In this category come the epoxy resins, noted for their high adhesive power (see under 'Adhesives').

Adhesives and consolidants

III

ADHESIVES

The main purpose of this section of the report will be to discuss certain fundamental aspects of adhesives and to consider those classes of synthetic resins which have proved of value in the realm of conservation.

Classification.

Adhesives can be classified under different headings, e.g., their chemical nature, physical state, or particular application, but in the present context the most appropriate method of classification is that based on the nature of the reaction whereby the adhesive sets. To make a strong joint a liquid adhesive must be solidified, and this can be achieved in various ways. There are four main classes:

1. Setting due to change in temperature alone, i.e., the freezing of a molten solid (the so-called sealing-wax technique). This class includes the various types of adhesives based on mixtures of waxes and resins which have been used successfully, for example, in the relining of canvas paintings.
2. Setting due to change in temperature accompanied by loss of solvent (usually water). This class is exemplified by the various types of animal glues which have been used since earliest times.
3. Setting due to loss of solvent only. This class includes the large variety of adhesives in which a solid with adhesive properties is dissolved or dispersed in a liquid, and sets by evaporation of the liquid. True solvent adhesives and emulsion adhesives are to be found in this class.
4. Setting due to chemical reaction. This class includes the many new types of synthetic-resin adhesives which remain in a liquid state until they are caused to set by the addition of a chemical (so-called hardener) which leads to the formation of an insoluble solid. There are two important groups in this class; in the first, loss of volatile matter, usually water, occurs during the setting reaction, whereas in the second the setting reaction occurs without loss of any volatile material. In the former group are included the phenol- and urea-formaldehyde resins and their various modifications, and in the latter group are the epoxy and polyester resins.

This particular method of classification has been chosen because it serves to emphasize one particular property which is of paramount importance as regards the use of adhesives in the restoration of museum objects. This is the question of the amount of shrinkage which may occur when an adhesive sets.

Thus, in the case of adhesives of classes 2 and 3 which set by loss of solvent, and of those of class 4 in which the setting reaction involves loss of volatile matter, there is considerable shrinkage which can produce stresses that may weaken the adhesive joint or cause distortion of the bonded complex. On the other hand, the adhesives of class 4 in which the setting reaction occurs *without* loss of volatile matter do not shrink to any appreciable extent; these adhesives therefore merit particular consideration in conservation, since certain of them approach in some respects almost the ideal type of adhesive—namely, a liquid adhesive which is a 'potential solid' and can be converted into the actual solid state at a controlled rate at room temperature with scarcely any shrinkage.

It must, incidentally, be noted that an adhesive of the same *chemical* type may be included in more than one of the above classes, depending upon its mode of application. Thus, for example, a thermoplastic material such as polyvinyl acetate might be caused to set by solidification of the molten polymer (class 1), by solidification of a solution or emulsion of the polymer by loss of solvent (class 3), or by solidification as the result of a chemical reaction of the polymer dissolved in the monomer (class 4).

The adhesives considered in the above classification are usually referred to as 'structural' adhesives. This term is used to denote the essential difference between these adhesives which solidify on setting and the so-called 'pressure-sensitive' adhesives which remain as viscous, permanently tacky liquids, and are most familiar in the form of adhesive tapes.

Thermoplastic adhesives

The individual synthetic resins in this group which have been used in conservation are as follows.

Polyvinyl acetate. This material is available either as a white solid which is soluble in a variety of organic solvents or in the form of aqueous emulsions. It is essentially a polar substance and shows good adhesion to both porous and non-porous materials. A characteristic feature is the flexibility of the adhesive film, which makes it particularly suitable in the treatment of materials such as textiles, paper and leather. There is now available a considerable number of emulsions of polyvinyl acetate, each having its own special characteristics; it is generally agreed that internally plasticized emulsions stabilized with polyvinyl alcohol are most suitable as adhesives in conservation. It should be borne in mind that adhesives of this type are liable to swell slightly in water but will not dissolve and that they are slightly acid (Afcolac, Cascorez, Galatac, Lemac, Texicote, Vestolet, Vinamul, and Table 1 above).

Polyvinyl alcohol. This material is produced by the hydrolysis of polyvinyl acetate, whereby a number of acetyl groups are split off and replaced by hydroxyl groups. A number of different grades are available which differ in the degree of polymerization and the extent to which hydrolysis has occurred. The substance is strongly polar, is insoluble in most organic solvents but completely soluble in cold water if about 75 per cent of hydroxyl groups are present. A solution of a good-quality polyvinyl alcohol should be practically neutral and should remain so even stored for a long period. It has been used in the glueing of fragile textiles, such as flags, to plastic supports (see Tables 2-4).

Polyvinyl acetals. These are prepared by reacting polyvinyl alcohol with various aldehydes, such as formaldehyde, acetaldehyde or butyraldehyde. The materials are white solids soluble in organic solvents, and are normally used as solvent adhesives. Polyvinyl formal has been recommended as an adhesive for the attachment of delicate textiles to supports, as it does not tend to stain the textile, though it requires strong solvents for its removal. Polyvinyl butyral is better in this respect.

Acrylates. Esters of acrylic and methacrylic acid have been used in the preparation, by copolymerization of suitable monomers, of a wide variety of materials of potential value as adhesives. In general their properties are similar to polyvinyl acetate adhesives, and they are available commercially either as solutions in organic solvents or as emulsions (Bedacryl, Elvacite, Methacrol, Plexisol, Plextol, Vedril, Vynacryl).

Synthetic rubber. Varieties of synthetic rubber produced by copolymerization of such substances as butadiene, styrene and acrylonitrile have been utilized in the preparation of adhesives. The special virtues of these adhesives are their capability of developing good specific adhesion between a large variety of adherents and the fact that, if the adhesive is subjected to stresses, its high elongation permits it to absorb much of the strain without causing rupture of the bond. They can be used either as solutions in organic solvents or as emulsions.

Cellulosic derivatives. One of the first of the synthetic-resin adhesives to be developed was cellulose nitrate (usually incorrectly called nitrocellulose). This has been used extensively in conservation in the form of a solution of an appropriate grade of cellulose nitrate in equal parts of amyl acetate and acetone. It was found particularly suitable for the repair of such materials as pottery, porcelain and glass. Subsequently, derivatives of a similar type such as cellulose acetate and cellulose caproate, dissolved in an organic solvent, have been used as adhesives.

Also derivatives of cellulose have been produced which are soluble in water and have adhesive action; these include the ether derivatives, ethyl and methyl cellulose and the derivative known as sodium carboxymethyl cellulose. These water-soluble compounds are useful as general-purpose adhesives in the textile and paper field (Celacol, Cellofas, Courlose, Modocoll).

Soluble nylon. This is a special chemically modified form of nylon (*n*-hydroxymethyl nylon) which is produced by treating nylon with formaldehyde. It is available as a white powder which is soluble in methyl or ethyl alcohol and in industrial methylated spirits or in a mixture of 70 parts of these alcohols with 30 parts of water. The solution tends to gel at room temperature, but reliquefies on warming to 40°C. It is particularly useful in cases where it is desirable to use a mobile, non-aqueous adhesive; also the adhesive film has a fair degree of flexibility and does not tend to exert contractile forces when used, for example, in the reattachment of flaking paint on a tempera wall-painting (Elvamide, Maranyl, Calaton CA, Soluble Nylon).

Thermosetting adhesives (cold-setting)

Urea-formaldehyde and melamine-formaldehyde. These types of materials, produced by the action of formaldehyde on urea or melamine, have found extensive use as adhesives for wood. They have completely displaced the phenol-formaldehyde types of resin which tend to darken and are not suitable in conservation. These resins set by a chemical reaction between the actual resin component and a hardener, and the mode of application can be varied according to the way in which the hardener is mixed with the resin component. There are three main variations, namely:

1. The hardener is added to the resin in a given proportion to give a mixture which sets within a given short period of time.
2. The hardener is applied to one adherent and the resin to the other, and the two surfaces are held together under pressure until the adhesive system sets.
3. The adhesive is supplied as a dry powder consisting of resin plus hardener to which it is only necessary to add water to obtain an active adhesive system which can be applied in the conventional manner.

Special hardeners have been developed to suit particular needs. Certain urea-formaldehyde adhesives can be used as so-called gap-filling adhesives in which relatively thick glue-lines can be used to form a strong permanent bond. Such gap-filling adhesives are clearly of potential value in the repair of museum objects in which the parts to be joined cannot be made to match exactly (Aerolite, Cascamite, Melocol, Sumibond).

Epoxy (or ethoxylin) resins. These resins are among the latest additions to the range of synthetic adhesives; they consist essentially of a viscous resin component having an epoxy ring which is reacted with a suitable hardener (of which there are many) to produce a liquid system which sets to the final solid state without the evolution of any volatile material. This means that the setting takes place without appreciable shrinkage, so that no strains are set up which might cause distortion of the glued assembly. Furthermore, these resins are the most versatile type of adhesive yet produced; they can form strong bonds between all kinds of surfaces. The adhesives are produced in a variety of forms, as solids, liquids, or pastes, so that the conservator can choose the particular type most suitable to his immediate needs (Araldite, Lekutherm, Permagile, UHU-plus).

Cross-linked acrylate. Recently a special type of adhesive (Acrifix 90) based on an acrylate resin which can be cross-linked by a special hardener has been introduced as a fast-setting adhesive; it is particularly suitable where high bond strength and water resistance are required. The adhesive is prepared ready for use by adding hardeners to the resin solution.

Miscellaneous

Eastman 910 adhesive. This is a new and unusual type of adhesive which differs from conventional adhesives in that it does not set by loss of solvent nor by chemical reaction induced by a hardener. The material is a mobile liquid cyanoacrylate monomer which can be caused to polymerize to a solid under pressure. Thus the adhesive bond is produced by merely brushing a thin film of the monomer on one of the clean degreased surfaces, placing it in intimate contact with the other surface and applying manual pressure for a very short period of time. High bond strength is built up between almost every kind of material. It is particularly useful for the repair of glass objects. The hardened resin is soluble in dimethyl formamide.

CONSOLIDANTS

The need to restore mechanical strength to objects which have been rendered fragile as a result of exposure to adverse conditions or to impregnate a friable surface are constantly recurring problems in conservation. The traditional materials were either beeswax or solutions of natural resins, such as shellac. However, these suffer from certain disadvantages, and the introduction of synthetic materials offers the possibility of developing improved methods of consolidation. These may conveniently be considered under the following headings.

Synthetic waxes

Microcrystalline waxes. These are semi-synthetic waxes isolated as by-products from the refining of petroleum. They have a microcrystalline structure which confers on them a plasticity in marked contrast to the brittle paraffin waxes. They are obtainable in a wide range of melting points and physical consistencies from hard to soft (see Index: Cosmolloid).

Polyethylene glycol waxes. Polyethylene glycols are polymers of ethylene glycol. The lower members of the series are viscous liquids, the intermediate members pastes, and the higher members are solids having the physical appearance of waxes, but distinguished from ordinary waxes by the fact that they are freely soluble in water at room temperature. Trade names in U.S.A. and the U.K. are 'Carbowax' and 'PEG', and on the European Continent 'Polywachs'. Two examples will indicate the potential value of these waxes as consolidants. Carbowax 1500 can be used to restore flexibility to ancient leather which has become brittle and fragile owing to desiccation, and Carbowax 4000 has been successfully used to replace the water in fragile waterlogged wooden objects in such a way as to prevent deformation and to confer mechanical strength.

Modified waxes. The development of amorphous high molecular weight thermoplastic copolymers of ethylene and vinyl acetate has made possible the imparting of plastic-like properties to waxes, which enable bonds based on paraffin waxes or microwaxes to compete effectively with high-quality polymeric coatings. These copolymers are marketed, both in the U.S.A. and Europe, under the trade mark Elvax.

Solutions of synthetic resins

The synthetic resins described under 'Adhesives' can be used in suitable solutions for the consolidation of fragile objects. This technique works reasonably well in the case of porous objects such as bone and ivory, but in other cases the need for the solvent to evaporate usually results in the formation of a skin of resin on the surface unless impregnation can be carried out under vacuum. This imposes severe limitations on this technique of consolidation.

Non-solvent resins

The availability of the non-solvent types of synthetic resin which can be applied as mobile liquids that solidify *in situ* at room temperature under the influence of a hardener offers a new approach to the problem of consolidation. The system is very flexible and the conditions can be altered to suit particular needs; the setting time can be varied by suitable choice of hardener or by the addition of an accelerator, and the degree of resilience of the set resin can be varied by the addition of a plasticizer or by altering the nature of the resin.

From a chemical point of view the resins employed are the following:

Polyesters. These materials are produced by a reaction between a polyhydroxy alcohol and a polybasic acid. A large variety of products are available depending upon the particular nature of the reacting components. They are often mixed with inert solids (Bondafiller, Crystic, Leguval, Palatal, Stratyl).

Epoxy (thoxylin) resins. These are chemically similar to the resins already discussed as adhesives. The special types of resins which have been produced commercially as casting resins are the ones which can be best adapted to serve as consolidants. The most important feature of these materials is the fact that they set at room temperature without appreciable shrinkage. Various compositions can be chosen for the consolidation of metals, wood and stone (Araldite, Epophen, Lekutherm).

Polyacrylate resins. These are available as a two-component system of a polymer together with the monomer in which a catalyst is dissolved. The solid polymer is mixed with the liquid monomer plus catalyst to form a mobile liquid or paste which sets at room temperature. In some preparations there may be appreciable shrinkage (up to 10 per cent), but recently a material produced under the trade name Technovit merits special mention as it is claimed to set with very slight shrinkage. For this reason it has proved of particular value in the restoration and consolidation of glass and metal objects (Technovit, Tensol, Plexigum M355).

IV Miscellaneous materials

ULTRA-VIOLET ABSORBERS

Ultra-violet absorbers are chemicals which absorb ultra-violet radiation. Added to transparent sheets or varnishes they function as filters allowing visible light to pass, but removing the ultra-violet. Thus the transparent material, while remaining almost colourless, is able to protect colours and materials which are liable to be deteriorated by ultra-violet radiation.

Among the many chemicals which have been proposed for the absorption of ultra-violet light, there are two important classes available in pure powder form: the benzophenones and the benzotriazoles.

The varieties of benzophenone available vary (a) in strength of ultra-violet absorption, and (b) in solubility and compatibility characteristics. As far as our knowledge goes, there is no great difference in permanence among these varieties, and there is therefore no point in choosing a weak absorber when a smaller quantity of a stronger absorber will do the same job. Consequently the weaker absorbers (except for two water-soluble varieties) have not been included in the list below.

To remove substantially all radiation of wavelength shorter than 4000 Angstroms only a strong absorber should be considered in a thin film such as a varnish, since the concentration of one of the weaker absorbers would become prohibitively high.

Ultra-violet-absorbing powders

Substituted benzophenones (see Table 8). Formula of benzophenone, with substitution numbers:

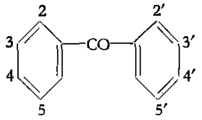


TABLE 8.

Trade name	Producer	Formula	Solubility
Uvinul D-50	Antara	2:2′:4:4′ tetrahydroxy.	Alcohols, esters, ketones.
Uvinul D-49		2:2′ - dihydroxy - 4 methoxy.	Esters, ketones, toluene.
Uvinul 490		Mixed isomers of hydroxy and methoxy.	Alcohols, esters, ketones.
Uvinul DS-49			Water.
Cyasorb UV 24	Cyanamid	As Uvinul D-49	
Cyasorb UV 284		2 - hydroxy - 4 - methoxy - 5 - sulpho, trihydrate.	Water.

TABLE 9.

Trade name	Producer	Formula	Compatibility
Tinuvin P	Geigy	Both hydroxyphenyl benzotriazole derivatives.	Cellulose esters.
and			
Tinuvin 326			Polyvinyl acetate; polymethacrylates; polyesters.

TABLE 10.

Trade name	Producer	Formula	Solubility
OPS	Eastman Kodak	p-octylphenylsalicylate.	Alcohols, ketone, aromatic and aliphatic hydrocarbons.
RMB		Resorcinol monobenzoate	Alcohols, ketone.

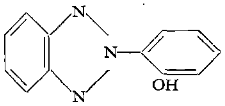
TABLE 11.

Trade name	Producer	Thicknesses (mm)	UV absorber
Plexiglas UF-1 and UF-3 Oroglas UF-1 and UF-3 (outside U.S.A.).	Rohm & Haas (U.S.A.).	1.5-6	Not stated.

TABLE 12.

Trade name	Producer	Thicknesses	UV absorber
Cast sheet Formula L. 822 Colour L. 419.	Amcel.	75-250 microns.	A Uvinul.
Celastoid S 661.	British Celanese.	1.5 mm only.	0.03 per cent of Tinuvin P by weight of sheet.
Rhodialine U Incolor (clear).	Rhône-Poulenc	0.1 mm.	Not stated.

Triazoles (see Table 9). Formula of hydroxyphenyl benzotriazole:



Others (see Table 10)

Ultra-violet-absorbing sheets

Polymethyl methacrylate and cellulose acetate sheets are available in which UV-absorbers have been incorporated. For thicker sheets, up to perhaps 5 mm, the methacrylates mentioned should be considered. They are much more expensive, but more durable. Cellulose acetate is not the ideal material for thin sheets because of its limited durability (cellulose acetate butyrate would be better), but more permanent materials are not yet on the market. Cellulose acetate should give 5-10 years' service in temperate countries.

Polymethyl methacrylate (see Table 11).

UF-3 is a stronger UV absorber than UF-1, and is therefore to be preferred wherever its slight yellow tint can be tolerated. UF-3 may also be obtained in tube form to fit over fluorescent tubes.

Cellulose acetate (see Table 12).

Ultra-violet-absorbing varnishes

It is a simple matter to add one of the powders listed above to a varnish solution, and thus to compound one's own ultra-violet-absorbing varnish. Any such varnish ought at the very least to be tested for the following: (a) compatibility (i.e., unimpaired clarity) of absorber in fresh film; (b) continued compatibility (in some cases the absorber crystallizes out after weeks or months); (c) ultra-violet absorption curve of fresh film; and (d) ultra-violet absorption curve of the aged film (in certain synthetic oil varnishes, the life of an ultra-violet absorber may be greatly reduced).

The application on to glass of an ultra-violet-absorbing varnish which will be invisible is difficult, since brush-strokes, tears, and runs are readily noticed in clear films, and also since the thickness of the film must be controlled to give correct absorption.

Because of the above difficulties there is much to be said for buying a manufactured varnish and employing skilled work in its application (see Table 13).

Note. At the time of going to press, information has been received that a 'safety glass' is manufactured consisting of two layers of glass with a UV filter between them. The UV filter is an American Cyanamid benzophenone in polyvinyl butyral. Trade name: Fadeban UV 393.

A diffusing form is also available, Northlite UV 393, with 50 per cent transmission of visible light, a UV filter, and good anti-radiant heat properties. No museum tests have yet been done on these products, though theoretically they should be highly satisfactory. Manufacturer: Shatterprufe Safety Glass Co. Ltd., Port Elizabeth (South Africa).

MOULDING AND EMBEDDING MATERIALS

In making replicas of museum objects it is essential to choose moulding materials which will not have any deleterious effect on the surface of the object. Possible danger to antiquities which are undergoing a process of moulding arises from several causes. These include the following:

1. The presence of substances in the moulding material which may react with the object. A suitable parting medium may be adopted to isolate the one from the other.
2. Lack of resilience in the mould which may enable it to lock on to asperities on the object and cause them to be broken away when the mould is removed. This difficulty may be overcome by the adoption of a piece-moulding technique.
3. Adhesive properties which may have the same result as 2 above.
4. Liberation of excessive heat during setting of the moulding material.

It is the material and condition of the antiquity that determines which of the causes listed above is dangerous in any particular case. A further property of moulding materials which is of interest is its degree of shrinkage, and the possibility of swelling the mould back to its original dimensions again.

Many synthetic materials have been introduced as moulding materials. Among those which may be considered suitable for the moulding of antiquities are the products listed in Table 14.

TABLE 14

Producer and trade name	Chemical type
ICI: Welvic.	Polyvinyl chloride copolymer.
Kautschuk: Naftoflex.	Polysulphide rubber.
Bayer: Siloprene.	Silicone rubber.
Midland Silicones: Silastomer.	Silicone rubber.
ICI: Silcoset.	Silicone rubber.
Revertex: Revultex.	Rubber latex.

In using these synthetic materials it must be noted that in certain cases it may be necessary to apply an isolating or release film to the surface of the antiquity in order to facilitate removal of the mould or to prevent possible staining of the surface, particularly in the moulding of antiquities of a porous nature.

Details of isolating materials can be obtained from the producers. The most suitable for use

TABLE 13.

Trade name	Manufacturer	Varnish type	UV absorber
Antisol	Antisol Developments, 28 Blackfriars, Manchester (United Kingdom).	Not an alkyd.	A benzophenone.
R. 1721/15	Industrial Colours, Walham Grove, London S.W.6 (United Kingdom).	Acrylic.	A benzophenone and triazole.

with antiquities are silicone fluids or polyvinyl alcohol. Welvic is a thermosetting material and is therefore only suitable for making moulds of objects which can withstand heating to the required temperature. The other materials are all cold setting, and have been successfully used for the moulding of a wide variety of antiquities. They are characterized by their resilience and relatively small degree of shrinkage.

TEXTILES

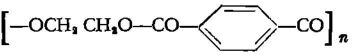
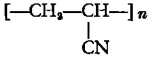
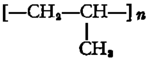
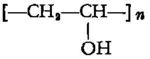
A number of synthetic materials can be fabricated in the form of textiles which possess certain advantages over natural textiles and can be used as supports. These materials are characterized by their tensile strength, durability, relative dimensional stability to moisture, and freedom from attack by moths and fungi.

The most important textiles used in conservation are shown in Table 15.

Of these textiles, the nylons are noted for their very high strength and the polyesters for greatest resistance to creasing. All except the triacetates are unaffected by moisture, bacteria, and mould growth. Many are available as relatively thick and strong monofilaments (e.g., nylon), and some find this their only suitable textile form (polyethylene, polypropylene, PVC, Teflon). Nylon and the polyesters can be obtained in a wide range of weights, from fine gauze to heavy canvas.

Certain textiles, such as PVC and PVDC (Saran, Velon, Tygon, Rhovyl), have not been included because they are not regarded as highly stable materials. For the same reason, triacetates should be avoided for permanent treatment, though their special properties may give them other uses in the conservation laboratory.

TABLE 15. Textiles

Type and some trade names	Chemical structure
Polyamides (Nylon) Nylon is sufficiently well known to be so described by the manufacturers, though many trade names are still used. This applies in varying degrees to the other textiles below.	Made in one of two ways: (a) by linking units of an aminoacid, e.g. Nylon 6:[1] $[—NH(CH_2)_5\ CO—]_n$ (b) by joining alternately a dibasic acid with a diamine, e.g., the common nylon, Nylon 66: $[—CO\ (CH_2)_4\ CO—NH\ (CH_2)_6\ NH—]_n$
Polyesters Terylene (U.K.), Dacron (U.S.A.), Tergal (France), Tetlon (Japan).	Polyethylene terephthalate: 
Acrylics Orlon, Acrilan, Courtelle (U.K.), Crylon (France)	Polyacrylonitrile: $[—CH_2—CH(CN)—]_n$
Modacrylics Verel (U.S.A.), Dynel (U.S.A.).	Copolymer of acrylonitrile and vinylidene chloride.
Triacetates Arnel (U.S.A.), Tricel (U.K.), Trilan (Canada).	Cellulose triacetate (see Formula, p. 317, R′, R″, R‴ = CH_3 — CO-O—).
Polyethylene Reevon, Wynene, Velon (U.S.A.), Courlene, Courlene X3 (high-density polythene), (U.K.).	$[—CH_2—]_n$
Polypropylene (U.K.), (U.S.A.), (Italy).	$[—CH_2—CH(CH_3)—]_n$
Polyvinyl alcohol[2] Vinylon (Japan).	$[—CH_2—CH(OH)—]_n$
Polytetrafluoroethylene Teflon (U.S.A.).	$[—CF_2—CF_2—]_n$

[1] The code numbers signify the number of carbon atoms in the units (Nylon 66 has 6 carbons in the dibasic acid and also 6 in the diamine).
[2] Made insoluble by treatment with, e.g., formaldehyde.

Index of trade names

In this list are included a selection of the trade names given by various producers to the most important synthetic materials used in conservation, except textiles, which are given in Table 15, page 328.

Abbreviations used in the trade names list:

M/F = melamine-formaldehyde;
PV = polyvinyl;
PVA = polyvinyl acetate;
PVC = polyvinyl chloride;
U/F = urea-formaldehyde.

Trade name	Chemical type	Producer[1]	Reference	Page
Acrifix.	Acrylic.	Röhm & Haas (Fed. Rep. Germany).	Adhesive.	321
Acrylite.	Acrylic.	Mitsubishi Rayon Co. (Japan).	Sheet.	317
Acryloid (Primal).	Acrylic copolymer.	Rohm & Haas (U.S.A.).	Varnish.	314
Aerolite.	U/F.		Adhesive.	321
Afcolac.	PVA emulsion.	Ciba.	Adhesive.	320
Alcotex.	PV alcohol.	Revertex.	Varnish.	312
Alvar.	PV acetal.	Shawinigan.	Adhesive.	313
Antisol.	Benzophenone.	Antisol Developments.	UV-absorbing varnish.	326
Araldite.	Epoxy.	Ciba.	Adhesive/consolidant.	321, 323
AW2.	Polycyclohexanone.	BASF.	Varnish.	315
Bakelite AYAF.	PVA.	Bakelite.	Adhesive and varnish.	313
Bakelite XYHL and XYSG.	PV butyral.	Bakelite.	Adhesive and varnish.	313
Bedacryl 122X.	Methacrylate.	ICI.	Consolidant.	320
Bedacryl L.	Methacrylate emulsion.	ICI.	Consolidant.	320
Bondafiller.	Polyester + inert filler.	Bondaglas, 55, South End, Croydon, Surrey (U.K.).	Consolidant.	323
Butvar.	PV butyral.	Shawinigan.	Adhesive.	313
Calaton CA.	Soluble nylon.	ICI.	Adhesive.	321
Caparol.	PVA emulsion.	Deutsche Amphidin Werke, Hamburg. (Fed. Rep. Germany).	Consolidant.	—
Carbowax.	Polyethylene glycol wax.	Union Carbide.	Consolidant.	322
Cascamite.	U/F.	Leicester Lovell, North Baddesley, Southampton (U.K.).	Adhesive.	321
Cascorez.	PVA.	Leicester Lovell.	Adhesive.	320
Castsheet, Formula L822.	Cellulosic.	Amcel.	UV-absorbing sheet	325
Celacol.	Soluble cellulosic.	British Celanese.	Adhesive.	321
Celastoid.	Cellulose acetate.	British Celanese.	UV-absorbing sheet.	325
Cellofas.	Soluble cellulosic.	ICI.	Adhesive.	321
Cosmolloid.	Wax (microcrystalline).	Astor Boissellier & Lawrence, 9 Savoy St., London W.C.2 (U.K.).	Consolidant.	315, 322
Courlose.	Soluble cellulosic.	British Celanese.	Adhesive.	321
Crystic.	Polyester.	Scott Bader.	Consolidant.	323
Cyasorb.	Benzophenone.	Cyanamid.	UV-absorber.	324
Eastman 910.	Cyanoacrylate.	Eastman Kodak.	Adhesive.	321
Elvacite.	Acrylic.	Du Pont.	Varnish/adhesive.	314

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[1] The addresses of the main producers are given in the Index of Producers.

Trade name	Chemical type	Producer	Reference	Page
Elvamide.	Polyamide (soluble nylon).	Du Pont.	Adhesive.	321
Elvanol.	PV alcohol.	Du Pont.	Varnish/adhesive.	314
Elvax.	Vinyl copolymer.	Du Pont.	Wax modifier/adhesive.	322
Epon.	Epoxy.	Shell Chemicals.	Casting.	—
Epophen.	Epoxy.	Leicester Lovell.	Consolidant.	323
Ercalene *and* Frigelene.	Cellulose nitrate.	W. Canning & Co., 77 St. John St., London E.C.1 (U.K.).	Lacquer for metal antiquities.	—
Fadeban UV 393.	Benzophenone.	American Cyanamid.	UV-absorbing sheet.	326
Formvar.	PV formal.	Shawinigan.	Adhesive.	313
Galatac.	PVA emulsion.	ICI.	Adhesive.	320
Gelva.	PVA.	Shawinigan.	Adhesive, varnish.	312
Gelvatol.	PV alcohol.	Shawinigan.	Adhesive, varnish.	312
Gohsenol.	PV alcohol.	Nippon Synthetic Chemicals, Tokyo (Japan).	Varnish/adhesive.	312
Hostaphan.	Polyester sheet.	Hoechst.	Sheet.	318
Kodacel.	Cellulose acetate.	Eastman Kodak.	UV absorbing sheet.	318
Leguval.	Polyester.	Bayer.	Adhesive.	323
Lemac.	PVA.	Borden.	Varnish/adhesive.	312
Lekutherm.	Epoxy.	Bayer.	Consolidant.	323
Lemol.	PV alcohol.	Borden.	Varnish/adhesive.	312
Luminar.	Polyester.	Rayon Co., Tokyo	Sheet	318
Maranyl C 109/P.	Soluble nylon.	ICI.	Adhesive.	321
Melinex.	Polyester sheet.	ICI.	Sheet.	318
Melocol.	M/F and U/F.	Ciba.	Adhesive.	321
Methacrol.	Acrylic.	Du Pont.	Adhesive.	320
Modocoll.	Water-soluble cellulosic.	Mo & Domsjö.	Adhesive.	321
Mowilith.	PVA.	Hoechst.	Adhesive, varnish.	312
Mowiol.	PV alcohol.	Hoechst.	Adhesive, varnish.	312
Mowital.	PV acetal.	Hoechst.	Adhesive.	313
MS2.	Polycyclohexanone.	Howards.	Varnish.	315
MS2A.	Polycyclohexanol.	Howards.	Varnish.	315
Mylar.	Polyester.	Du Pont.	Sheet.	318
Naftoflex.	Polysulphide.	Kautschuk.	Moulding.	326
Northlite UV 393.	Benzophenone.	Shatterprufe Safety Glass Co. (South Africa).	UV filter.	326
OPS.	Phenylsalicylate.	Eastman Kodak.	UV-absorbing powder.	325
Oroglas (see Plexiglas).				325
Palatal.	Polyester.	BASF.	Consolidant.	323
Paraloid.	Acrylic copolymer.	Rohm & Haas (U.S.A.).	Consolidant/adhesive.	315
PEG.	Polyethylene glycol wax.	Shell Chemicals *and* Mo & Domsjö.	Consolidant.	322
Permagile.	Epoxy.	Permagile Distributors Inc., 130 Sunrise Highway, Valley Stream, Long Island, N.Y. (U.S.A.).	Adhesive.	321
Perspex.	Acrylic.	ICI.	Sheet.	317
Pioloform.	Polyvinyl butyrol.	Wacker.	Adhesive.	313
Plexiglas.	Acrylic.	Rohm & Haas (U.S.A.).	Sheet.	320
Plexigum.	Acrylic.	Röhm & Haas (Fed. Rep. Germany).	Adhesive.	323
Plexisol.	Acrylic.	Röhm & Haas (Fed. Rep. Germany).	Adhesive.	320
Plextol.	Acrylic.	Röhm & Haas (Fed. Rep. Germany).	Adhesive.	320
Polyviol.	PV alcohol.	Wacker.	Adhesive, varnish.	312
Polywachs.	Polyethylene glycol wax.	Hoechst.	Consolidant.	322
Poval.	PV alcohol.	Kurashiki, Rayon Co., Osaka (Japan).	Varnish and adhesive.	312
Primal.	Acrylic emulsion.	Rohm & Haas (U.S.A.).	Adhesive.	315
R. 1721/15.	Benzophenone and triazole.	Industrial Colours (U.K.).	UV-absorbing varnish.	326
Revultex.	Rubber emulsion.	Revertex.	Moulding.	326
Rhodester.	Polyester.	Rhône-Poulenc.	Adhesive, varnish.	—
Rhodialine U.	Cellulosic.	Rhône-Poulenc.	UV-absorbing sheet.	325
Rhodopas.	PVA.	Rhône-Poulenc.	Adhesive.	312
Rhodoviol.	PV alcohol.	Rhône-Poulenc.	Adhesive, varnish.	312, 314
Rhonax II.	Cellulose derivative.	Rhône-Poulenc.	Sheet.	318
Rhoplex.	Acrylic emulsion.	Rohm & Haas (U.S.A.).	Adhesive.	315

Trade name	Chemical type	Producer	Reference	Page
Rhovinal.	PV acetal.	Rhône-Poulenc.	Adhesive.	313
RMB	Resorcinol benzoate	Eastman Kodak	UV-absorbing powder	325
Setamul (see Vinamul).				320
Silastomer.	Silicone.	Midland Silicones, 68 Knightsbridge, London S.W.1 (U.K.).	Moulding.	326
Silcoset.	Silicone.	ICI.	Moulding.	326
Siloprene.	Silicone.	Bayer.	Moulding.	326
Soltrans.	Acrylic.	Productos Canfe.	Sheet.	317
Soluble nylon (see also Maranyl).	Soluble nylon.	Tokyo Rayon Co., Tokyo (Japan).	Adhesive.	321
Stratyl.	Polyester.	Pechiney.	Adhesive/consolidant.	323
Sumibond.	M/F.	Sumitomo Bakelite Co., Tokyo (Japan).	Adhesive.	321
Technovit.	Acrylic.	Kulzer GmbH, Frölingstr. 29, Bad Homburg v.d. Höhe, (Fed. Rep. Germany).	Adhesive.	323
Tensol.	Acrylic.	ICI.	Consolidant.	323
Terphane.	Polyester.	Cipso, 24 av. Montaigne, Paris-8e (France).	Sheet.	318
Terplet.	Acrylic.	Terps Kemiske.	Sheet.	317
Texicote.	PVA emulsion.	Scott Bader.	Adhesive.	320
Tinuvin.	Triazole.	Geigy.	UV-absorber.	324
UHU-plus.	Epoxy.	UHU-Werk.	Adhesive.	321
Uvinul.	Benzophenone.	Antara Chemicals.	UV-absorber.	324
Vedril.	Acrylic.	Montecatini.		320
Vestolet.	PVA.	Hüls.	Adhesive.	320
Vinacryl.	Acrylic emulsions.	Vinyl Products.	Adhesive.	320
Vinalak.	PVA.	Vinyl Products.	Varnish.	—
Vinamul (Setamul).	PVA emulsion.	Vinyl Products.	Adhesive.	320
Vinavil.	PVA.	Montecatini.	Adhesive, varnish.	312
Vinavilol.	PV alcohol.	Montecatini.	Adhesive, varnish.	312
Vinnapas.	PVA.	Wacker.	Adhesive, varnish.	312
Vinylite.	PVA.	Bakelite.	Adhesive, varnish.	313
Vyon.	Polyethylene.	Porous Plastics Ltd., Dagenham (U.K.).	Porous sheet.	316
Welvic.	PVC.	ICI.	Moulding.	327

Index of producers[1]

With their principal agents in other countries

AMCEL Celanese Corporation of America, 180 Madison Avenue, New York 16, N.Y. (U.S.A.)

United Kingdom Celanese Corporation of America, 49 Old Bond Sreet, London W.1.

France 8, place Vendôme, Paris.[2]

Germany (Fed. Rep.) Plastica Repenning K.G., Anderalstr. 26, Hamburg.

Italy Soc. Usvico, Via Generale Albricci, 8, Milano.

Sweden Scandinavian Raw Materials A.B., Virebergswagen 19, Solna, Stockholm.

India Industrial and Allied Chemicals, Bombay.

Japan Percy Breen, Tokyo.

ANTARA Antara Chemicals 435 Hudson Street, New York 14, N.Y. (U.S.A.).

United Kingdom Fine Dyestuffs and Chemicals Ltd., Calder Street, Manchester 2.

ANTISOL DEVELOPMENTS Antisol Developments, 28 Blackfriars, Manchester (United Kingdom).

BASF Badische Anilin and Soda Fabrik A.G., Ludwigshafen am Rhein (Federal Republic of Germany).

U.S.A. BASF Inc., 375 Park Avenue, New York 22, N.Y.

United Kingdom Allied Colloids Ltd., 2 The Green, Richmond, Surrey.

France Imaco S.A., 5, rue Alfred de Vigny, Paris-8^{e}.

Italy SASEA, via Matteo Bandello, 6, Milano.

Sweden AB Triga, PB 2064, Kungsportsavenyen 31-35, Gotenburg 2.

India Chemicolour Private Ltd., POB 1881, Kasturi Buildings, Jamshedji Tata Road, Bombay 1.

Japan Color-Chemie Trading Co. Ltd., Tazan Building, no. 9, 4-chome Honcho, Nihombashi Chuo-ku, Tokyo.

BAKELITE Bakelite Division, Union Carbide Corporation, 30 East 42nd Street, New York 17, N.Y. (U.S.A.).

United Kingdom Bakelite Ltd., 12-18 Grosvenor Gardens, London S.W.1.

France Compagnie Industrielle Savoie-Acheson, 12, rue du Général Foy, Paris-8^{e}.

Germany (Fed. Rep.) A. Richard Tischer, Neuer Jungfernstieg 17A, Hamburg 36.

Italy Chem-Plast, via Carducci, 21, Milano.

Sweden Edstrom Trading Co., A.B., Kungsgatan 33, Stockholm.

India National Carbon Co., PO Box 2170, Industrial Products Division, Calcutta.

Japan Tomoe Engineering Company, Minagawa, Building, 1-chome, Ginza st., Chou-Ku, Tokyo.

BAYER Bayer A.G., Anwendungstechnische Abteilung, Gruppe K, 509 Leverkusen (Federal Republic of Germany).

BORDEN Borden Chemical Company, 350 Madison Avenue, New York 17017 (U.S.A.).

BRITISH CELANESE British Celanese Ltd., Celanese House, Hanover Square, London W.1 (United Kingdom).

France Loiret & Haentjens S.A., 44, rue du Louvre, Paris-1^{er}.

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[1] The list of manufacturers was established by the Rome Centre. Unfortunately, the Centre was not able to obtain information concerning products manufactured in all of the countries of the world.

[2] European headquarters: AMCEL Europe, 251, avenue Louise, Brussels (Belgium).

Switzerland L. Wachendork & Cie., Basle.
Italy Giambattista Borsa, via Comelico, 40, Milano.
Sweden Harald Pihl, Nybrokajen 7, Stockholm.
Far East Yuen Hing Hong & Co. Ltd., PO Box 2016, Hong Kong.

CIBA Ciba A.G., Klybeckstrasse 141, PO Box 4000, Basle 7 (Switzerland).
United Kingdom Ciba A.R.L. Ltd., Duxford, Cambridgeshire.
U.S.A. Ciba Products Co., 556 Morris Avenue, Summit, N.J. 07901.
France Prochal, Arago-Defense, 5, rue Bellim, Puteaux, Hauts-de-Seine.
Germany (Fed. Rep.) Ciba A.G., 7867 Wehr, Baden.
Italy Ciba Industria Chimica S.A., casella postale 88, Saronno, Milano.
Japan Ciba Products Ltd., Ciba Building, 50 Manzai-cho, Kita-ku, Osaka, CPO, Box 795.
India Ciba of India Ltd., Esplanada House, 29 Wandby Road, PO Box 479, Bombay 1.

CYANAMID American Cyanamid, Berdan Avenue, Wayne, N.J., 07470 (U.S.A.).
United Kingdom Cyanamid of Great Britain, Bush House, Aldwych, London W.C.2.
Switzerland Cyanamid International Corporation, Seehaf Building, Faerberstrasse 6, Postfach 8021, 8008 Zurich.
India Cyanamid (India) Ltd., Worli Building, 254-D2 Dr. Annie Besant Road, PO Box 6577, Worli, Bombay.
Japan Cyanamid (Japan) Ltd., 417 Nikkatsu International Building, 1 Yuraka-cho, 1-chome, CPO 1687, Chiyoda-Ku, Tokyo.

DU PONT E. I. Du Pont de Nemours Inc., Wilmington 98, Del. (U.S.A.).
Switzerland Du Pont de Nemours International S.A., 81, rue de l'Aire, CH 1211, Genève 24.
United Kingdom Du Pont Company (United Kingdom) Ltd., 18 Bream's Buildings, Fetter Lane, London E.C.4.
Japan 47, 2-chonie, Andoji bashi-dori, Minami-ku, Osaka.
Germany (Fed. Rep.) Du Pont de Nemours (Deutschland) GmbH, Bismarckstrasse 95, 4000 Düsseldorf.
Belgium Du Pont de Nemours (Belgium) S.A., 6 Ankstraat, Malines.
France Du Pont de Nemours (France) S.A., 9, rue de Vienne, Paris-8e.
Netherlands Du Pont de Nemours (Nederland) N.V., Stadthouderplantsoen 214, The Hague.
Sweden Du Pont de Nemours Nordiska A.B., Industrigatan 1, Maersta.

EASTMAN KODAK (Tennessee Eastman, Eastman Chemical Products Inc., Kingsport) Tenn. (U.S.A.).
United Kingdom Eastman Chemical International A.G., 246 High Holborn, London W.C.1.
Europe Eastman Chemical International, ZVB Hans an der Aa, 6301, Zug (Switzerland).
Far East Eastman Chemical Products Inc., PO Box 14050, Hong Kong.
Canada Eastman Chemical Inter-American Ltd., 164 Eglington Avenue East, Toronto 12, Ontario.

GEIGY J. R. Geigy S.A., Basle 16 (Switzerland).
U.S.A. Geigy Chemical Corporation, PO Box 430, Yonkers, N.Y.
United Kingdom Geigy (Holdings) Ltd., Middleton, Manchester.
France Produits Geigy S.A., 43, rue Vineuse, Paris-16e.
Germany (Fed. Rep.) Geigy Verkauf GmbH., Liebigstrasse 53, Frankfurt am Main.
Italy Geigy S.A., via Martiri Oscuri, 24, casella postale Milano SERR 3697, Milano.
Sweden Geigy A.B., Norrkoping.
India Suhrid Geigy Trading Private Ltd., PO Box 965, Bombay 1.
Japan Instrument Engineers Inc., 520 Kishimoto Building, no. 18, 2-chome Marunouchi, Chiyoda-Ku, Tokyo.

HOECHST Farbwerke Hoechst A.G., 45 Bruningstrasse, Frankfurt am Main (Federal Republic of Germany).
U.S.A. International Chemical Corporation, Empire State Building, Suite 8211, 350 Fifth Avenue, New York 1, N.Y.
United Kingdom Hoechst Chemicals Ltd., 50 Jermyn Street, London S.W.1.
France Peralta S.A.R.L., 10, rue Clément Marot, Paris-8e.
Italy Emalfa S.p.A., casella postale N. 1847, Milano.
Sweden Hoechst Anilin Aktiebolag, Box 204, Göteborg.

India Fedco Private Ltd., Mafatlal House, Backbay Reclamation, Bombay 1.
Japan Hoechst Dyestuffs and Chemicals Trading Co. Ltd., New Toyama Building, no. 10, 2-chome Azuchi-machi, Higashi-ku, Osaka.

HUELS Chemische Werke Hüls A.G. Marl, Kreis Recklinghausen (Federal Republic of Germany).
U.S.A. Henley & Co., Inc., 202 East 44th Street, New York 17, N.Y.
United Kingdom Herbert G. F. Greenham, 41/42 Dover Street, London W.1.
France SOGEP, 45, avenue Kléber, Paris-16e.
Italy Eigenmann & Veronelli, Piazza S. Maria Beltrade, 8, Milano.
Sweden A. Johnson & Co., Hans Michelsensgatan 2, Malmö.
India Chika Ltd., Mehta Chambers, 13 Matthew Road, Bombay 4.
Japan Chemdyes Ltd., 8th floor, Chiyoda Seimei Building, 2-chome Kyobashi, Chou-ku, Central PO Box 1125, Tokyo.

ICI Imperial Chemical Industries Ltd., Millbank, London S.W.1 (United Kingdom).
U.S.A. ICI (New York) Ltd., 444 Madison Avenue, New York, N.Y. 10022.
France ICI (France) S.A., boîte postale 305, 69, rue Ampère, Paris-17e.
Germany (Fed. Rep.) ICI (Deutschland) GmbH, Schaumainkai 17, Frankfurt am Main.
Italy Beghe & Chiapetta, via Ironzo 25, Milano.
Sweden Svenska ICI, Box 184, Gothenburg.
India ICI (India) Private Ltd., PO Box 182, GPO, Calcutta 1.
Japan ICI (Japan) Ltd., GPO Box 411, 8th floor, Palace Building No. 10, 1-chome, Marunouchi, Chiyoda-ku, Tokyo.

KAUTSCHUK Kautschuk GmbH, Leerbachstrasse 21, Frankfurt am Main (Federal Republic of Germany).

MO & DOMSJÖ Mo & Domsjö AB, Strandvagen 1, Stockholm (Sweden).
U.S.A. Gaston Johnston Corporation, 24-64 45th Street, Long Island City, 3, N.Y.
United Kingdom Modo-Products, 4/6 Savile Road, London W.1.
France Seppic S.A., 70, avenue des Champs-Elysées, Paris-8e.
Italy Gei & Heidenreich, piazza Castello, 20, Milano.
Japan F. Kanematsu & Co. Ltd., Central PO Box 209, Osaka.

MONTECATINI Montecatini, via F. Turati, 18, Milano (Italy).
U.S.A. Chemore Corporation, 2 Broadway, New York 4, N.Y.
United Kingdom Joseph Weil & Son Ltd., 39-41 New Broad Street, London E.C.2.
France Procédés Industriels & Produits Chimiques, 7, rue Vièle, Paris-17e.
Germany (Fed. Rep.) Montan-Chemie GmbH., Baselerstrasse 37, Frankfurt am Main.
Sweden Aktiebolaget Teaf, Skeppargatan 26, Stockholm 14.
India R. K. Dundas Eastern Ltd., 133 Mahatma Gandhi Road, Fort, Bombay.
Japan Shiro Trading Co. S.A., Fukoku Building, 2-chome-Uchisaiwai, Cho-Chiyoda-ku, Tokyo.

PECHINEY-SAINT GOBAIN 16, avenue Matignon, Paris-8e (France).

REVERTEX Revertex Ltd., 51-55 Strand, London, W.C.2 (United Kingdom).

RHÔNE-POULENC Société des Usines Chimiques Rhône-Poulenc, 21, rue Jean-Goujon, Paris-8e (France).
United Kingdom *Sheet and film:* M. & B Plastics Ltd., 23-25 Eastcastle Street, London W.1. *Polymers:* R. W. Greeff and Co. Ltd., 31 Gresham Street, London E.C.2.
U.S.A. Rhodia Inc. N.Y., Central Building, 230 Park Avenue, New York 17, N.Y.
Italy Luigi Clivio, via Matteo Bandello, 6, Milano.
Germany (Fed. Rep.) Herbert Bahr, Grosse Burstah 23, Hamburg 11.
Sweden Aktiebolaget Trebec, Postfach 16077, Stockholm 16.
India Voltas Ltd., Graham Road, Ballard Estate, PO Box 199, Bombay.
Japan Nichizui Trading Co. Ltd., Kinsan Building, Nihonbashi Muromachi, Chuo-ku, Tokyo.

RÖHM & HAAS (Fed. Rep. Germany) Röhm & Haas GmbH., Weiterstadtstrasse 42, Darmstadt.

United Kingdom Cornelius Chemical Co., Ibex House, Minories, London, E.C.3.
France Produits Chimiques de la Seine, 45, avenue Kléber, Paris-16^{e}.
Italy Theodore Mohwinckel, via Mercalli, 9, Milano 323.
Sweden A.B. Texotan, S. Brog 2, Gotenburg 14.
Japan Higuchi Oil Co. Ltd., 14 Building Marunouchi, Tokyo.
India Bakelite (India) Private Ltd., India House, P. Box 1948, Bombay 1.

ROHM & HAAS (U.S.A.) Rohm & Haas Co., Independence Mall West, Philadelphia, Pa., 19105.
United Kingdom Lenning Chemicals Ltd., 26 Bedford Row, London W.C.1.
France Minoc S.A.R.L., 17, rue de Miromesnil, Paris-8^{e}.
Italy Filital S.p.A., piazza Velasca, 5, Milano.
Japan Sanjo Trading Co., 11 2-chome, Kandaniskiki-cho, Chiyoda-ku, Tokyo.

SCOTT BADER Scott Bader and Co. Ltd., Wollaston, Wellingborough, Northants (United Kingdom).

SHAWINIGAN Shawinigan Products Corporation, Shawinigan Falls, P.Q. (Canada).
U.S.A. Monsanto Company, International Division, 800 N. Lindbergh Boulevard, St. Louis, Mo.
United Kingdom Shawinigan Ltd., Marlow House, Lloyd's Avenue, London E.C.3.
India Monsanto Chemicals of India Private Ltd., Wakefield House, Sprott Road, Ballard Estate, Post Box 344-A, Bombay 1.

SHELL Shell Chemical Co. Ltd., Marlborough House, 15 Great Marlborough Street, London W.1 (United Kingdom).
U.S.A. Shell Chemical Co., 50 West 50th Street, New York 20, N.Y.
France S.A. des Produits Chimiques Shell-St. Gobain, 27, rue de Berri, Paris-8^{e}.
Germany (Fed. Rep.) Deutsche Shell Chemie GmbH., Mainzerlandstrasse 82/84, Frankfurt am Main 1.
Italy Shell Italiana S.p.A., Palazzo Shell, Piazza della Vittoria, Genova.
Sweden AB Svenska Shell, 64 Birger, Jarlsgatan, Stockholm 19.
India Burmah-Shell Oil Storage and Distributor Co. of India Ltd. (Chemicals), PO Box 688, Burmah Shell House, Currimbhoy Road, Ballard Estate, Bombay 1.
Japan Shell Sekiya K.K., Tokyo Building, 3-2 chome, Central PO Box 1239, Marunouchi, Chiyoda-ku, Tokyo.

UHU-WERK UHU-Werk HnM. Fischer Bühl Baden (Federal Republic of Germany).

UNION CARBIDE *See* Bakelite.

VINYL PRODUCTS Vinyl Products Ltd., Butter Hill, Carshalton, Surrey (United Kingdom).
U.S.A. Reichhold Chemicals, R.C.I. Building, White Plains, N.Y.
France Reichhold-Beckacite S.A., boîte postale 21, 119, route de Carrières, 95 Bezons (Val d'Oise).
Germany (Fed. Rep.) Reichhold Chemie A.G., PO Box 1081, 2 Hamburg 1.
Italy Resia, S.p.A., Casoria, Napoli.
Sweden Perstorp AB, Perstorp.
India The Ahmedabad Manufacturing & Calico Printing Co., Calico Chemicals and Plastics Division, Arik-Chembur, Bombay 74 (AS).
Japan Dainippon Ink and Chemicals Inc., 3,3-chome, Nishiki-Cho, Kanda, Chiyoda-ku, Tokyo.

WACKER Wacker-Chemie GmbH., Prinzregentenstrasse 22, München (Federal Republic of Germany).
U.S.A. Henley and Co. Inc., 202 East 44th Street, New York, N.Y.
United Kingdom Bush, Beach and Segner Bailey ICI, Marlow House, Lloyds Avenue, London E.C.3.
France Arnaud & Rouff, 2 rue Jules César, Paris-12^{e}.
Italy Fratelli Wittner, via Mario Pagano 10, Milano.
Sweden A.B. Paul Freyse, Box 102, Stockholm.

Subject index [1]

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[1] Further information on certain products printed in *italics* in this index may be found in the 'Index of Trade Names', pp. 329-331.