cameras and bellows, featuring through-the-lens metering, for use on a copying stand. Other Leica 'R' macro lenses for use with this system enable reproduction from infinity to × 3.

The 'M400' photomacroscop of Wild-Leitz is a fully integrated unit featuring 35 mm to 9 × 12 cm format, automatic exposure control, and a 1:5 macrozoom objective, focusing being accomplished via a binocular system. With the optional use of three additional objectives and using the 35 mm format it covers the macro range × 1 to × 20. A 1:6 'Apozoom' objective has recently been introduced for this set-up. Wild-Leitz also offer a similar automatic system in the macro range on their 'M420' zoom macroscop. It is debatable whether the macrozoom lenses used on these systems can out-perform the individually computed Leitz or Nikon macro lenses, although the photomacroscop would seem to win over the 'Aristophot' and 'Multiphot' in terms of convenience of operation, combined with the relative lack of experience required to obtain reasonable results.

Special techniques

More specialist techniques are sometimes employed in the macrophotography of fossils. Stereophotography involves photographing the specimen in two slightly different attitudes differing by an angle of rotation of 7–10° (Fig. 1D). The resultant two photographs give a three-dimensional image when optically fused by means of a steroscope (Evitt 1949). Immersion of a specimen in a liquid such as alcohol, water, glycerin, or xylene is undertaken particularly if the fossil is of low relief, and where the distinction between the fossil and the surrounding matrix needs enhancement, and also to make clearer internal structures (Rasetti *in* Kummel & Raup 1965). Photographs taken in ultraviolet radiation at low inclinations also bring out features of low relief (e.g. Whittington 1985). Lastly, X-ray photography with the use of long exposures has been successfully employed on pyritized material (Stürmer *et al.* 1980). A combination of the above techniques is possible, as with stereo and X-ray photography.

Processing and printing

A fine grained developer should be used for the film, to maintain detail. The enlarger should have a good quality lens and hold the film perfectly flat. Resin coated paper has advantages over traditional fibre-based paper in speed of development, fixing, and washing, and the fact that glazing is unnecessary — it can be simply air-dried if required. Multigrade paper (either fibre-based or resin coated) is convenient to use and enables very fine contrast control on the finished print by utilizing enlarger filters graduated to half a grade of monograde papers; it also makes redundant the potentially wasteful practice of having five boxes of different grade paper open simultaneously. Glossy paper provides a wider range of contrast and tone, and more detail than matt paper. Optimum use of space and prints of matching tone with parallel edges are necessary for an aesthetically pleasing plate (Fig. 1).

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6.2.4 Electron Microscopy

D. CLAUGHER & P .D. TAYLOR

Both the transmission (TEM) and scanning (SEM) electron microscopes have wide-ranging applications in palaeobiological research, including studies of skeletal microstructure and growth, functional morphology, and taphonomy.

Transmission electron microscopy

The TEM produces an image by passing a beam of electrons through a specimen which must be very thin (90–250 nm) and must fit onto a 3.5 mm diameter microscope grid. Methods for investigating fossils using the TEM were developed in the early days of carbon replication. This technique involved coating a specimen with carbon, dissolving the specimen, and examining the carbon replica of the specimen surface in the microscope. Although much useful information could be gained using carbon replicas, the technique was relatively unpopular because of limitations on specimen orientation in the microscope, and the delicate nature of the replica. Before the advent of SEM, however, small specimens, such as coccoliths and diatoms, and fragments of larger specimens were routinely examined in this way.

Fossil plant and animal tissue is generally mineralized and unsuitable for direct study with the TEM. However, unmineralized tissue may be prepared for TEM examination by releasing it from the matrix using acids or other solvents. The released tissue is thoroughly washed in distilled water to remove any remaining acids or solvents, and is then dehydrated through a graded series of acetone solutions. After two changes in pure acetone, it is embedded in an epoxy resin. Sections are cut with a glass or diamond knife on an ultramicrotome, then mounted on grids, dried, and examined in the TEM (see Glauert 1974). Using this method Urbanek & Towe (1974) were able to produce some excellent micrographs of unstained graptolite tissue, and the palaeobotanical literature contains many similar examples.

Scanning electron microscopy

The introduction of the SEM in 1968 gave palaeontologists an instrument of such versatility that 20 years later new techniques for investigation are still being developed. The SEM produces an image by bombarding the surface of a specimen held in a high vacuum with a stream of electrons. This provokes the generation of X-rays, secondary electrons, and backscattered electrons, which may be collected and processed to form a visual image of the specimen on a cathode ray tube (see Goldstein *et al.* 1981). The method is non-destructive, and some microscopes can accommodate specimens up to 10 cm in diameter.

Stereoscopic images can be prepared with SEM. Two photographs are taken at a separation of 8° and, when examined using a stereo viewer, these may give much additional information on the spatial arrangement of the specimen. Good examples of this application can be found in issues of *A Stereo-Atlas of Ostracod Shells* (British Micropalaeontological Society, London).

A disadvantage of the early SEMs was that all material to be examined had first to be coated with a thin layer of conducting metal such as gold, platinum, or aluminium. Many museum curators are unwilling to commit type or other valuable specimens to this treatment, despite the fact that some coatings can be subsequently removed (e.g. gold by treatment with cyanide). A device known as CFAS (charge free anticontamination system) is now available which allows uncoated specimens to be examined (Taylor 1986). The microscope chamber is pumped to a poorer vacuum than the gun and column, and a backscattered electron detector is used in place of the normal secondary electron detector to collect the signal. Specimens do not have to be glued or permanently attached to a stub, but are simply held on a metal plate with plasticine or a similar substance which does not contaminate the inside of the microscope. Clear micrographs of uncoated specimens can be obtained using CFAS (compare Fig. 1E, F).

The coating of valuable specimens may also be avoided by preparing replicas (Fig. 1C) for examination in the SEM. Hill (1986) investigated various replicating materials and concluded that cellulose acetate (which must be used with care on delicate material) gave the best results, whereas the more commonly used latex rubber gave poor results.

The method of attachment specimens to stubs is of paramount importance, especially if the specimen is later to be recovered for examination of the reverse side. Double-sided adhesive tape is commonly used because it is convenient and permits specimen removal using an organic solvent. However, this is not a recommended procedure; the volatile components of the adhesive tape evaporate in the microscope and deposit in the form of carbon on the inside of the column and apertures, giving rise to poor image resolution. A simple and inexpensive method for attaching microfossils (e.g. foraminifera, pollen, and spores) and small fragments of macrofossils is as follows: (1) cut dried processed film into small squares and glue it to stubs with the emulsion side of the film uppermost; (2) moisten a small area of the film with water using a fine paintbrush to soften the gelatin; and (3) manipulate the specimens onto this area and leave them to dry (after examination, removal or reorientation can be achieved using a wet paintbrush).

Permanent attachment of material to stubs should be made with epoxy resin (not the quick setting varieties, which may not set as hard as normal types). Only small quantities of epoxy should be used for small specimens, and special care should

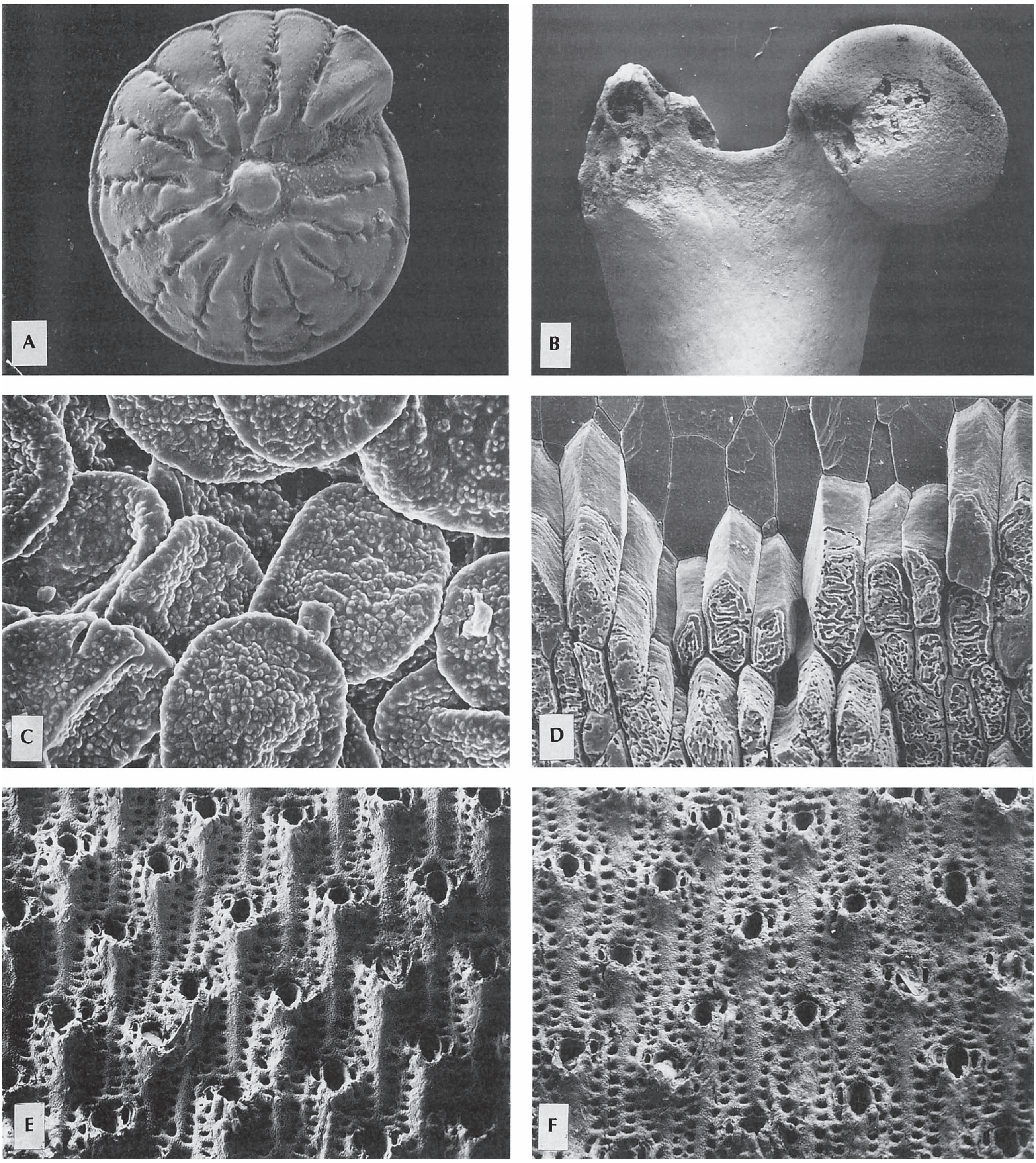

Fig. 1 Scanning electron micrographs illustrating some of the diverse palaeobiological applications of the SEM. A, Umbilical view of the benthic foraminifer *Pseudorotalia yabei* (Ishizaki), a species from the Miocene of Borneo potentially useful in stratigraphy, × 33. (Micrograph courtesy of Dr J.E.P. Whittaker.) B, Proximal end of a rodent femur from a British Pleistocene cave site showing evidence of digestion by a predator, × 10. (Micrograph courtesy of Dr P.J. Andrews.) C, Dow Corning silicon rubber replica of *in situ* spores of the fern *Qasimia schyfsmae* (Lemoigne) from the Permian of Saudi Arabia, × 1000. (Micrograph courtesy of Dr C.R. Hill). D, fractured shell of the British Jurassic bivalve *Deltoideum delta* (Smith) showing prismatic microstructure with endolith borings, × 335. E,F, part of a colony of the bryozoan *Metrarabdotos moniliferum* (Milne Edwards) from the Pliocene of U.K. depicted as a conventional secondary electron image of the gold-coated specimen (E) and a backscattered electron image of the uncoated specimen (F) prepared using CFAS, × 13.

be taken with porous material which tends to absorb the adhesive and in some cases obscures surface detail. For very small fossils (e.g. diatoms), which are not practicable to mount individually, the following method is advocated: (1) abrade a clean stub with very fine wet and dry emery paper, wash thoroughly in an ultrasonic bath and dry; (2) rub epoxy resin into the abraded surface using a cocktail stick and remove the excess adhesive with a lint-free tissue such as 'vellin' to leave the epoxy only in the very fine grooves; and (3) onto this surface place the specimens which will adhere permanently.

Coccoliths are among the most difficult fossils to prepare, but dry material can be treated as above if the stub is very finely abraded and the excess epoxy wiped off very thoroughly. The most successful method for mounting coccoliths is simply to abrade a stub with very fine emery paper, wash, dry, and then pipette a suspension of material onto the stub; dry and coat before examining.

Many fossils in the SEM accumulate charge which degrades image quality. Charging may be related to the composition of the specimen, poor attachment to the stub, or inadequate coating. The use of CFAS, a backscattered electron detector, or reduction of the accelerating voltage may eliminate charging but often does so at the cost of poorer resolution. One of the most promising developments to help overcome the charging problem is a method of collecting and processing the signal prior to recording it, known as *scanstore*. The last and most successful method is the use of a Field Emission SEM. This instrument produces a thousand times more electrons than a conventional SEM and can be operated at very low voltages without apparent loss of resolution.

Quantitative and qualitative analysis of elements can be undertaken with suitably equipped SEMs (and also TEMs). Analysis is usually best carried out on flat specimen surfaces, but new computer controlled and corrected systems can allow analysis of rough surfaces.

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6.2.5 Determination of Thermal Maturity

J. E. A. MARSHALL

Introduction

Fossils, in addition to their importance in biostratigraphy, are invaluable as indicators of *thermal maturity* or *rank*. The fossil groups used are exclusively microfossils and have to be organic (e.g. spores) or have an organic component in a mineralized wall (e.g. conodonts). Such microfossils indicate thermal maturity because their organic matter alters through progressive burial. As temperature increases with depth, hydrogen and oxygen are lost in excess to carbon, which changes physical properties such as colour, reflectivity, and fluorescence. Thus measurement of these properties is an estimate of the maximum temperature reached, although determination of exact values is complicated by factors such as time. Not all methods are of equal value for the different microfossil groups, or applicable throughout the geological column.

Vitrinite reflectivity

The origins of thermal maturation studies lie in the investigation of coal rank and particularly the optical properties of coal revealed by incident light examination of polished blocks. (If light is shone on the polished coal surface a consistent amount is reflected back, proportional to burial depth.) The coal maceral adopted for measurement is *vitrinite*; the rank indicator is known as *vitrinite reflectivity* and is expressed as a percentage. Vitrinite is not restricted to coals and is found widely dispersed in dark mudrocks (but not carbonates). Measurement is made on a microscope equipped with a photometer and stabilized power sources; the sample is observed using oil immersion objectives to obtain sufficient contrast to resolve individual macerals. Measurements are made relative to a standard of known reflectivity for calibration. Reflectivity determination is routine, although difficulties can be encountered in identifying vitrinite and discriminating between types of vitrinite which behave differently during maturation. There is also the phenomenon of suppressed reflectivity values in amorphous organic matter (A.O.M.) kerogen rich in as opposed to woody dominated kerogen — the former showing systematically lower values. This effect must be considered when comparing samples, or in calibration against temperature.

The relationship between temperature and vitrinite reflectivity is not simple: time must be considered in addition to maximum temperature (time--temperature dependence remains a controversial subject, but the concensus is moving towards temperature as the single factor). Temperature values corrected for the effect of time can be estimated directly from a *Karweil type diagram* (Fig. 1) in which both are cross plotted against a series of reflectivity values. More complex models are also used, which involve a detailed burial history rather than a single heating event. In many instances vitrinite reflectivity is used as a thermal index without recourse to temperature conversion and, as such, is the most widely accepted indicator of hydrocarbon generation. Hydrocarbons, such as oil and gas, are generated by the action of heat on kerogen over time, so vitrinite reflectivity values may be used to define the major phases of generation. In general, reflectivity values below 0.5% show that no hydrocarbons have been generated, whilst the range 0.5–1.3% defines the oil window where the bulk of hydrocarbons are produced. Gas production continues above 1.3%.

Spores and pollen

Colour. The colour of spores and pollen is the second most important index of organic maturity after vitrinite reflectivity. When determining colour in spores and pollen it is important always to select taxa of similar construction, as variation occurs in any assemblage. It is good practice to select simple spores and pollen with a 'single' unpigmented wall and without prominent sculpture; the sacci of bisaccate pollen satisfy these criteria and are ubiquitous in most Permian to Recent sediments.

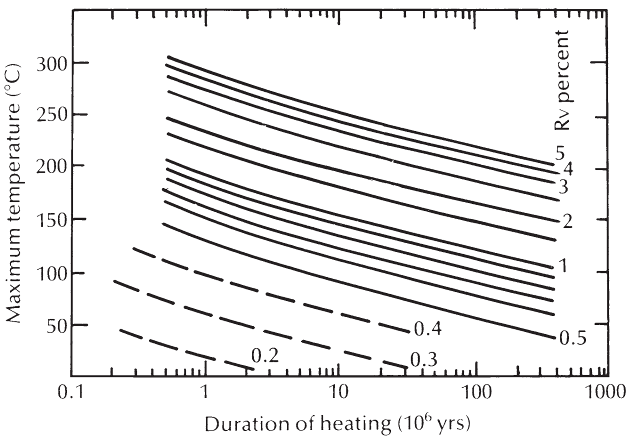

Fig. 1 A Karweil type diagram from which maximum temperature can be determined from known vitrinite reflectivity and estimated duration of heating/burial. (From Bostick *et al.* 1979.)

Colours are estimated on a visual scale (Fig. 2) by reference to a set of spore/pollen standards (most of which have been produced by commercial laboratories and are therefore not widely available because of cost and confidentiality).

The range of colour in spores is continuous and the scale boundaries are imposed arbitrarily. The colours are also difficult to describe in words so that, without recourse to standards, these scales can only be crudely applied. They are also frequently non-linear when compared to both depth of burial and other maturity indicators; brown and darker colours become unpredictable in their occurrence, rendering the scales of limited value at higher temperatures. The influence of time is important since changes in colour are not instantaneous. Thus a time–temperature cross plot like that used for vitrinite can be employed (Fig. 3) to estimate maximum temperature. The correlation of colour against vitrinite reflectivity in different depositional basins does not give a constant relationship since these materials behave differently kinetically. Differing geological histories result in different durations of thermal input and each basin has a somewhat different correlation.

Fluorescence. The walls of spores and pollen (in common with plant cuticle, acritarchs, dinoflagellate cysts, and certain types of A.O.M.) fluoresce in the visible spectrum when excited with ultraviolet light. Fluorescence colour (Fig. 2) varies both with organic matter composition and thermal maturity. The generation of these colours requires a sophisticated microscope with an incident ultraviolet light

Spore colour	SCI	TAI	Rv (SCI)	RCH	Spore fluorescence colour & spectra
Colourless–pale yellow	1		0.3		Blue-green
Pale yellow–lemon yellow	2	1.5	0.4	0.5	400 700 Green–yellow
Lemon yellow	3	2.2	0.5		
Golden yellow	4		0.6	0.7	Yellow
Yellow orange	5	2.4	0.7	1.0	Yellow–orange
Orange	6		0.8		
Orange brown	7	2.6 2.8	0.9	1.2	
Dark brown	8	3.0	1.0	1.4	Orange–red
Dark brown–black	9	3.5			Brown
Black	10	4.0	1.5	2.0	No further fluorescence

Fig. 2 A comparison of the Spore Colour Index (SCI) and Thermal Alteration Index (TAI) scales with verbal colour description. Vitrinite Reflectivity (Rv), Chitinozoan Reflectivity (Rch), spore fluorescence colours, and spectra are also included. The latter are measured over the range 400–700 nm and normalized to the same relative intensity. (From Otterjahn *et al.* 1974; Fisher *et al.* 1980; Smith 1983.)

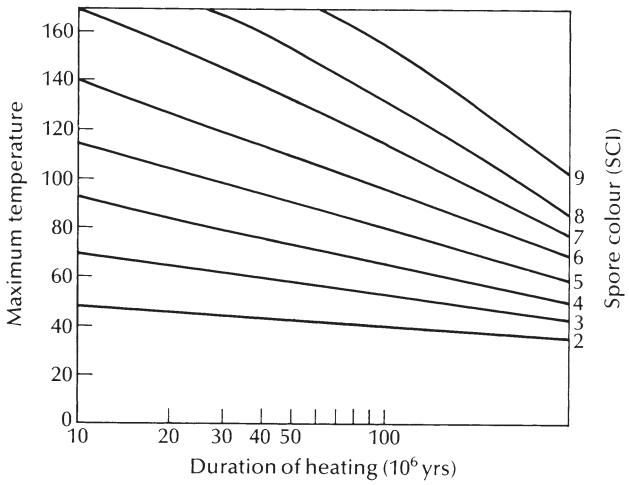

Fig. 3 A Karweil type diagram from which maximum palaeotemperature can be determined from a known spore colour (SCI only) with an estimated duration of heating/burial. (From Cooper 1978.)

source and dichroic beam splitters. The colours are difficult to estimate (in comparison to spore colours in white light) as they are pastel shades and rather faint. Colour can also be quantified with a photometer/monochrometer that generates a curve relating intensity–wavelength (nm), for which the maximum peak height, width, and position change with maturity (Fig. 2). Quantitative fluorescence measurements are complicated by additional factors, such as intensity fading, microscope corrections, and uncertainty over absolute standards. The technique is therefore only employed in specialist laboratories.

Conodonts

Conodonts have proved a popular group for determination of rank in Palaeozoic rocks due to the widespread adoption of a single colour scale and the availability of standards. The *conodont alteration index* (CAI) is an eight-point scale (Fig. 4) that covers the temperature range $<50°$ to $>700°C$. It is thus applicable to the widest range of maturity, including schists, although above CAI 6 difficulties occur in the event of hydrothermal alteration. The essential difference between conodonts and other microfossils used in organic maturation studies is that conodonts are composed of a phosphatic mineral, with only trace amounts of organic matter. The initial colour changes (1–5) result from maturation of this

Table 1 Use of fossils as indicators of organic maturity.

Microfossil group	Reflectivity	Colour	Fluorescence	Geological range
Spores	*	***	**	Silurian–Recent
Pollen	*	***	**	Devonian–Recent
Acritarchs		*	*	Precambrian – sub-Recent
Dinoflagellate cysts		*	*	Triassic–Recent
Chitinozoans	*			Ordovician – Devonian
Conodonts		***		Cambrian–Triassic
Vitrinite	***			Silurian–Recent

Note: * = minor application; *** = significant use.

material, whilst above CAI 6 the mineral itself recrystallizes with oxidation of the organic matter and becomes clear. The phosphatic composition generally restricts their recovery to carbonate rocks and low rank shales, whilst the trace amount of organic matter limits the colour changes so only two CAI points are available within the oil window. Like all colour scales it is a series of points imposed on a continuous colour series and difficult to express in words, so standards are required for serious work.

Acritarchs

Acritarchs, like pollen and spores, undergo changes in wall colour with increasing maturity. They have not been as widely used because the colour changes are more subtle and difficult to determine on the thinner walled tests, whilst thicker walled forms are frequently pigmented with significant natural colour. Consequently, where their geological ranges overlap, pollen and spores are used in preference to acritarchs. In the Lower Palaeozoic, where spores and vitrinite are largely absent, acritarch colour (and fluorescence) become important (although conodont colour is also available for this interval). An acritarch colour alteration index has been produced (Fig. 4), with a five point scale based on colour changes in simple leiospheres.

Chitinozoans

Polished sections through chitinozoan walls show reflectivity properties similar to the vitrinite maceral (a calibration is given in Fig. 2). Usage is still only at an initial stage but chitinozoans should provide early Palaeozoic researchers with a quantitative scale as precise as that of vitrinite. Chitinozoans have the advantage of being large and thus easily measured in comparison to acritarch walls; they can also be recovered from every type of sediment within which they occur, unlike conodonts. Problems with low numbers in polished whole-rock preparations can be solved by using polished thin sections.

Other microfossil indicators of thermal maturity

Kerogen components, such as dinoflagellate cysts, plant cuticle, and most types of A.O.M., generally show colour and fluorescence changes with increasing rank in a similar way to spores and pollen, although changes relate differently to temperature. For various reasons they have not become established as routine thermal maturity indicators but can be used if required, and related approximately to the major points of existing scales. Situations where they are used include A.O.M. rich or distal

<table>
<tr><th>CAI</th><th>Temp. range (°C)</th><th>Conodont colour</th><th>AAI</th><th>Acritarch colour</th><th>Hydrocarbon generation</th></tr>
<tr><td>1</td><td><50–80</td><td>Pale yellow</td><td>1</td><td>Translucent–light yellow</td><td rowspan="2">Immature</td></tr>
<tr><td rowspan="2">1½</td><td rowspan="2">50–90</td><td rowspan="2">Very pale brown</td><td>2</td><td>Light yellow–pale yellow</td></tr>
<tr><td>3</td><td>Pale yellow–orange</td><td rowspan="3">Oil & wet gas</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">60–140</td><td rowspan="2">Brown–dark brown</td><td>4</td><td>Orange–dark brown</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">Black</td></tr>
<tr><td>3</td><td>110–200</td><td>Very dark greyish brown–dark reddish brown</td><td rowspan="7">Dry gas</td></tr>
<tr><td>4</td><td>190–300</td><td>Black translucent</td></tr>
<tr><td>5</td><td>300–480</td><td>Black opaque</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>6</td><td>360–550</td><td>Medium dark grey–medium grey</td></tr>
<tr><td>6½</td><td>440–610</td><td>Medium light grey–light grey</td></tr>
<tr><td>7</td><td>490–720</td><td>Very light grey–white</td></tr>
<tr><td>8</td><td>>600</td><td>Colourless or crystal clear</td></tr>
</table>

Fig. 4 Correlation of conodont colour and acritarch colour with verbal colour descriptions, temperature ranges, and the main zones of hydrocarbon generation. (From Legall *et al.* 1981; Rejebian *et al.* 1987, by permission of the Geological Society of America.)

oxic marine kerogen facies which may either lack a terrestrial input, with no spores, pollen, or vitrinite, or have had it diagenetically modified and/or diluted.

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6.3 Museology

6.3.1 Collection Care and Status Material

P. R. CROWTHER

Introduction

The fundamental aim of good fossil storage is to ensure the long-term survival of specimens, thus guaranteeing their future availability for study and display. The clean, ordered storage of specimens in a controlled environment is the physical basis of a good collection (Brunton *et al*. 1985; Rickards *in* Bassett 1979). The ability to view and handle fossils easily, the use of appropriate containers, and the logical ordering of specimens enables material to be found as required, often without recourse to a manual index or computerized documentation system (Section 6.3.2).

Storage environment

Storage areas should be as free as possible from fluctuations in temperature and relative humidity (r.h.). Extremes and rapid changes of r.h. are the most common cause of damage to fossil material in museums. The vulnerability to oxidation of pyritized fossils and pyrite-bearing matrices ('Pyrite Disease') increases to unacceptable levels when r.h. rises above about 55%. Neutralization of affected material (Cornish *in* Crowther & Collins 1987) is no protection against future damage, which can only be prevented by keeping r.h. down. On the other hand, subfossil bone and some shale matrices shrink and crack when r.h. falls below about 45%. Rapid fluctuations of r.h. causes some clays and shales to swell and shrink alternately, leading to deterioration and loss. Monitoring and control of r.h. is therefore essential in geology storage areas, to keep conditions at 50 ±5% r.h. This is achievable either through full air conditioning or, more economically, through the use of portable dehumidification and humidification equipment. Conditioned silica gel can maintain small, sealed volumes (storage boxes or display cases) at whatever r.h. is required.

Temperature variation alone has little detrimental effect on fossil material, but because temperature is so intimately associated with r.h. (a fall in temperature causes r.h. to rise, and vice versa), its stabilization is essential for r.h. control. A combination of high r.h. and high temperature accelerates the hydrolysis of hemicellulose to acetic acid in the wood of oak or birch ply cabinets; this may attack calcareous fossils and matrices (the so-called 'Bynes Disease') and such woods are best avoided for cabinet construction.

Airborne dust is a particular and obvious menace to collections. It makes material difficult to examine and its removal is both time consuming and potentially damaging to fragile specimens. Dust proofing can be incorporated at several levels within a quality storage system: individual storage trays can be made deep enough to support acetate tops; storage drawers and boxes should have tightly fitting lids; and the mobile bays in a compactable racking system can be edged with seals which mesh together when picking aisles are fully closed.

Storage furniture

The ordered physical storage of fossils in a controlled environment cannot be realized cheaply. The specialized storage requirements of 'difficult' categories of specimens dictate particular solutions, e.g. large vertebrates (Brunton *et al*. 1985; Gentry *in* Bassett 1979). Inside more generalized storage units, specimens should sit in paper-lined card trays (made of acid-free materials) to prevent abrasion and mixing. Storage unit design should be flexible regarding the use of drawers or shelves, and in the variety of drawer or shelf depths. They should incorporate good dust seals. Wooden cabinets are preferable (but not oak or birch ply for the reason given above) since they buffer against changes in r.h. and cushion vibration. Mobile, rail-mounted, compactable racking systems make the most effective use of limited space, but they require strong floors and inevitably subject their contents to more vibration.

Status material

Article 72(g) of the 1985 *International Code of Zoological Nomenclature* (see Section 5.1.1) states that name-bearing types (holotypes, syntypes, lectotypes, and neotypes) are international standards of reference and are held in trust for science by those responsible for their safe keeping. Institutional responsibility in this regard is set out in the Code's Recommendation 72G as follows:

Every institution in which name-bearing types are deposited should:

1 Ensure that all are clearly marked so that they will be unmistakably recognized as name-bearing types.
2 Take all necessary steps for their safe preservation.
3 Make them accessible for study.
4 Publish lists of name-bearing types in its possession or custody.
5 So far as possible, communicate information concerning name-bearing types when requested.

Failure to heed this code of practice hinders the progress of science and puts type material at risk. Any museum holding fossil type material should have a geologist on its permanent establishment; any university department or museum with types but no designated curator should deposit them elsewhere (Owen 1964). It is the responsibility of the name giver to ensure that types go to an appropriate repository, and it follows that editors must insist on authors carrying out this duty as a condition of publication. Indeed, taxonomic practice would be greatly enhanced if all status material (type, figured, and referred specimens) had to be registered in an appropriate institution as a condition of publication.

The question of how best to store status material has provoked some disagreement (Brunton *et al*. 1985, p. C25). Arguments that favour separating status material from the main collections include: meeting the ICZN and ICBN requirements regarding type specimen care; convenience of access; increasing its physical security in better quality storage by improving protection from theft and damage from fire, flood, etc.; and ease of evacuation in emergencies. Disadvantages of isolating such material include the risk that users might overlook its existence when working through the main collection; and that it might be totally destroyed in the event of a disaster affecting that one particular part of the store.

Whether type material should remain in its country of origin is another vexed question, although the ability of the home country to properly house and curate such material must be a primary consideration. Practices differ from nation to nation: Canada has legislation to ensure that types erected on Canadian material taken abroad for study are eventually repatriated; the Palaeontological Museum, Oslo, functions in effect as the National Museum for Norway and preferred policy is for all Norwegian primary type material to be held there (Bruton *in* Bassett 1979); the British Museum (Natural History) regards its holdings as international in scope, and considers it essential that related collections from different parts of the world are kept together, because palaeontology is a comparative science (see comment by Ball *in* Bassett 1979, p. 147).

Publication of a museum's holdings of status specimens should be given high priority, since the dissemination of such information to the world at large is one of the important responsibilities that goes with being a type repository. Many of the larger museums can utilize an in-house publication for this purpose (Section 6.4), while smaller repositories can still fulfil their obligations to the wider scientific community via specialist journals such as the *Geological Curator*.

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6.3.2 Collection Management and Documentation Systems

P. R. CROWTHER

Introduction

All science depends on being able to 'repeat the experiment', to check the data on which conclusions drawn by others were based. In whatever way the fields of palaeobiology, biostratigraphy, taxonomy, evolutionary studies, etc. are delineated, each relies to a greater or lesser extent on our interpretation of the fossil record. It follows that fossil collections and their associated data represent the primary material evidence that underpins the intellectual structure of these elements of Earth science. The survival and availability of such collections is crucial to the advancement of knowledge, so that past results can be checked and new observational and analytical techniques can be applied. Without museum collections, palaeobiology could not exist.

The management of museum collections concerns the accessioning, control, cataloguing, use, and disposal of specimens. The accelerating awareness of the importance of collections management has been triggered by: pressures on museums to demonstrate accountability for their collections; modern security and audit requirements; and the higher standards of inventory control expected by governing authorities (Roberts 1988). Effective documentation is the key to collections management and is essential if the legitimate aspirations of museum users are to be met.

Information storage and retrieval

A fossil without certain basic information (locality, stratigraphy, collector, etc.) is of little scientific value, however visually attractive it may be. Conversely, the most unprepossessing fossil fragment can continue to provide answers to new questions if it was effectively documented at the outset. A precise record of where, when, and how such a fossil was collected, and by whom, guarantees its future utility. All serious collectors have an obligation to science to ensure the long-term survival of their fossil material — which may represent an irreplaceable resource from a temporary exposure, and was perhaps collected at great public expense from a remote part of the globe.

The principle of being able to repeat an observation is as axiomatic to the large numbers of specimens associated with biometrics, population dynamics or phylogenetics as it is to the holotype concept in taxonomy. Today's collector/researcher can ensure the continued availability of primary source material — be it a unique type specimen or the thousands of measured specimens in a statistical study — by:

1 Allocating a unique identifying number to each specimen at the earliest opportunity.

2 Securely recording certain essential data about the specimen (locality, stratigraphy, collector name, collection date) and keying such a record to the specimen via its unique identifier.

3 Greatly improving the specimen's chances of survival and long-term availability for future study by depositing it in an appropriately staffed and funded museum.

This procedure ensures that the specimen's latent scientific potential is protected. The additional benefits that follow from producing specimen labels, classified catalogues, indexes (by donor, locality, age, etc.) are many, and certainly make a collection more accessible to the user. But they can all be created later as required, manually or by computer, if the essential collection data has been properly recorded. Museum collections are assemblages of facts in the form of specimens, specimen-related data (Light *et al*. 1986), and (increasingly) site-related data (Raup *et al*. 1987; Crowther & Wimbledon 1988). Many of these facts are available nowhere else; in the museum they remain available for reexamination, reinterpretation, and restructuring, over and over again (Waterston *in* Bassett 1979). The physical well-being of collections (Section 6.3.1) and the dissemination of information relating to those collections are both fundamental to the role of museums in Earth science today. An effective documentation system is the key to fulfilling such a role.

The theory of how best to permanently link a specimen with its essential data is well established in museology, using a unique number and a secure register of sequentially ordered data entries. Unfortunately, museum performance in this area has often left much to be desired, either through curatorial incompetence or (more usually) through understaffing and the tug of conflicting priorities.

The efficient retrieval of specimen data in a form capable of satisfying the needs of all museum users has proved an intractable problem. The traditional, manual approach is to maintain alongside the main register as many running card indexes (by taxon, locality, age, donor, etc.) as staff time allows. Any collection is to some extent 'self indexing' through the classified storage strategy adopted — by taxonomic group, stratigraphical division, geographical location, or (more likely) by a combination of these. But in reality many museums are unable to keep pace even with basic registration of specimens, and it is very rarely possible to resource a fully effective manual system.

Computerized documentation systems

Computing techniques are having a major impact on both the scale and type of problems being attacked within contemporary palaeobiology (Section 6.1). Museums were quick to appreciate the potential of computer-based information technology for the sorting and selective retrieval of specimen-related data. Any conceivable index can be generated from a single input of specimen data, and interactive retrieval can be used to interrogate the database directly. Some museums with access to mainframe computers, either in-house or through computer bureaux, now have more than 15 years of experience to draw upon. The more recent development of the desk-top microcomputer, with its increasingly more powerful data-processing abilities and data storage capacity, has opened up the same advantages to a much wider spectrum of potential users. The sophisticated inputting, sorting, batch, and interactive retrieval routines that characterized the mainframe software packages of the nineteen-seventies can now be duplicated on a micro, while the storage capacity of hard discs enables typically lengthy museum specimen records to be held in sufficient numbers to cater for large collections. The availability of powerful relational database packages for microcomputers opens up exciting possibilities for the interactive interrogation of large complex files on low-cost hardware, in a way that would have seemed impossible just a few years ago. The capacity of the newest optical storage media makes it likely that within a very short time storage will cease to be any kind of limiting factor, even for the very largest collections.

The effectiveness of computerized information retrieval has had additional benefits on the way museums deal with specimen-related data. The information must be structured in a standard form before inputting, and the terminology applied to different data categories must be rigidly controlled if sorting procedures are to produce useful output. This inflicts higher standards of data recording on museums than has traditionally been the case. Taken to its logical extreme, the adoption of a single data standard by museums, combined with an agreed thesaurus for terminology control, opens up the exciting prospect of combining museum databases and of their remote interrogation by users. However, there is as yet little international agreement about the structuring of museum data, and the question of terminology control is at an even more rudimentary stage. The U.K. is probably as far advanced as any other country in this regard, with the Museum Data Standard of the Museum Documentation Association (MDA) now in widespread use by museums, whether they employ the MDA's manual recording cards and/or supporting software packages or choose to develop in-house applications of commercial database packages.

Full computerization of specimen records entails a massive short-term commitment of data preparation time, since it obviously involves keying in all the manual records accumulated during a museum's history. Crucially, it also entails structuring the data and terminology to conform with agreed standards — and rigorously checking the data input. This is beyond the staffing resources of most museums, and computerization is commonly restricted initially to upgrading inventories; detailed computer cataloguing is often limited to new material entering the museum. Nevertheless, the automatic scanning of manual records using developments of the 'optical character readers' already available open up the exciting possibility of direct input of typed or even handwritten records to a computer database, thereby drastically reducing data preparation time.

At a time when museums are coming under increasing pressure to make their reserve collections more accessible, new technology has an important role to play. As the efficient management of large taxonomic collections in the public domain becomes increasingly expensive, those responsible for such collections must become more adept at justifying their unique role to those who ultimately pay the cost through taxes or entrance charges. A database compiled for basic collections management purposes can be made available to the general visitor via interactive terminals, after only minor modifications to strip out sensitive information (donor address, insurance value, storage location, etc.). Linked to a video disc (which are already capable of holding 50 000 images), such a system could provide instant visual access on demand to a collection, yet involve no physical risk to the specimens themselves.

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6.3.3 Exhibit Strategies

R. S. MILES

Introduction

The purpose of mounting exhibits is normally to communicate information, so this section looks at some of the principles behind successful *distance communication*. By distance communication we imply the existence of a gap, either in time or space, between the sender and receiver of a message. This mode of communication applies typically to exhibits, whether comprising single posters or entire museums. Classroom teaching, lectures and demonstrations, on the other hand, involve face-to-face communication, in which the sender is there in person. It is important to distinguish between these two modes of communication, because if the sender is not there to answer questions, an effort must be made, at the stage of designing the communication, to ensure that it is intelligible to its intended audience. Good communication is selected for a purpose, and has a sound logical structure. Successful communicators know their audience, and attend both to the content ('what to say') and the form ('how to say it') of their communications.

The audience

The organizers of exhibits inevitably form a mental image of their audience. Ideally this is based on hard data, e.g. the audience's vocabulary, understanding, interest in the subject, and commitment to its study. Care must be taken to avoid creating a false image, either through professional self-interest or limited experience of the audience. Where sufficient data are not available, survey techniques similar to those found in market research can be used. Questionnaire design and sampling methods have been described by Loomis (1987) and Miles *et al*. (1988). Accurate knowledge of the audience helps the communicator to connect his or her message with the viewer's world, and use language that is matched to the viewer's requirements. It is also helpful to know about the audience's misunderstandings (or 'alternative conceptions'), for these may need to be removed before the desired information can be imparted. For example, an intuitively held Lamarckian view of evolution might block understanding of Darwin's theory of natural selection.

Selection and structure of content

What to communicate, where to start, and how to continue? — in other words, the selection and ordering of the content — are basic questions in organizing any exhibit. Generally, there is more to say about a subject than the space or other resources allow, or the viewer's stamina permits, and there has to be some selection. The basis of this selection is a clear statement of purpose. For a group of exhibits this statement takes the form, at the broadest level, of a series of *aims*. But a more detailed statement of purpose is required for individual exhibits, and this is best provided by listing the *teaching points*, i.e. the facts, concepts, relationships, procedures, and so on that need to be communicated. Teaching points generally divide into key concepts and ancillary points. Thus some are included simply in order to define other concepts or to remove misconceptions, others to ensure the positive transfer of knowledge. Teaching points also help to promote clear communication among those responsible for exhibits, and provide a basis for judging the success of exhibits as pieces of communication (below).

The ordering or sequencing of content is done with the help of a strong central theme, to give a good flow of ideas and a framework that unifies the facts, theories, and so on that are spelled out in the teaching points. It is important to tell only one story at a time; to organize things so that the audience knows what is going on (e.g. where they are going and how long it will take to get there); and to make the status of each message clear (e.g. is it the main conclusion or a supporting argument, is it a question or an instruction?).

A common way of ordering ideas is to place them in a logical sequence, e.g. concept A is dealt with before concept B because concept A must be understood before concept B can be understood. However, it is often unwise to argue from first principles in exhibitions for the lay public, because of the need to attract and keep the viewer's interest and connect the message to his or her familiar world. Thus, if no particular sequence of concepts can be chosen on grounds of logical relations, it might still be better to deal with concept A before concept B, because on psychological grounds it is easier for the viewer to understand concept A before concept B (Fig. 1).

To help the audience know what is going on it should be told, in an introductory exhibit, what the exhibits are about and how they are organized. In large exhibitions it may be necessary to repeat such information in different places. In addition to conceptual orientation, it may also be necessary to provide topographic orientation, i.e. signposts, maps, and exhibit numbers. The aim is to indicate the correct route through the exhibits, and such orientation devices must be designed to make sense to viewers who have no prior understanding of the content and arrangement of the exhibits (Miles *et al*. 1988).

Selection of media

Communications media are the physical means of transporting messages from the sender to the receivers. Some media are normally used in the static mode, e.g. three-dimensional objects, graphics, and text; others are used in the dynamic mode and undergo a change of state during operation, e.g. audiovisuals and interactive computers. Selecting the appropriate medium for a particular message is important, yet never easy. There are few rules to assist the selection procedure, and the assessment of setting-up and maintenance costs is likely to weigh as heavily as educational advantage.

If an exhibit is to communicate change over time or movement (e.g. continental drift), it is useful to use a dynamic medium, possibly a film or working model. But the basic exhibit media still remain

1. Diversity of life —— 2. Charles Darwin
3. Domestic selection
4. Species as taxonomic groups
5. Species as breeding groups
6. Reproductive potential
7. Environment
8. Inheritance + variation —— 9. Population genetics
10. Theory of natural selection —— 11. Types of selection
12. Allopatric speciation

Fig. 1 Chain of concepts from an exhibition on *Origin of species* at the British Museum (Natural History), London. Logical dependency relations are found between concepts 12 and 10, 11 and 10, and 6, 7, 8, and 10 — although 6, 7, and 8 (the premises of the theory) could be in any order. Concepts 1–5 are ordered in relation to 6–12, and to each other, on psychological grounds.

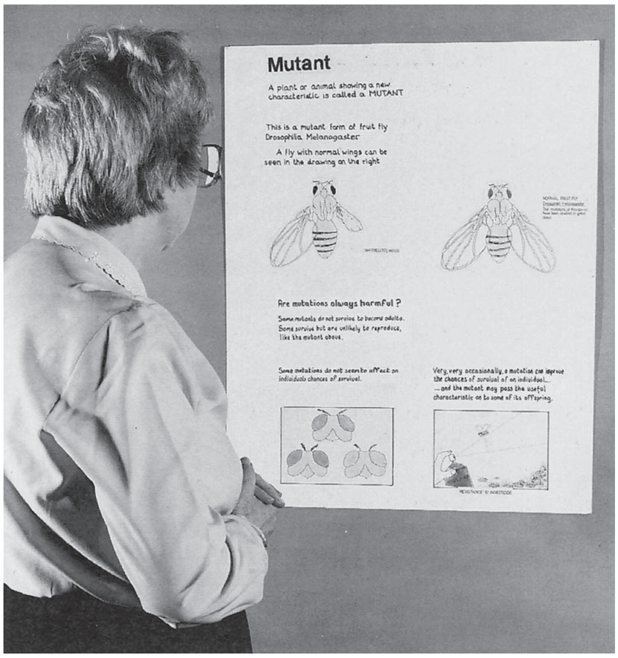

Fig. 2 Mock-up of an exhibit used in developmental testing.

objects (real things, replicas, and models), graphics (illustrations, diagrams, and photographs), and text (text panels and labels), and these are often used in combination. Although traditional, these media nevertheless require skill and care if they are to be used effectively. Lighting, conservation (e.g. certain fossils decay if conditions exceed 60% relative humidity; print fades under ultraviolet rays), the selection of type and line lengths, and the integration of different media so that they work together, are just some of the things that have to be considered. For further information on all aspects of design, see Screven (1986), Hall (1987), and Miles *et al.* (1988).

Static object-cum-graphics exhibits elicit a relatively passive response from viewers, who are simply asked to look and read. However, educationalists have long understood that actively engaged learners are more likely to be successful than passive learners, which has led to the development of 'hands-on' exhibits that involve viewers in some sort of physical activity. This may be as simple as handling specimens, or as complex as operating interactive videodiscs. With larger exhibitions the more modern, dynamic media also give variety to the exhibits, which serves to maintain the viewers' interest. One caveat here: it is normally a good idea to employ professional help with complex media such as audiovisuals and computers. Such media are difficult to use well, and the exhibits are expensive to set up and maintain.

Testing

It is difficult for the distance communicator to be sure that a message will be clearly understood without further explanation. Exhibit organizers who check on the effectiveness of their displays are often surprised at the variety of interpretations put on apparently simple and straightforward messages. The causes are to be sought in viewers' alternative conceptions, the different meanings attached to words, and the false perception of objects and graphics. The need to know the audience has been mentioned above; a further important way of lessening the chance of being misunderstood is to put exhibits through a process of developmental testing (also called *formative evaluation*).

The recommended procedure is called *cued testing*. Rough mock-ups of the exhibits are made. These may be handwritten, and photographs or drawings can often substitute for three-dimensional objects (Fig. 2). The mock-ups are then tried out on small samples of the intended audience (ten people are generally sufficient) with the help of a simple questionnaire. Designs can be quickly adjusted and the procedure repeated until satisfactory results are obtained. This is a qualitative approach involving no difficult statistics, and its worth has been demonstrated over and over again with a variety of audiences and institutions. For further information on the procedure, and for examples of questions used in testing, see Jarrett (1986). Broader aspects of evaluation, including the summative evaluation of completed exhibitions, have been covered by Loomis (1987) and Miles *et al*. (1988).

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6.4 Societies, Organizations, Journals, and Collections

J. NUDDS & D. PALMER

International bodies

There are two international bodies whose areas of interest serve to link palaeobiologists world-wide.

International Union of Geological Sciences (IUGS). This is one of the three largest scientific unions in the world. It was founded in 1961 to facilitate international co-operation in geology and is affiliated directly to UNESCO. Much of its work is concerned with the establishment of international commissions and committees on various branches of geology, e.g. Commission on Stratigraphy (see Section 5.8), Committee on Geology Teaching, and its membership is composed mainly of international associations. There is, however, no commission on palaeontology, although the International Palaeontological Association (see below) is affiliated to the IUGS. *Episodes*, which replaced the *Geological Newsletter* in 1978, is the official organ of the IUGS.

International Palaeontological Association (IPA). This is the major international organization linking palaeontologists throughout the world. Originally titled the International Palaeontological Union (IPU), it was formed in 1933 in Washington, D.C., at the Sixteenth International Geological Congress, its aim being the collaboration and co-operation of international activity in palaeontology and stratigraphy. Membership was open to both societies and individuals. On becoming affiliated to the IUGS in 1966, the IPU was required to alter its name from 'Union' to 'Association', although this was not formalized until 1972.

Much of the IPA's activity is devoted to fostering smaller research groups (e.g. International Association for the Study of Fossil Cnidaria, Graptolite Working Group, etc.) and providing a forum for international co-operation between them (for list see Teichert & Yochelson 1985). The IPA also co-sponsors relevant meetings and is currently composed of some 22 societies and nearly 500 individual members. *Lethaia* is its official organ (see below).

Societies and organizations

There are over 500 extant geoscience organizations according to a directory published in *Geotimes* (1987, **32**(10); annually updated); some 30 or more are solely palaeontological but these do include several small local societies. Listed below are those relatively few international and major national palaeontological organizations, with information on their publications, etc. Also appended to this chapter (Appendix 1) is a more extended list of contact addresses for a number of other palaeontological organizations world-wide.

There are also many 'non-geological' societies whose interests and activities impinge upon palaeontology and result in meetings and publications of direct concern to the palaeontologist, e.g. the Linnean Society, the Systematics Association, the Royal Society of London, the Society of Economic Paleontologists and Mineralogists. Access to this literature is best gained through the standard Earth science and biological bibliographies, such as the *Bibliography and Index of Geology* and *Biological Abstracts*.

Association of Australasian Palaeontologists (AAP). This is a specialist group of the Geological Society of Australia and is responsible for a variety of publications. Its official journal is *Alcheringa* (see below), while the *Memoir* series (begun in 1983) have thus far been either thematic in nature or in honour of an Association member. The free annual newsletter, *Nomen nudum*, acquaints members with the activities of palaeontological colleagues throughout Australasia. Members of the AAP, who must also be members (ordinary, associate, or student) of the Geological Society of Australia, receive *Alcheringa* at a reduced rate, while the *Memoirs* are individually priced. Applications for membership should be made to: the Administrative Officer, Geological Society of Australia Inc., 606 A.N.A. House, 301 George Street, Sydney, New South Wales 2000, Australia.

Palaeontological Association. Founded in 1957 to promote research in palaeontology, the Association is based in London, U.K., but has a world-wide membership which is open to individuals, institutions, libraries, etc. on payment of the appropriate annual subscription. Institutional membership is only available by direct application, not through agents, while student membership is open to persons receiving full-time instruction at an institution recognized by Council. Applications for membership should be made to: the Membership Treasurer, Dr. H.A. Armstrong, Department of Geological Sciences, The University, South Road, Durham DH1 3LE, U.K. The Association holds an Annual Conference in December, and organizes review seminars, lecture meetings, and field excursions throughout the year. It publishes the quarterly journal *Palaeontology* (see below) and a quarterly *Newsletter*, which are issued free to all members of the Association; and *Special Papers in Palaeontology* (see below).

Paleontological Society. Founded in 1908, the Paleontological Society is based in the U.S.A. and produces a number of publications. Applications for membership should be made to the Secretary, Dr D.L. Wolberg, New Mexico Bureau of Mines, Socorro, NM 87801, U.S.A. All members receive the bi-monthly *Journal of Paleontology* (see below) and *Memoirs of the Paleontological Society* (see below). Members may also receive the quarterly journal *Paleobiology* (see below) at a reduced subscription. (*Paleobiology* Subscriptions, P.O. Box 1897, 810 East 10th St., Lawrence, KS 66044, U.S.A.). The Society also publishes two series of topical publications: *Short Course Notes* are published each year as part of the University of Tennessee Studies in Geology Series, for distribution at the Society's annual short course, held with the Annual Meeting of the Geological Society of America; the *Special Publications* series includes the proceedings of symposia sponsored by the Society at its regional meetings. Both are available from The Paleontological Society, Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996–1410, U.S.A.

Palaeontographical Society. Founded in 1847, the Society exists for the purpose of figuring and describing British fossils in its *Monographs* (see below). Subscriptions are due on 1st January each year. Membership applications should be made to the Secretary, Mr S.P. Tunnicliff, British Geological Survey, Keyworth, Nottingham NG12 5GG, U.K. All members receive the Annual volume, which consists of a number of complete or part monographs. Members also receive 25% discount on all in-print and reprinted publications, and 33% discount on micro-edition publications, which may be ordered through the Secretary.

British Micropalaeontological Society (BMS). Founded in 1970, the Society's aim is to further the study of micropalaeontology. Meetings and demonstrations are held regularly throughout the year and the BMS now publishes a number of both serial and occasional publications. Membership is open to individuals and to libraries on payment of the appropriate annual subscription. Membership applications should be made to the Treasurer, Dr. I.P. Wilkinson, British Geological Survey, Keyworth, Nottingham NG12 5GG, U.K. Publications include the *Journal of Micropalaeontology* (see below) and