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Volume 6 Number 8

GEOLOGICAL CURATORS' GROUP

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

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

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Cover: A broken *Arambourgiania philadelphiae* metacarpal premodel being repaired using household filler. See article by Lorna Steel *et al.*, p. 305 - 313

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GEOLOGICAL CURATORS' GROUP - November 1997

THE REPAIR OF MICROVERTEBRATE MAMMAL TEETH USING SURFACE TENSION AND CAPILLARY ACTION

by Paul C. Ensom

Ensom, P.C. 1997. The repair of microvertebrate mammal teeth using surface tension and capilliary action. *The Geological Curator* 6(8): 293-295.

The recovery of fragments from the same minute mammal teeth has necessitated the development of a novel method for their repair. Working under a binocular microscope, surface tension has been used to accurately locate and hold in place fragments of the same tooth. Capillary action has then provided the means to draw an adhesive along the fracture while maintaining a perfect or near-perfect join.

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Introduction

Occasional sub-millimetre sized fragments of mammal teeth which are themselves frequently less than a millimetre in size, are amongst considerable numbers of microvertebrate specimens contained in an horizon within the Cherty Freshwater Member of the Purbeck Limestone Group (Lower Cretaceous, Berriasian) of southern England. The specimens picked from residues concentrated from the horizon are the subject of active research (Ensom *et al.* 1994, Ensom and Sigogneau-Russell in press, Kielan-Jaworowska and Ensom 1992 and 1994 and Sigogneau-Russell and Ensom 1994).

The damage is likely to be partially the result of compaction of the sediments in which the microvertebrate remains were buried but may also be the result of the processes used to concentrate the specimen rich residues. Evidence for the former can be deduced from one specimen where making a perfect join between the two parts was impaired by a tiny calcite crystal within the pulp cavity of one fragment. Other specimens recovered have been fractured but remain in contact, cemented by calcite or other diagenetic deposits. Evidence for the latter is difficult to quantify but experiments are being carried out to see if different grading techniques used on the residues before they are picked will lead to a reduction in breakages.

As one or more fragments of the same tooth are occasionally found, there has been a need for a novel method of repair suited to the size of the specimens in question.

The aims

- To accurately position pieces of tooth together.
- To introduce adhesive to the fracture without coating the surfaces of the tooth, while maintaining a perfect union of the fragments.

The problems

Repair of such tiny fragments poses the following problems:

- The handling and manipulation of the fragments.
- Identifying fractures common to fragments and ascertaining the order in which they should be bonded together.
- Accurately uniting two or more pieces and successfully bonding them together.

The handling and manipulation of fragments is carried out using a moistened 00 sable brush while working under a stereo-zoom binocular microscope. The identification of which piece of tooth belongs is best ascertained with the specimens dry. However, as outlined in Stage 5 below, a drop of water on the broken surfaces can help to bring together different elements through surface tension.

The bonding of such minute broken surfaces introduces an additional range of difficulties:

- The application of adhesive onto a fracture surface and the positioning of tooth fragments may lead to the

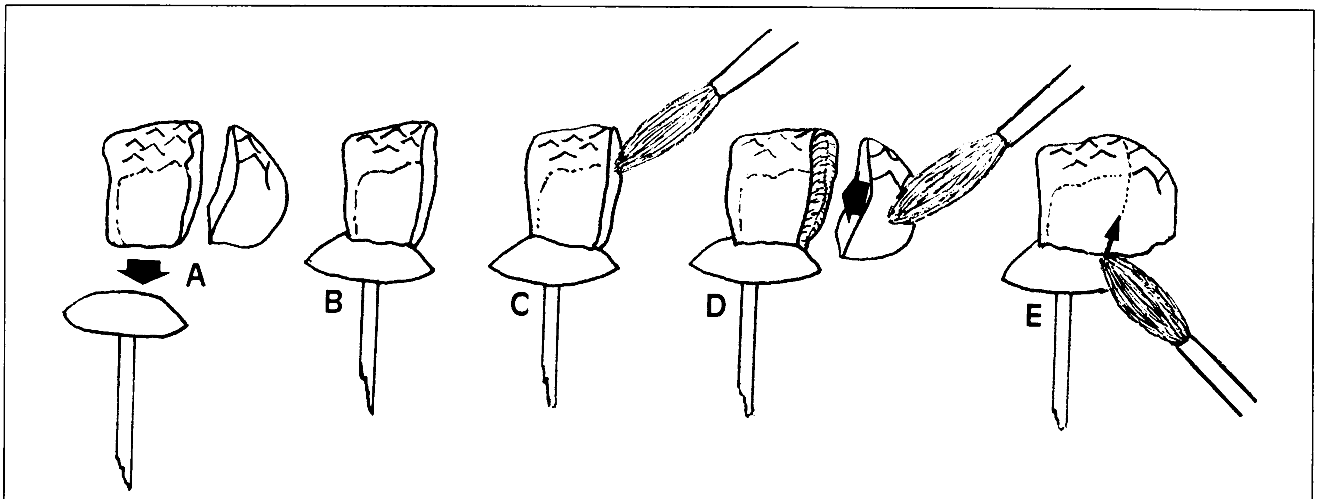

Figure 1. Schematic diagram showing stages in the repair of a multituberculate tooth. Not to scale. **A.** The two fragments to be joined; **B.** The larger fragment is attached to the stainless steel pin; **C.** Water is applied to the broken surface; **D.** The second fragment is placed on the wet fractured surface of the tooth; **E.** The brush carrying a very dilute solution of p.v.a. is touched against the fracture at the base of the tooth. Capillary action enhanced by water in the fracture draws the thin adhesive solution along the fracture.

adhesive encroaching onto the surface of the tooth, potentially obscuring important details.

• The premature attachment of the fragment with the pieces incorrectly aligned.

• If the adhesive layer is too thick it causes a significant displacement of the tooth fragments. This will compound the problems of accurately locating minute fragments in a multiple fragment repair.

• A thin coat of adhesive is liable to dry rapidly, especially if solvent based, and any delay in positioning the fragment may end with fragment(s) having to be cleaned before starting again.

Ideally the bonding should be easily reversible, either during the process or at a later date.

Equipment and materials

The following are required: a binocular microscope and good light source; a piece of clean and fibre-free cloth; a 00 sable brush; corked glass tubes with a stainless steel pin inserted in the cork; distilled or deionised water; aqueous p.v.a. adhesive; an embryo dish for both holding the water and providing a margin upon which to mix solutions of adhesive; absorbent material to draw off excess water or adhesive from the brush. Additionally a very steady hand and, on some occasions, boundless patience is required.

Repairing the tooth

The following sequence of actions have been employed by the writer to achieve repairs of high quality, sometimes involving several fragments.

Stage 1. Identify the fragments and decide what order they can be bonded together.

Stage 2. Attach the root or basal part of the tooth to the pin head using a thin covering of p.v.a. adhesive. N.B. Take into account the order in which fragments will be reassembled and ensure that the piece attached to the pin is positioned in such away that the rebuilding process can proceed unimpaired by the pin head. The pin in a cork inserted in a glass tube is the storage method which has been adopted for the mammal teeth. Great care is required to ensure that during the handling and checking of fractures, fragments of tooth are not flicked over considerable distances. A surface which damps down such 'activity' is sensible as are having rims around your working area to catch specimens with a wanderlust!

The author has found that Stages 3 onwards are best carried out with the pinned specimen and the fragments on or close to the surface of the fibre-free cloth so that all items remain in the field of view and minimal vertical movement of the specimens is required.

Stage 3. Once the first fragment is securely attached to the pin in the cork making handling easier, the next fragment to be attached can be offered up against the mounted specimen. One option is to clamp the pin mounted specimen within the field of view. The draw back to this method may be the inability to manipulate both specimens at once. The advantage is that both hands are free to handle the brush, which will be used to apply first water and then a thin solution of p.v.a. adhesive to the fracture, and other materials.

Stage 4. Prepare a very thin solution of p.v.a. in water (<20% solution). Only a very small amount is required, but there should be sufficient on the side of the embryo dish to ensure that it does not dry out before Stage 6 is reached.

Stage 5. The broken surface of the tooth fragment on the pin has a tiny drop of water placed on it from the sable brush. The tooth fragment to be attached is placed on the water on the fracture. If correctly orientated, the surface tension imparted by the water between the two pieces pulls them togther. Usually, with little or no encouragement the fractures marry up perfectly. Avoid getting water on the outer surfaces of the tooth. More than one attempt is sometimes required as the water applied can be drawn down into the tooth at first. At this stage endeavour to hold the specimens so that any gravitational effects, however slight, are minimised.

Stage 6. Before the water dries out, collect a little of the aqueous solution of p.v.a. on the brush. Very carefully bring the tip of the brush against the fracture between the two pieces which are being held by surface tension. The thin solution is drawn into the fracture by capillary action, enhanced by the trace of water still present at the interface of the two fragments. Do not apply excess solution and where possible apply the solution from below the crown of the tooth, e.g. between the roots. Experience will enable the repairer to judge the amount of p.v.a. solution to carry on the brush to achieve this. If excess is applied, this can be drawn off using a clean but damp brush.

Stage 7. Check the accuracy with which the union has been made. If there are problems, e.g. an imperfect join, either:

> Immerse the specimen in water by inverting the cork and pin into a glass tube full of water and let the fragments separate. Clean and dry and then start again;
>
> *or*
>
> Apply water to the fracture and keep the two pieces mobile. Adjust their relative positions with an adhesive free brush. The danger with this approach is that some adhesive will almost inevitably escape onto the surface of the tooth and that attachment to the brush will become increasingly likely.

Stage 8. Leave to dry

Repeat Stages 3 - 8 for any additional fragments being careful not to flood the fractures with water as there is a danger of dissolving the adhesive on the repair already carried out.

Conclusions

Experience has shown this to be an highly effective means for repairing small teeth. The author has not carried out tests to ascertain the maximum size of specimen to which this can be successfully applied. A point will be reached where water will be unable to hold specimens together by surface tension, and capillary action will be unable to pull adhesives through the fractures. At this point, conventional bonding techniques will become the only practicable alternative. The technique should be effective on specimens other than teeth provided significant distortion of the bones has not occurred.

Acknowledgment

I wish to thank my colleague Stuart Ogilvy for reading and commenting on this short paper.

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THE REMOVAL OF MUSEO PALEONTOLÓGICO "RODRIGO BOTET" (VALENCIA, SPAIN) UNDER DISASTER CONDITIONS

by Margarita Belinchón, Carmen Diéguez, Ángel Montero and Plinio Montoya

GEOLOGICAL CURATORS GROUP GCG

Belinchón, M., Diéguez, C., Montero, Á. & Montoya, P. 1997. The removal of Museo Paleontológico "Rodrigo Botet" (Valencia, Spain) under disaster conditions. *The Geological Curator* 6(8): 297-303.

In 1989 a collection of South American Quaternary mammals, housed in the Rodrigo Botet Palaeontological Museum of Valencia, Spain was moved to new accommodation. This move was precipitated by the discovery of serious structural and other damage to the 15th century Arab building in which it had been exhibited and housed since 1908. The collection numbered nearly 50,000 specimens including seventeen edentate and other mammals, three thousand skeletal fragments and 43,000 Recent molluscs. The rescue operation was divided into three phases: planning and funding acquisition; treatment, packing, transportation and unpacking of specimens; development of new exhibition in a temporary location in Valencia.

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Introduction

In any approach to museology it is important to consider the vital role played by old buildings generally deemed of architectural interest and of patrimonial value. While in a number of countries including the U.S.A., Canada and Australia such a consideration may be unnecessary due to the young age of buildings, it is a point worthy of study.

Although it may seem almost paradoxical, the placing of a palaeontological collection of patrimonial value within the aged walls of an honourable ancient building (also of patrimonial worth) might not be in the better interests of either. Such was the case of the "Rodrigo Botet" collection housed in a medieval Arab building in Valencia from 1908 to 1989.

Within Europe, and indeed anywhere, where museology has been neglected, whole collections such as the Rodrigo Botet, or parts of them, are put at unnecessary and great risk. The climatic conditions of Valencia where extensive flooding can occur in an almost tropical-like manner were the determinant factor in the eventual removal of the collections to safe quarters. The removal, which will be described in detail below, is an example of a removal carried out under disaster-like conditions.

The building and the collection

At the end of the last century, the Rodrigo Botet Mammalian Collection from the Quaternary of South America was donated to the city of Valencia. In 1908 it was finally decided to temporarily house the collection in a medieval (15th century) Arab building of great historic value, and the Rodrigo Botet Palaeontological Museum was established. The collections remained at this provisional location for many decades despite its unsuitability to house or conserve the collection. This was due as much to the some characteristics of the building including high Relative Humidity, and great changes in temperature, as to the lack of adequate technical infrastructure and the disordered manner in which the collection grew. This resulted in palaeontological and malacological specimens being exhibited together with weighing and measuring instruments of historical interest.

For many years it was clear that the exhibition space in the Museum needed to be relocated. It had became out of date, lacked didactic function, and more space was required in order to house the collections. Nevertheless, this poor situation continued up to the end of 1989, when it was decided to close the Museum altogether and reallocate the collections. Due to torrential rains

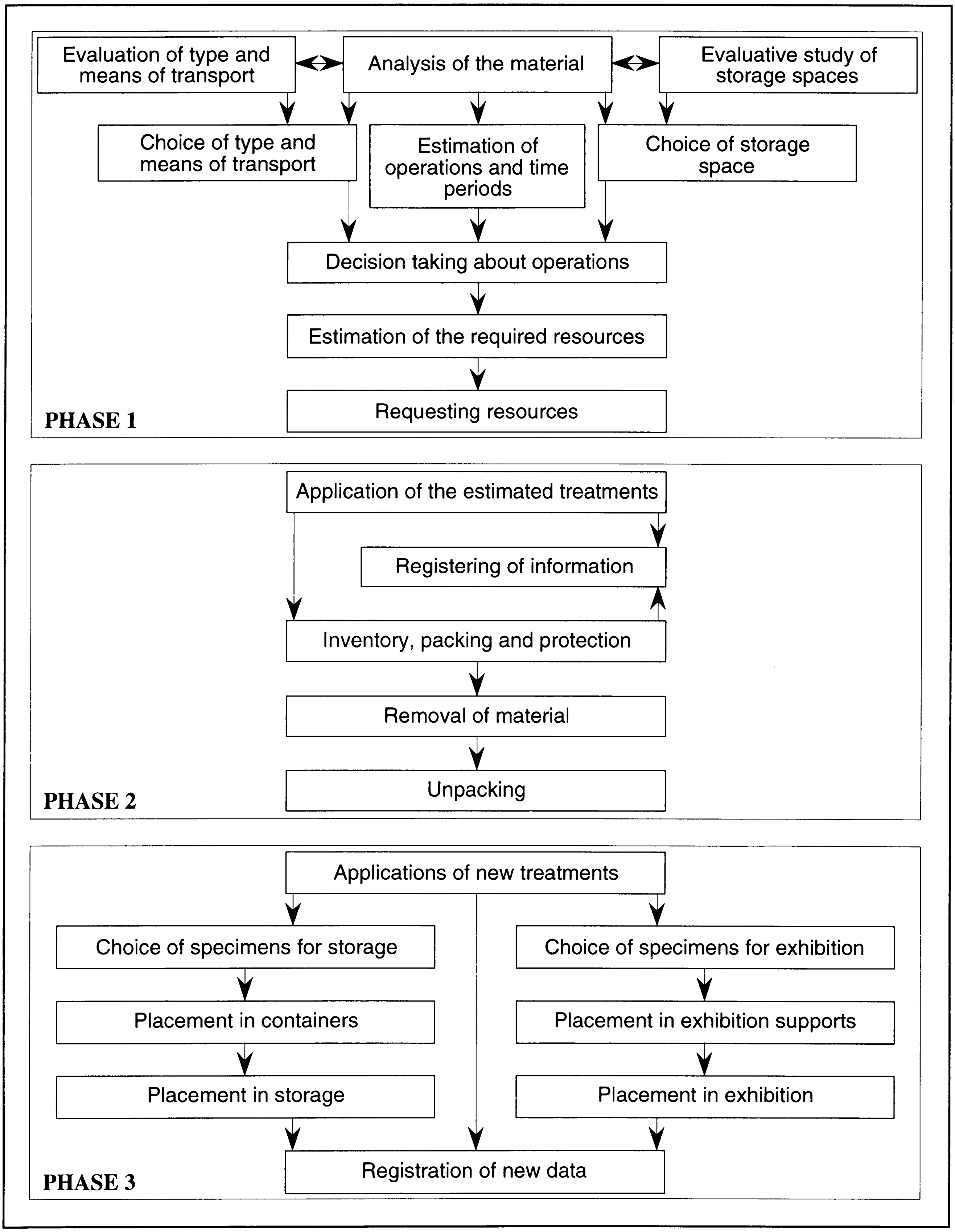

Figure 1. Flow charts of the three phases of the recovery and and restoration of the collections of the "Rodrigo Botet" collections.

which had caused serious flooding in the building, as well as structural damage to the roof, this move was urgently necessary. This dangerous situation, in terms of potential injury to the general public as well as to the specimens in the collections was first highlighted by Belinchón *et al.* (1990).

The removal of the entire contents of a museum is unusual. As far as we know, the only similar case occurred at the North of England Open Air Museum (Walden 1972). However, while there are similarities between the English case and that of the Rodrigo Botet collections, notable differences were in the type of collection removed and in the larger scale of the Spanish removal.

The rescue and removal of the collections was carried out in three phases described below.

Planning and carrying out the removal of the collections

In order to reduce the time taken for this operation, cut costs and to obtain optimal results it was decided to follow a meticulous plan which had been tried and proven successful on previous occasions (Diéguez and Montero 1991) (Figure 1). Note however, that all steps in Phase 3 were not precisely followed. We considered this the best course to follow given the very short time available and the huge volume of specimens to be moved, the majority of which were very large.

Phase 1: Planning the operation and dismantling the collections.

Prior to the task of removal a quantitative and qualitative analysis of the collections had to be made (Figure 2). In the qualitative analysis the following were taken into account: size; shape; characteristics; and preservation and conservation state of each specimen. These fundamental premises were considered in order to successfully complete the removal, since a first look at the material showed specimens such as small molluscs of less than 5 cm, and specimens in excess of 4 meters in height existing side by side. In general, there was an extraordinary variation in the composition and fragility of the material: bones, teeth, and diverse types of sedimentary rocks which included marl and limestone. The state of preservation was also very variable according to the type of fossil (complete specimens, casts, or impressions) or the conservation state, which ranged from almost intact (e.g. molluscs) to badly damaged. The latter was due to the lack of treatment and care which the specimens had received over a long period of time. Some bones encountered has a consistency was so brittle that it did not permit even very careful cleaning with a soft natural fibre brush.

Edentates (with mounted skulls)	8
Edentates (without mounted skulls)	7
Other mounted mammals	2
Post-craneal skeletal pieces	3,000
Dental elements	800
Dinosaur remains	2
Fishes	15
Fossil invertebrates	200
Living molluscs	43,000
Plants	50

Figure 2. The contents of the collection.

The results of this analysis showed up a series of points which required major attention. Firstly, and of most concern was that the entire collection, which had never been treated and had been on exhibit for almost a century in an unsuitable space, was in a poor condition. This was particularly noticeable, as we have mentioned before, in the bone remains which were so damaged, that without extreme care in their handling they could have been damaged irreparably. Some further problems also existed:

- Some large size edentate mounted skeletons including *Megatherium* and *Scelidotherium* were rather soft which together with their volume, weight and fragility hampered removal.
- Presence of type-specimens of edentate mammals.
- Existence of unique specimens such as *Eutatus punctatus* which is the only existing specimen in the world that has both its skeleton and shell. The metal structure of the mount of the specimen which was assembled at the beginning of this century, together with the fragility of the terminal parts of the limbs, resulted in this specimen being of particular concern and so it became a source of major attention.
- The form and volume of edentate shells, which with the application of lateral and/or downward pressure often results in damage and breakage.
- Fragility of fossil insects and plant remains with cuticle conserved due to their preservation type and having been fossilised in brittle marl.
- Inadequacy of the containers and fragility of the Malacological Collection.
- Lack of a complete and up to date inventory of the collection. The only inventory in existence was for the

INSTITUTION / CONCEPT	INEM	VALENCIA CITY COUNCIL	UNIVERSITY	Subtotal
Personel	2,640,000		•• 1,000,000	3,640,000
Conservation products and photography		200,000		200,000
Packaging and containers		975,000		975,000
Infrastructure*/transport		650,000		650,000
TOTAL	2,640,000	1,825,000	1,000,000	5,465,000

*: mounting structures (scaffolding, wooden planks).
••: the emoluments of museum staff (6) is not included

Figure 3. Breakdown of the expenses (in pesetas) incurred during the removal of the collections, with the contribution made by three institutions. [£1 = 230 pesetas].

Botet Collection of Edentate Mammals (Martell and Aguirre 1964) and another begun in 1984 which updated the latter. A photographic register of the funds was also lacking.

• Damage to the original labels, which had been attacked by different types of insects including moths and *Lepisma*.

As soon as we became familiar with the characteristics of the collection, with the problems which its removal could cause, with the approximate space needed for its storage and/or exhibition, and once we had made an estimate of costs (ideal preparation of the specimens for their removal; staff costs; materials for cleaning, hardening and restoration; quantity and type of packing material, etc.) and of the forecast minimum carrying out time, we applied to the Local Government for a suitable space to deposit the collection and to different institutions for the money necessary to cover estimated costs.

After studying several possibilities, the proposal to house the collection on a temporary basis at a site offered by the Council of Valencia was accepted. This site was smaller than the previous but was in good condition from an architectural point of view and fulfilled all the requisites for good conservation. It consists of five adjoining exhibition rooms offering a total area of approximately 300 m^2. A small storage room and annexed office space were also available.

The personnel team was formed of six palaeontologists, the Director of the Museum, two general assistants and two carpenters.

Costs were paid by the National Employment Office (INEM), the University of Valencia and the Valencia City Council. The contributions were divided as follows: 48.3% INEM; 18.4% University and 33.3% Valencia City Council (Figure 3).

The total costs of the removal were 5.465.000 pesetas of which 67% was for staff expenses, and 33% for material and transport.

Phase 2: Packing and transportation.

In the second phase, given that the necessity to transfer the material was becoming more and more urgent due to the rapid and progressive deterioration of the building, we opted to apply the required treatment to each piece at the same time as a complete inventory and computer programming of the data were being carried out. Later, the specimens were packed in a suitable manner (see below).

We began with the disassembly of large and heavy specimens which supposed transport problems and which were in greatest danger of being damaged if moved in their original mounts. *Megatherium americanun*, being the greatest in volume and because of its peculiar characteristics is a good example. This specimen was taken apart into twelve pieces (skull, jaw, separate limbs, pelvis). Each part was individually treated as if they were independent pieces (Figure 4).

The mounted skeletons and the bone pieces were first cleaned by hand using a soft natural fibre brush. In certain cases this was not possible due to the very deteriorated state of the bone which was so brittle that even the fibre brushes disturbed some bone material. In such cases it was decided to proceed directly to a process to harden the most deteriorated parts. Later, chemical cleaning by way of diluted alcohol and/or acetone was carried out, and after drying, further hardening, using 10% acrylic resin diluted in acetone, was achieved. The consolidator was applied by brush, since due to the lack of space and time it could not be carried out by soaking which would have been the most suitable procedure. Preference in treating specimens in this way was given to those which had been exposed to

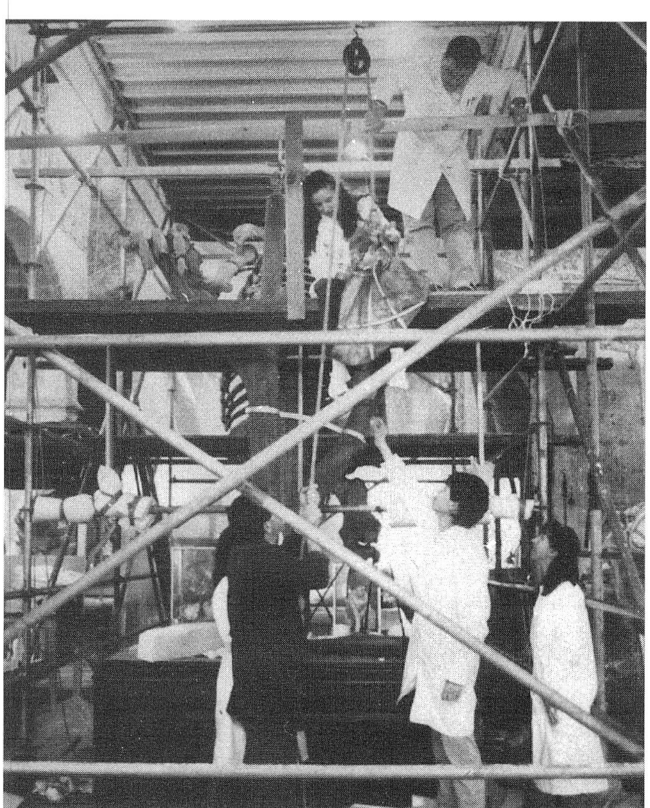

Figure 4. Removal of a wrapped portion of the *Megatherium* skeleton.

the public, some of which even showed changes in colour due to having been constantly touched.

In some cases, the dental pieces and the fossil invertebrates were not treated as they did not require any type of technical treatment. Insects and fossil plants were not treated because of their extremely delicate state of preservation.

The specimens of the Malacological Collection were cleaned of dust in a dry state with an artist's paintbrush before packing.

The labels, due to their precarious state of conservation having been attacked by bibliofagous insects (*Lepisma*), were treated with specific insecticides.

In beginning the packing, we took into account that the materials could be grouped into three categories according to their characteristics:

• Twenty-seven mounted, complete or partially complete skeletons of great size and weight.

• Isolated fossil specimens (teeth, bones, invertebrates, fossil plant remains.

• The Malacological Collection. The specimens which formed the latter two groups were packed in the same type of packaging due to similarity in fragility and size.

The assembled skeletons and the diverse parts into which *Megatherium* was divided were packaged with a triple layer of protection starting with, on the inside, acid-free paper then, moltoprene of different widths (from 0.5 to 1.5 cm) depending on the specimen (ribs, skulls, long bones) and finally, a plast-ball layer. The packaging was fixed by adhesive tape, after which an assembly of splints of pine wood of various widths (from 0.5 to 3 cm) were applied. The widths varied according to the volume and the weight of the specimen or piece, and had the function of totally immobilising the articulations (Belinchón *et al.* 1992). After packaging, the specimens were put into ready-made pine wood boxes which were then screw-closed (Figure 5). This type of fastening had already been described by Stolow (1980, 1987) who also listed its inconveniences. This method was advised by one of the members of the team as the only way to avoid damage which the specimens might suffer from vibrations produced by hammering in fastening the boxes. The space between the specimen and the container was filled with moltoprene of diverse widths, in the form of corrugated strips and layers, and a wooden frame which held the specimen or the large specimen parts (*Megatherium's* pelvis).

Each wooden box was numbered and its contents listed into a control notebook with the number and the contents of each container.

The packaging process of the Malacological Collection and the small and delicate fossil specimens (dental elements, invertebrates, plants remains) was very similar to that of the larger specimens. Firstly the specimens were wrapped in a cushioning material, and together with their labels were put into polythene boxes. Previous evaluator studies had demonstrated the suitability of this type of container (Montero and Diéguez 1990, 1991). These boxes, of various sizes according to the specimen's dimensions, were then put into cardboard boxes with lids. The boxes had a standard size of 36 cm long x 28 cm wide x 13 cm high. A copy of the inventory of the contents of each box was also placed inside. With the aim of transporting the least number of packages and of avoiding the dispersal of the collections, every twelve of these boxes were placed into other

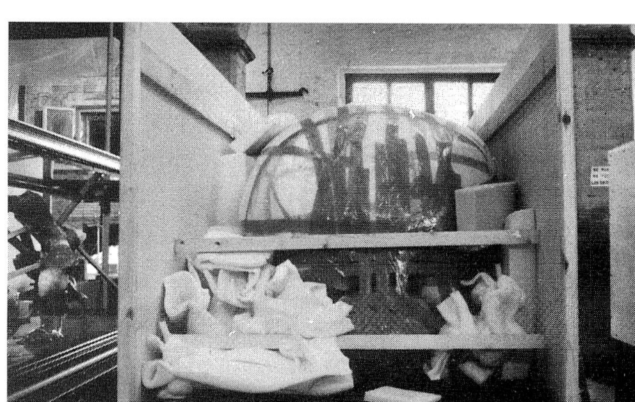

Figure 5. Specimen in packing case awaiting transportation.

boxes of more resistant cardboard and were securely placed by putting moltoprene layers of 0.5 cm in width between them. The application of this system permitted the packaging of the entire Malacological Collection (43,000 specimens) into just only 13 large boxes. These large cardboard boxes contained a list of the boxes placed inside, and, as soon as they were sealed, they were numbered in an clearly visible place. The material, thus packaged, was orderly stored for later removal. We used two trucks and one van for the removal, distributing the boxes inside these and placing blankets and moltoprene blocks of medium width between them and along the interior sides of the vehicles to cushion possible blows which might be caused by irregularities of the road surface or abrupt manoeuvres caused by traffic during the trip. This type of cushioning was used because, as before mentioned, the vehicles used, given the brevity of the trip and the reduction of the costs, lacked any form of specialised interior cushioning.

Altogether it took a period of three months, including weekends, to disassemble, organise, treat and pack the collection.

The removal of material from the old site to the new was carried out a one single day by way of a sum total of 20 journeys.

Phase 3. Unpacking, restoration and exhibition.

As soon as the material was in its new location a selection of specimens best suited for exhibition. These were then deposited in a temporary exhibition space (Figure 5) while the remaining specimens were directly placed in storage.

The unpacking process, which affected only those specimens to be exhibited, was very carefully carried out so that in the case of damage to a specimen no fragment would be lost. While unpacking took place, a study of damage suffered was undertaken so that the most suitable remedial treatment could be applied to each case.

Primarily, damage was to a greater or a lesser degree to bone remains of some rare specimens. All of these showed some deterioration largely due to incomplete hardening which could only have been achieved by soaking the specimens. Fragments of ribs, large bones and skulls were noted. In some specimens the spongy bone parts (distal parts of large bones of the extremities) suffered, apart from fractures, a loss of bone material.

The restoration process undertaken was made up of the following steps:

• A scrupulous mechanical cleaning of each fragment.

• Joining of the fragments with ethyl and amyl acetate adhesives (soluble in acetone).

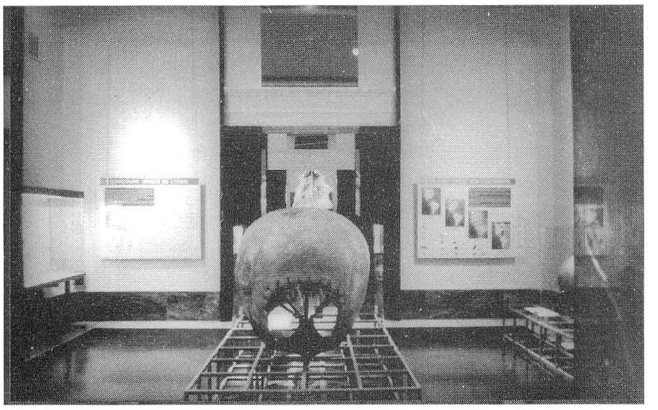

Figure 6. View of the new temporary exhibition.

• Reintegration of the lost parts using ceramic powder.

• Definitive hardening by soaking.

• Final mechanical cleaning.

The pelvis of the assembled specimen of *Megatherium* constituted a special case, as much for its size as for the scale of damages, presenting multiple fractures and significant loss of spongy bone. As a consequence of the lamentable state of this specimen, it was deemed necessary to insert stainless steel rods and restore the lacking internal tissue with ceramic powder. The restoration of missing pieces, as they were numerous, was concealed by water based paint (a reversible treatment, for aesthetic purposes).

The remainder of assembled skeletons (9 in total) presented minimum damage consisting of small fractures and fissures which were easily repaired by applying an adhesive but which did not need restoration. Other specimens which showed no damage were cleaned mechanically (soft natural fibre brush) or chemically (alcohol or acetone) as required.

As soon as the suitable treatments had been applied to each specimen they were mounted for exhibition. The *Megatherium* skeleton was placed on a metal grid platform 50 cm high, which had a methacrylate protection of 1.20 cm in height, surrounding it. The old metal structure which supported the skeleton was respected as it was in perfect condition. In mounting the specimen, the same scaffolding was used as during its dismounting.

As far as the remainder of small and medium sized specimens chosen for the exhibition were concerned, these were placed inside glass show-cases on transparent methacrylate bases and fixed in place by transparent silicone. In cases where the size or relevance of the specimen deemed fit (Ammonites, dinosaur tracks, Bennettitalean trunks) another types of exhibiting systems were employed: such specimens were exhibited freely on compact platforms with no protective barrier between them and the visitor.

Acknowledgements

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ARAMBOURGIANIA PHILADELPHIAE: GIANT WINGS IN SMALL HALLS

by Lorna Steel, David M. Martill, Jonathan R.J. Kirk, Alexandra Anders, Robert F. Loveridge, Eberhard Frey and John G. Martin

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A life-sized model skeleton of the giant pterosaur *Arambourgiania philadelphiae*, with an 11.5 metre wingspan, was designed and constructed in just 11 weeks. *Arambourgiania* was reconstructed on the basis of better-known but related pterosaurs. The postcranial skeleton was modelled in clay, moulded in silicone rubber and cast in epoxy resin. The skull was modelled from plastic sheeting, epoxy putty and polyurethane foam. The finished model appeared on the BBC's children's programme "Blue Peter", before being displayed at Portsmouth City Museum and Records Office as part of an exhibition entitled "Giant Wings over Dinosaur World" from 28th September to 10th November 1996. The exhibition has since appeared in Leicester and Germany.

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Introduction

Pterosaurs, flying diapsids of the Mesozoic, have fascinated palaeontologists since their discovery more than 150 years ago. This fascination partly stems from pterosaurs having had a wing structure (and presumably mode of flight) distinct from that of the extant actively flying vertebrates; birds and bats. More recently, renewed interest in these animals has been stimulated by the realisation that some Late Cretaceous forms reached gigantic proportions and were the largest-ever animals to fly (Lawson 1975, Langston 1981, Frey and Martill 1996).

Pterosaurian anatomy differs radically from that of other diapsids, the most obvious feature being the modification of the forelimbs into wings. The wing digit was extremely elongated and supported a flight membrane, while the other digits were comparatively short, and tipped with claws. The pteroid, a thin elongate bone, was directed anteriorly from a lateral carpal, and supported a membrane anterior to the wing finger. The extent of this membrane distally is unclear, but it probably went at least as far as the short digits. The humerus bore a prominent deltopectoral crest for the attachment of powerful flight musculature originating from a large keeled sternum. The scapulae and coracoids were fused to form a rigid shoulder girdle (scapulocoracoid) in later forms. The vertebrae in the shoulder region were often fused to form a notarium, while the sacral vertebrae were fused into a synsacrum. Two pterosaur body plans are known. The Triassic and Jurassic rhamphorhynchoid condition was characterised by a long tail with a terminal vertical vane, and the Jurassic and Cretaceous pterodactyloid condition by a very short tail and often a large skull. The hind limbs of pterosaurs were slender, with the fibula considerably longer than the femur. The fibula tended to become reduced and fused to the tibia, as did the proximal tarsals. An additional flight membrane stretched between the hind limbs in some forms, and may have been used for steering and breaking. The feet typically had long metatarsals, and long toes, with claws. In pterodactyloids, the fifth toe was very reduced.

The skulls of pterosaurs were quite variable in shape, but always delicately constructed. Some had sagittal crests, the positions and shapes of which differed between taxa. Pterosaur teeth also exhibited wide variation, and several Late Cretaceous pterosaurs were toothless. The bones of pterosaurs were extremely light due to the reduction in the thickness of the compacta, but strengthened by having complex microarchitecture, internal bracing and cross-sectional shapes which transmitted stress. For an excellent review of pterosaur construction and biology see Wellnhofer (1991).

The largest-known pterosaur, and indeed the largest ever flying animal, was *Arambourgiania philadelphiae*, previously known as *Titanopteryx* (Frey and Martill 1996). This pterosaur is known from four incomplete bones from Jordanian Upper Cretaceous phosphate deposits. The holotype material, an incomplete elongate cervical vertebra over 600 mm in length, was discovered in 1941 or 1942, but was initially thought to be a wing metacarpal (Arambourg 1959). The specimen was then lost for about 40 years, but a cast of it (see Wellnhofer 1991: 121) was reinterpreted as an elongate cervical vertebra, typical of the pterosaur family Azhdarchidae, Lawson (1975). Nessov (1984) showed that the name *Titanopteryx* was preoccupied by a dipteran fly, and erected the new name *Arambourgiania*, in honour of Camille Arambourg. In 1995, Frey and Martill launched a search for the missing holotype. In 1996, it was finally tracked down in the University of Jordan, by Mr Rushdi Sadaqah of the Jordan Phosphate Mines Co.

This vertebra (specimen number VF-1, University of Jordan, Department of Geology collections), was used as the starting point for an attempt at reconstructing *Arambourgiania's* skeletal dimensions. Other Jordanian material cautiously referred to *Arambourgiania* by Frey and Martill (1996) comprises a shorter cervical vertebra and the proximal and distal ends of the first wing phalanx. The giant azhdarchid *Quetzalcoatlus northropi*, known from an almost-complete left wing found in Upper Cretaceous strata in Southern Texas, as well as a considerable number of bones from a smaller *Quetzalcoatlus* sp., were used to determine the size of the missing skeletal elements of *Arambourgiania*. Where Texas Memorial Museum (TMM) material of *Quetzalcoatlus* was insufficient, reference was made to the skeleton of a small Chinese azhdarchid, *Zhejiangopterus* (Cai and Wei 1994, Unwin and Junchang 1997), as well as the non-azhdarchid, Cretaceous pterosaurs, *Tupuxuara* and *Pteranodon* (Wellnhofer 1978), and the small Jurassic *Pterodactylus* (Wellnhofer 1991).

Scaling up from other pterosaurs

The reconstruction of *Arambourgiania* began with a 10-day visit to the Staatliches Museum für Naturkunde Karlsruhe (SMNK), by one of us (L.S.). The purpose of this visit was to hold discussions with the staff of the Palaeontology Laboratory on the materials and methods needed for building the model, to examine the holotype material of *Arambourgiania* (which was then on loan to SMNK) and to view photographs and casts of *Quetzalcoatlus*. Photographs and drawings were made of all views of these bones, and dimensions were calculated for missing and incomplete elements.

a) The wings

The humerus (the most proximal bone in the wings of pterosaurs) was fairly stout, and bore a prominent

Species and specimen number	*Quetzalcoatlus* TMM 41961-1	*Q. northropi* TMM 41450-3	*Arambourgiania philadelphiae*
Scaling index	*x 1*	*x 2.1*	*x 2.4*
Longest cervical	315 mm	662 mm	**770 mm**
Metacarpal V	470 mm	987 mm	1128 mm
Digit V phalanx 1	585 mm	1285 mm (reconstructed)	1404 mm
Digit V phalanx 2	310 mm	651 mm	744 mm
Digit V phalanx 3	181 mm	380 mm	434 mm
Scaling index		*x 1*	*x 1.1*
Humerus		550 mm	605 mm
Radius		710 mm	781 mm
Ulna		740 mm	814 mm
Carpalia		145 mm	160 mm
Species and specimen number	*Quetzalcoatlus* TMM 42422-6		
Digit V phalanx 4	37 mm	95 mm	100 mm

Table 1. Scaling-up from specimens of *Quetzalcoatlus* to estimate the length of wing elements of *Arambourgiania*, based on the estimated original length of the *Arambourgiania* cervical. [After Frey and Martill 1996]

deltopectoral crest. The more distal bones of the wing, however, became extremely elongate and progressively narrower. In azhdarchids, a large proportion of the wing finger was formed by the elongation of the first phalanx, which had an aerofoil-shaped cross-section. The second, third and fourth phalanges were strengthened by having a "T"-shaped cross-section. The wing length in the small *Quetzalcoatlus* is approximately 2.24 m, and in the large *Q. northr*opi is restored to about 4.83 m (Frey and Martill 1996).

The wings of *Arambourgiania* are unknown (except for two fragments of a first wing phalanx which are suspected to have been associated with the holotype), so it was necessary to find a way of relating wing size to neck vertebra size. This was attempted by Frey and Martill (1996), using the relationship between the wing and the fifth cervical vertebra in *Quetzalcoatlus*. They assumed the *Arambourgiania* holotype vertebra to be the fifth, the longest of the cervical series, and used anatomical evidence to determine an original complete length of 770 mm (this has since proved to be a slight underestimate). They compared this with a 315 mm-long fifth cervical vertebra of *Quetzalcoatlus*. The probable original length of the *Arambourgiania* vertebra is 2.4 times as long as the *Quetzalcoatlus* vertebra. The wing bones associated with the *Quetzalcoatlus* vertebra were then scaled up by the same factor, to give an estimate of the size of the wings of *Arambourgiania* (Table 1).

b) The neck

Photographs of cervical vertebrae 3-9 of *Quetzalcoatlus* were examined, and life-sized drawings of each vertebra were made. The 5th cervical vertebra measured 410 mm long. To scale this length up to 770 mm, the restored length of the *Arambourgiania* vertebra, a scaling factor of 1.878 was applied. The remaining six neck vertebrae (excluding the atlas-axis) were scaled by the same factor (Table 2). A difference between the cervical vertebrae of *Quetzalcoatlus* and *Arambourgiania* is that *Quetzalcoatlus* vertebrae are slightly dorso-ventrally compressed, whereas in *Arambourgiania* they are circular or high oval in cross-section, although some of this difference may be due to compaction in the *Quetzalcoatlus* specimens. The overall shape of the model vertebrae were based on the incomplete *Arambourgiania* fifth cervical vertebra, but the configuration within the neck was based on *Quetzalcoatlus* sp. and *Zhejiangopterus*.

c) The skull

The skull of *Arambourgiania* is unknown, and azhdarchid skull morphology is poorly understood. A complete but crushed skull and lower jaw of *Zhejiangopterus*, figured by Cai and Wei (1994) and Unwin and Junchang (1997), and incomplete remains of the skull and lower jaw of *Quetzalcoatlus*, provide some insight to how the skull of *Arambourgiania* may have appeared. Incomplete cranial material of *Quetzalcoatlus* has been described by Kellner and Langston (1996), and includes a 760 mm long skull (TMM 42161-1), lacking its posterior portion, which was associated with an almost-complete lower jaw, 920 mm in length (TMM 42161-2), as well as two elongate cervical vertebrae. Assuming that the longest of these vertebrae, at approximately 400 mm long, is a 5th cervical, the scaling factor of 1.88 (previously calculated for the neck) was applied to the restored skull and lower jaw. This gave a calculated skull length of 2.11 m, and a lower jaw of 1.73 m long. The posterior part of the skull was restored according to the general morphology of *Tupuxuara*, a crested tapejarid, (a model of which

Quetzalcoatlus			*Arambourgiania*
Vertebra number	**Specimen number**	**Length**	**Scaling index x1.878**
3	TMM 42422-24	170 mm	319 mm
4	TMM 41544-8	265 mm	507 mm
5	TMM 41544-15	410 mm	770 mm
6	TMM 42180-19	380 mm	714 mm
7	TMM 42161-1	270 mm	507 mm
8	TMM 41954-42	85 mm	160 mm
9	TMM 41954-40	50 mm	94 mm

Table 2. Calculations for scaling-up the dimensions of the cervical vertebrae of *Quetzalcoatlus* to the size they may have been in *Arambourgiania*.

was examined at SMNK) and *Zhejiangopterus*, an azhdarchid (Unwin and Junchang 1997).

d) The thorax

The thorax of azhdarchid pterosaurs had several skeletal specialisations. The scapula and coracoid were fused together, and the scapula was fixed to the notarium. Similarly, fused sacral vertebrae formed the synsacrum, to which the pelvic girdle attached. The number of ribs was variable and the tail was short. A large keeled sternum was present. In pterodactyloids, the thorax was relatively small compared with the wings and skull

A model *Quetzalcoatlus* sp. scapulocoracoid (SMNK) was scaled up by the same factor as the wings (x 2.4). Photographs of a *Quetzalcoatlus* notarium (TMM 41954-60), sternum (TMM 42180-12), pelvis (TMM 41954-57) and prepubis (TMM 41954-58) were examined at SMNK. These bones were damaged, and first had to be restored according to pterodactyloid morphology. The *Quetzalcoatlus* prepubis and pelvis were associated with cervicals 8 and 9, so were enlarged by the same scaling factor (x 1.88). The sacrum of *Quetzalcoatlus* is unknown, so that of *Tropeognathus* was copied. The ribcage of *Quetzalcoatlus* is also unknown, but the notarium had facets for four ribs. The *Arambourgiania* model was given five free ribs, as in *Tropeognathus* (SMNK model).

Although the notarium and sacrum of *Quetzalcoatlus* are known, it is not clear how long the thorax was. The general body proportions of *Zhejiangopterus* were used to restore the thorax length of *Arambourgiania*. The length of the humerus of *Zhejiangopterus* is approximately two-thirds of the distance from the glenoid to the acetabulum. Extrapolating the same ratio to *Arambourgiania*, with a humerus predicted to be around 60 cm long, the distance from the glenoid to the acetabulum would be approximately 90 cm.

e) The hind limbs

In pterodactyloids, the legs were slender, and the fibula was reduced and often fused to the tibia. The femur was slightly sigmoid, bowed or straight. The head of the femur is thought to have been directed posteriorly, so that the animal flew with the anterior surface of its legs facing laterally.

The thorax length of *Zhejiangopterus* is approximately x1.09 of the femur length. With a calculated acetabulum-glenoid distance of approximately 0.9 m for *Arambourgiania*, the femur is estimated to have been approximately 0.83 m long, on the (not necessarily correct) assumption that *Arambourgiania* had similar body proportions. The tibiofibula is approximately 1.7 times the length of the femur in *Zhejiangopterus*, which would indicate a tibiofibula length of around 1.39 m for *Arambourgiania*. Only the proximal and distal parts of the femur of *Quetzalcoatlus* are known, making it difficult to scale up this bone for *Arambourgiania*. The tibiofibula was simplified so that the same mould could be used for each leg, thus saving on time and silicone rubber.

The pes of *Quetzalcoatlus* is unknown. In better-known pterodactyloid pterosaurs, such as *Pteranodon*, the fifth toe was reduced. The remaining four toes were elongate and tipped with robust claws. The proximal tarsals were fused to the tibia, and the distal tarsals fused to one another (Wellnhofer 1978). For *Arambourgiania*, we assumed a skeletal arrangement similar to that of *Pteranodon*.

Construction of the model

The model was constructed in two sections: the postcranial skeleton and the skull and lower jaw.

The postcranial skeleton model

The construction of the postcranial skeleton proceeded in stages, summarised in Table 3.

Stage 1. Constructing the premodel

A premodel was constructed from clay. For convenience, some bones were modelled together, e.g. the trunk vertebrae were modelled as a single row, the caudal vertebrae were combined with the synsacrum, and proximal and distal carpals were constructed as a single entity. Modelling began on the 13th July 1996. The postcranial skeleton was initially modelled in Red Terracotta clay which was the cheapest modelling clay available. When this was temporarily unavailable, Oxidising St. Thomas's clay was used. The latter was found to retain its shape better than the former, and the small extra expense was considered worthwhile. Attempts to save clay and minimise weight in large premodels such as the humeri included modelling them around hollow plastic pipe, but as the clay dried, it cracked and became detached from the pipe. Similar problems occurred when wire and wooden reinforcing rods were embedded inside other premodels, so they were finally constructed from solid clay, without reinforcement, and left to dry.

Whilst drying, the premodels were supported with screwed-up newspaper, to prevent sagging under their own weight and becoming flattened where they lay on the bench. A small amount of shrinkage was encountered during drying. To compensate, the premodels were made slightly oversize. For example, the left humerus shrank by 1.49% of its length, the ulna by 3.69%, and the second phalanx by 2.55%.

Figure 1. Ooops! A broken metacarpal premodel being repaired using household filler. In the foreground are the varnished synsacrum and tail (l) and right pelvic bones (r).

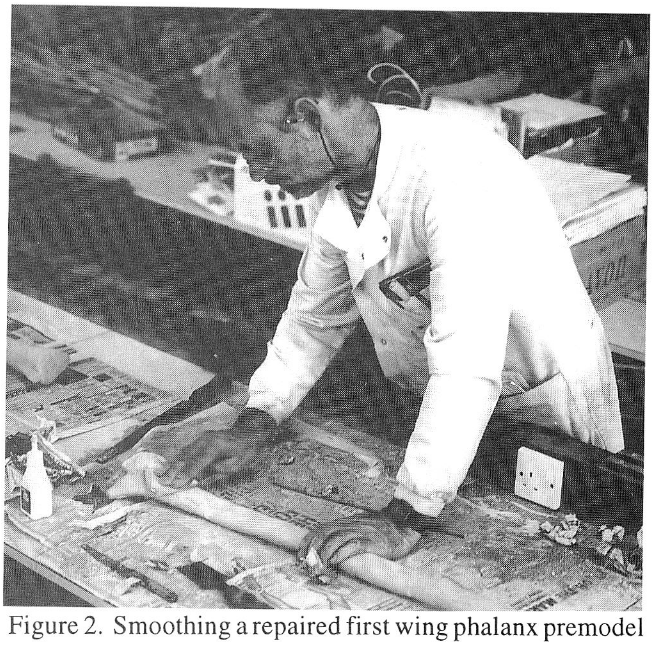

Figure 2. Smoothing a repaired first wing phalanx premodel using sandpaper.

The air-dried premodels were extremely fragile, and many broke, but were repaired using "Superglue", "Plastic Padding" and PVA adhesives. For the larger premodels, such as the metacarpals, glue alone was not strong enough, and reinforcement had to be provided by drilling into the broken surfaces and inserting wooden dowel to bridge the break. Remaining gaps were filled with proprietary filler (Figure 1). The surfaces of all the clay premodels were smoothed using sandpaper (Figure 2), and sealed with quick-drying wood varnish. A very thin film of petroleum jelly was applied to the varnished premodels to facilitate their later removal from their silicone moulds.

Stage 2. Moulding

Moulding commenced on the 16th August 1996, and the following procedure was undertaken for each premodel. The premodel was laid on a small sheet of wood or chipboard, and embedded in clay to approximately half-way up. The surface of the clay bed was carefully flattened and smoothed. Where it met the premodel, the surface of the bed was levelled using a small knife (Figure 3). It is important that no gaps between the premodel and the clay bed remain. The embedding stage must be undertaken very carefully to produce a neat and accurate mould.

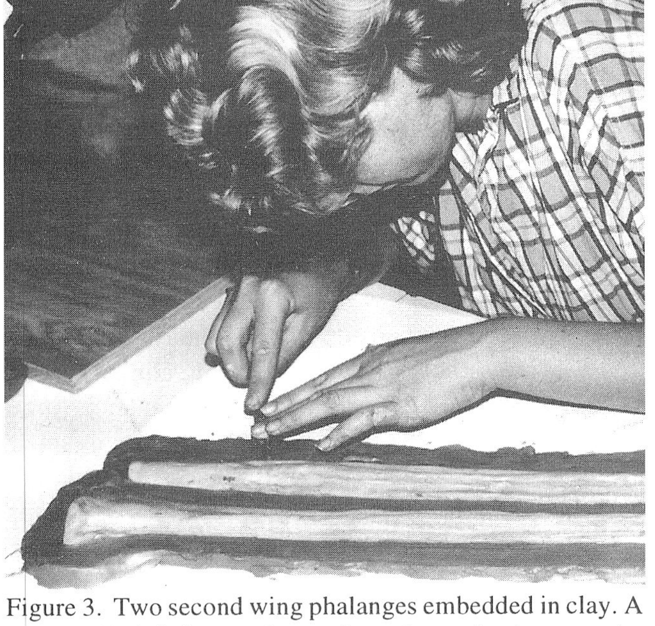

Figure 3. Two second wing phalanges embedded in clay. A small knife is being used to make a clean edge between the clay bed and the premodel.

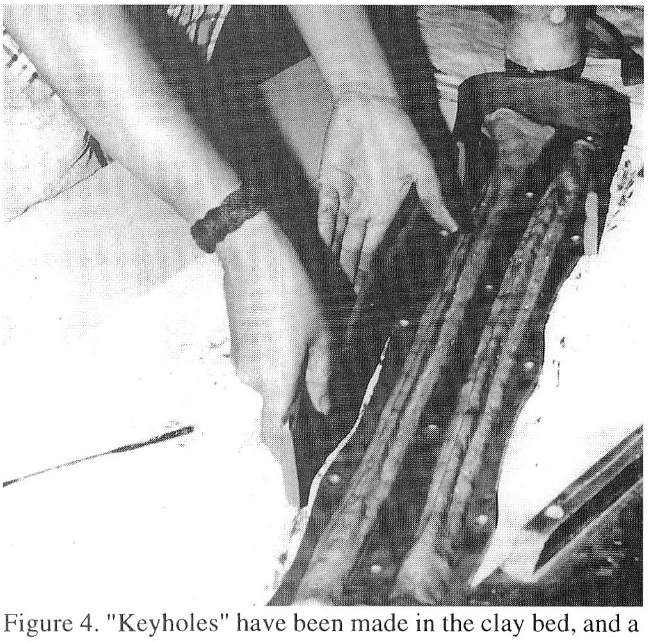

Figure 4. "Keyholes" have been made in the clay bed, and a clay wall is being fitted.

Figure 5. Silicone rubber is being poured over the embedded premodels.

Figure 6. Thickened resin being brushed into the humerus mould.

"Keyholes" were made by pressing the wetted blunt end of a thick pen into the clay bed to a depth of 10 mm, approximately 5-10 mm away from the premodel. Keyholes were spaced approximately 80-100 mm apart, and their edges smoothed with a wet finger. The outer edges of the clay bed were then cut back with a knife, to define the outer limits of the silicone mould. Clay was rolled into sheets about 7-10 mm thick, using a wooden rolling pin, and fitted around the clay bed (Figure 4). The walls had to be taller than the highest point of the premodel.

After ensuring that all surfaces were neat and smooth, and no gaps existed, a room-temperature vulcanising silicone rubber "Mastermould", was applied. The white fluid rubber and the blue liquid catalyst were mixed at a ratio of 10:1 by weight, carefully blended to minimise the inclusion of air bubbles, and poured over the exposed premodel (Figure 5). Four 5.5 kg cans of silicone rubber were used in the pourable state. This consistency of silicone rubber flowed downwards off the elevated areas and accumulated in the lower regions, leaving parts of the mould very thin, and liable to tear during casting. To solve this problem, a thixotropic additive was added to catalysed silicone, and applied to the thin areas of the mould using a spatula. In total, five 5.5 kg cans of silicone rubber thickened with the additive were used. While the silicone rubber cured, the clay walls were wrapped in wet cloths to prevent them drying out and cracking overnight.

When the silicone rubber had cured (after approximately 12 hours) moulding plaster was poured over the silicone mould to form a supporting jacket. As soon as the plaster had hardened, the clay wall was removed and the mould turned over. The clay bed was then removed from the lower surface of the premodel. After removing all clay from the newly-exposed surface of the premodel and the first silicone mould, more petroleum jelly was applied to the exposed edges of the first silicone mould and to the exposed parts of the premodel. A new wall was then made around the mould (or the old wall re-used), and the process of applying silicone rubber and plaster was repeated for the other side. Finally, the wall was removed to reveal the completed two-part mould, and any sharp edges on the plaster jacket were smoothed. This procedure was followed for all premodels.

Stage 3. Casting

The silicone moulds were cast in epoxy resin. This involved three stages: 1) surface coat; 2) lamination; 3) sealing of halves. Casting commenced on the 5th September. The moulds were opened, and the clay premodels removed. The internal surfaces of the moulds were cleaned and received another application of petroleum jelly. The working area was covered with plastic sheeting and newspaper, to protect against spillages. A two-pack epoxy resin "West 105/205", was mixed at a ratio of 5 parts of resin to 1 part of hardener, and a lightweight microcellulose thickener stirred in (the resin has to be thickened to prevent it flowing off the sloping sides of the mould). The fumes given off by the resin are harmful, and adequate ventilation must be ensured by working in a fume cupboard or outdoors. The resin was mixed in small plastic containers such as yogurt pots. After use, the hardened resin was removed by squeezing in the sides of the pots. When mixing resin, it is best to only mix as much as is required immediately, as large volumes of resin left in the pot cure rapidly.

The resin was carefully painted into both halves of each mould, leaving an unpainted margin of approximately 5 mm deep along the joining surfaces. This layer forms the surface of the cast, so it is important to cover all extremities and undercuts of the mould, and to exclude air bubbles. After about 4 hours, this initial coat was cured, and the laminating stage could proceed. Resin was thickened to about the consistency of wallpaper paste, and brushed thickly into each half of the mould (Figure 6). Pieces of woven fibreglass cloth (170 gsm) were laid on top of the wet resin, and gently pressed from the centre towards the edge, so that the resin soaked through the cloth, and they overlapped one another slightly. This process was repeated until the entire mould was lined with fibreglass, except for the narrow margin around the joining surfaces. When that layer had hardened, a second layer was applied in the same manner, and left to dry.

Blocks of wood were placed inside the larger moulds, wherever there would be an articulation with another bone. Lengths of wood or wire were laid along the axis of all long bones for reinforcement. The wooden blocks and reinforcing rods were fixed in place by resin-soaked lengths of fibreglass cloth. When the two halves of the mould were ready for joining together, additional resin was thickened until it formed peaks when dabbed with a spatula, and was quickly spread around the rims of the mould. Speed was essential to ensure that the resin did not cure in its mixing pot, yet care had to be taken to minimise the inclusion of air bubbles in this sealing layer. For the sake of speed, two people worked on each half of each mould. The resin was applied using spatulas, leaving it slightly proud of the rims of the mould. The two halves of the mould were united, ensuring that all keyholes were aligned. After at least 4 hours (usually overnight), the mould was opened, and the cast removed.

Brushes were stored in acetone when not in use, to prevent the resin hardening.

Stage 4. Finishing the casts

Often the resin seeped between the two halves of the mould, leaving a thin blade-like ridge. Most of this was removed by running a blunt metal tool along it. The remainder was ground away using a small hand-held electric drill (dust mask and goggles were worn). The numerous small holes on the surface of the casts were filled with thickened resin.

Construction of the skull and lower jaw

The pterosaur skull is a complex structure which is difficult to model in clay. In addition, its size would have made it very expensive to mould in silicone rubber, and difficult to cast as a single piece. With these points in mind, we decided to model the skull using various lightweight materials, including sheets of plastic, expanding polyurethane foam and epoxy putty. A large sheet of plastic was heated using a hot air gun, and bent into a steep apex, to form the basic shape. Further heating and bending of this structure formed the back of the skull and the palate. The plastic sheet eventually became deformed in the snout region after too much heating and bending, and had to be cut off. A replacement snout was made out of plastic sheet, and fixed to the remainder of the skull by two aluminium tubes of 1 m long and 8 mm thick, and one tube of 9 mm thick. Holes representing the orbits, nasoantorbital fenestrae and temporal openings were cut in the plastic sheet using jigsaws and hacksaws. A block of wood was glued inside the back of the skull, at the point where it would articulate with the neck.

One aerosol can of "Polycell" expanding polyurethane foam was used to fill gaps and give rounded contours to the flat plastic sheet. This foam was applied directly from the can, and allowed to cure for 24 hours, before being shaped using scalpels and sandpaper. Epoxy putty (car body filler) was mixed in small quantities, since it hardens rapidly, and applied fairly thinly over the foam. The putty was smoothed with a wet finger whilst still soft, thereby reducing the amount of sanding down required after it had hardened. It is heavy compared with the polyurethane foam, hence its use was kept to a minimum.

The lower jaw was constructed by heating and bending two long pieces of 10 mm-thick plastic to form the basic shape of the two rami, and supergluing these together at the symphysis. More pieces of box-section plastic were superglued onto this basic structure to make a more three-dimensional shape, yet keep the lower jaw as light as possible. Expanding foam was applied, and restricted by sheets of grease-coated card until the foam cured. This made it easier to achieve the correct shape and maintain an even surface. Epoxy putty was then applied.

Assembly of the model

Stage 1. Positioning the casts

A scaffolding was constructed in the workshop on which the casts could be hung from adjustable strings to determine their relative positions before drilling and fixing commenced. Due to lack of space, the entire model could not be hung in this way, so it was hung in large sections. Half of each wing, the entire neck, the thorax and the hind legs were hung together as units.

Stage 2. Drilling, fixing and painting

Holes were drilled approximately 50-60 mm into the wooden blocks, and aluminium tubes of 8 and 9 mm

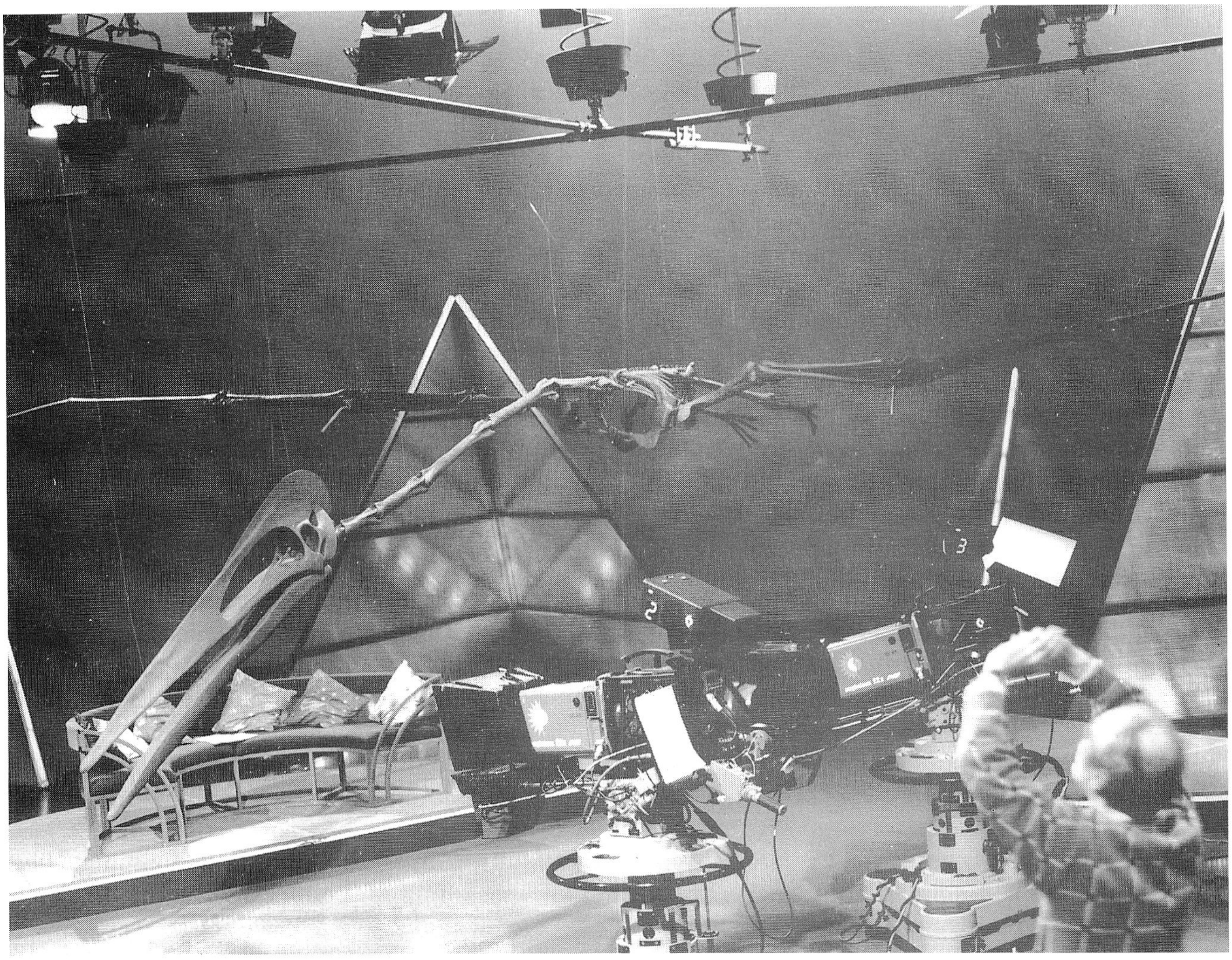

Figure 7. Lights, camera, action! The completed model takes to the air at Meridian TV Studios, Southampton. The pterosaur is hanging by fishing wire from a metal frame.

diameter were inserted. "Superglue", "Araldite" two-ton epoxy glue and epoxy putty were used to fix the tubes inside the holes in one of the bones to be joined, then the bones could be pushed together. In the thinner bones with solid resin ends, stainless steel welding rods (14 gauge) were used instead of the aluminium tube, and the bones were joined together permanently by gluing the rods in place. Two or three aluminium tubes were required at most joints, to prevent the bones rotating in relation to one another. Each wing was made in two sections, a proximal and a distal. Each section is a permanently constructed unit, and the two sections can be easily separated from one another for transit. The assembled model was painted with a dark brown water-based matt emulsion.

Stage 3. Mounting the model

In Portsmouth City Museum, the model was hung from the ceiling beams by thick string, so that the position of the sections could be changed easily. In places it was necessary to put a wire bridge across two beams, in order to provide a hanging point midway between them. 50 kg breaking strain wire was used for this purpose. The thorax was hung first, followed by the neck, legs, wings and skull. When the sections were fitted together correctly, and the model had been positioned so that it fitted in the gallery (it was a tight squeeze!), 15 kg breaking strain fishing wire replaced the string. In Leicester City Museum, the pterosaur was hung from a specially-made aluminium frame, which was bolted to the ceiling. A similar frame was used at Meridian TV Studio, Southampton (Figure 7).

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on moulding, casting and mounting. Thanks to Jane Evans for helping us hang the model. Thanks to John Whalley and his family for helping us paint the model, and last but not least, thanks to all the people who lent a hand when the deadline approached.

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Appendix A. Summary of materials used

115 x 12.5 kg bags of Red Terracotta clay; 15 x 12.5 kg bags of Oxidising St. Thomas's clay; 900 ml of quick-drying varnish; 9 x 5.5 kg tins of Strand "Mastermould" silicone rubber and nine packs of catalyst; 5 x 10 g pots of thixotropic additive; 6 x 12.5 kg buckets of dental plaster; 4 x 25 kg of mould plaster; approx. 35 kg "West 105/205" epoxy resin; approx. 3 kg "West microfibre"; 9 m x 1.27 m of 170 g/m2 fibreglass cloth; 2 x 3.6 kg tins of Strand epoxy putty; 2 x aerosol cans of "Polycell" polyurethane expanding foam; 2 x pieces of plastic (1.75 m x 100 mm x 10 mm); sundry pieces of plastic sheeting of 3-4 mm thick, sandpaper, "Superglue", "Plastic Padding", PVA wood glue; approx.10 m of 50 kg breaking strain fishing wire; approx. 20 m of 15 kg breaking strain fishing wire; approx. 20 crimps.

• Scott Bader, suppliers of Strand products (tel: 01489 589838), supplied silicone rubber, catalyst, thixotrope, plaster, epoxy resin, fibreglass cloth, microfibre and epoxy putty.

• Hampshire County Supplies (tel: 01962 846201) provided modelling clay and plaster.

Appendix B. Equipment used.

Modelling tools, ruler, knives, rolling pin, electronic balance, spatulas, spoons, assorted paintbrushes (cheap ones), plastic pots, acetone, newspaper, plastic sheeting, scalpels, pliers, hacksaw, jigsaw, heat gun, orbital sander, drill, drill bits, small grinder.

BOOK REVIEW

Nudds, J.R. and Pettitt, C.W. (eds). 1997. *The value and valuation of natural science collections.* Proceedings of the International Conference, Manchester, 1995. Geological Society, London, xii + 276pp. ISBN 1 897799 76 4. Hardback. Price: £55-00.

Four years ago, when my museum was in the midst of preparing a major new geology gallery, we were loaned a specimen of lunar basalt by the National Aeronautics and Space Administration in Houston, Texas. As a national museum, we are required to notify the Welsh Office of inward loans worth more than £200 so that they can be covered by the government indemnity scheme. Assuming that a decent-sized hand specimen of moonrock was worth more than a few hundred quid, but unable to put a true value on it, we merely informed the Welsh Office of the arrival of the specimen in the museum. This wasn't enough; they needed a figure for the box on their form. So we contacted NASA. A Texan drawl informed us that the cost of replacement would be 15 billion dollars. The term 'stunned silence' best describes the response of the civil servant who received this information.

Fortunately, this is an extreme example of the problem of valuing specimens, but it demonstrates that, at times, we do have to put a price on our collections. It may be for internal audit or insurance purposes, or perhaps we need to know if we are paying a fair price for specimens purchased from collectors or dealers. How do we go about it? We can try to keep up to date with prices in dealers' catalogues, but how can you put a financial value on the tens or hundreds of thousands or millions of natural history specimens in your stores, collected or donated perhaps over centuries? This volume, the proceedings of the conference co-sponsored by GCG and held in Manchester in April 1995, will point you in the right direction.

Covering the full spectrum of natural science collections from microbial genetic resources and live cultures of algae and protozoa to more traditional museum material like fish, shells, fossils, minerals and herbaria, this volume contains 45 papers from contributors from 17 countries. These are arranged in four sections: the scientific value of collections; the cultural value of collections; the financial value of collections; and additional papers presented as posters, as well as a discussion and the text of an invited lecture.

The first section, on the scientific value of collections, comprises 13 papers. While most of these, such as the papers by the Earl of Cranbrook, Simon Knell, and Andrew Jeram deal with suggestions for assessing the value of collections to science and how to decide what is important, others seem to belong elsewhere in the volume as they report on the financial value or the social history value of collections. A paper on the economics of botanical collections, for example, by David Mann of the Royal Botanic Garden in Edinburgh, concludes with an average acquisition cost of £25 and annual maintenance cost of 25 pence per specimen. Another paper in this section, by Stephen Blackmore and others from the Natural History Museum, attempts to calculate the financial value of the NHM's systematic biology collections. While they can work out very approximate figures for the costs of acquisition, curation and accommodation of the collections, they point out that these costs do not equal the financial value of the collections. They also highlight the difficulty and expense of establishing such indirect values as serendipity value (the value of the collections to as yet undiscovered research techniques) and their existence value - what people are prepared to pay for the very existence of the collection.

The second section, on the cultural value of collections, has 14 papers and opens with a contribution from Max Hebditch from the Museum of London who looks at parallels with the humanities. Papers here examine the cultural impact and educational value of natural science collections, from local and university collections to national collections in the Netherlands and Canada. This section draws particularly on geology: of special interest to GCG members here will be the papers by Janet Waddington on evaluating the geology collections at the Royal Ontario Museum; Simon Timberlake on the value of the collections in small museums; Nigel Monaghan on the giant Irish deer; Sally Shelton on fossil market prices; and Monica Price on the mineral specimen market.

The third section gets down to the nitty-gritty of pounds and pence and deals with the financial value of collections, with six papers. These include contributions from an insurer, a loss adjuster, an auction house valuer, and an accountant. These offer an interesting perspective to the problem of value and valuation.

The volume also includes 11 additional papers presented as posters, before closing with the text of an entertaining invited lecture by Sally Shelton of San Diego Natural History Museum. The poster papers contain much of interest on the experience of individual curators and conservators costing their work as well as reports on collections in Belgium, Brazil and Italy.

Out of the conference came the International Accord on the Value of Natural Science Collections which calls on governments to recognise the value and use of natural science collections and makes six recommendations to guide governments in their policy decisions about such collections. The Accord is included in the volume and has already been publicised and published elsewhere (see *Coprolite* **17** (1995): 15-16).

The editors have made the volume much easier to use with the inclusion of an index, a useful feature often missing from publications of conference proceedings. My only criticisms would be the absence of abstracts from some of the longer papers and the presence of some only as extended abstracts when I would have like to have seen full papers; one can also quibble about the arrangement and divisions of the various sections of the book. But these are minor complaints.

This is the most significant book dealing with natural sciences in museums to be published for many years. It goes some way to restoring the balance between the arts and sciences in museums, and should help to ensure that no longer are natural science collections regarded as the poor relations. This volume contains a huge amount of valuable information and experience; should you ever need examples of the practical use and value of collections, you will find plenty here. It should be essential reading not only for all natural scientists in museums, but especially for those (usually non-scientists) who manage and fund museums. The editors and publishers are to be congratulated.

Tom Sharpe, National Museum of Wales, Cathays Park, Cardiff CF1 3NP, Wales, U.K.

THE GEOLOGICAL CURATOR

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