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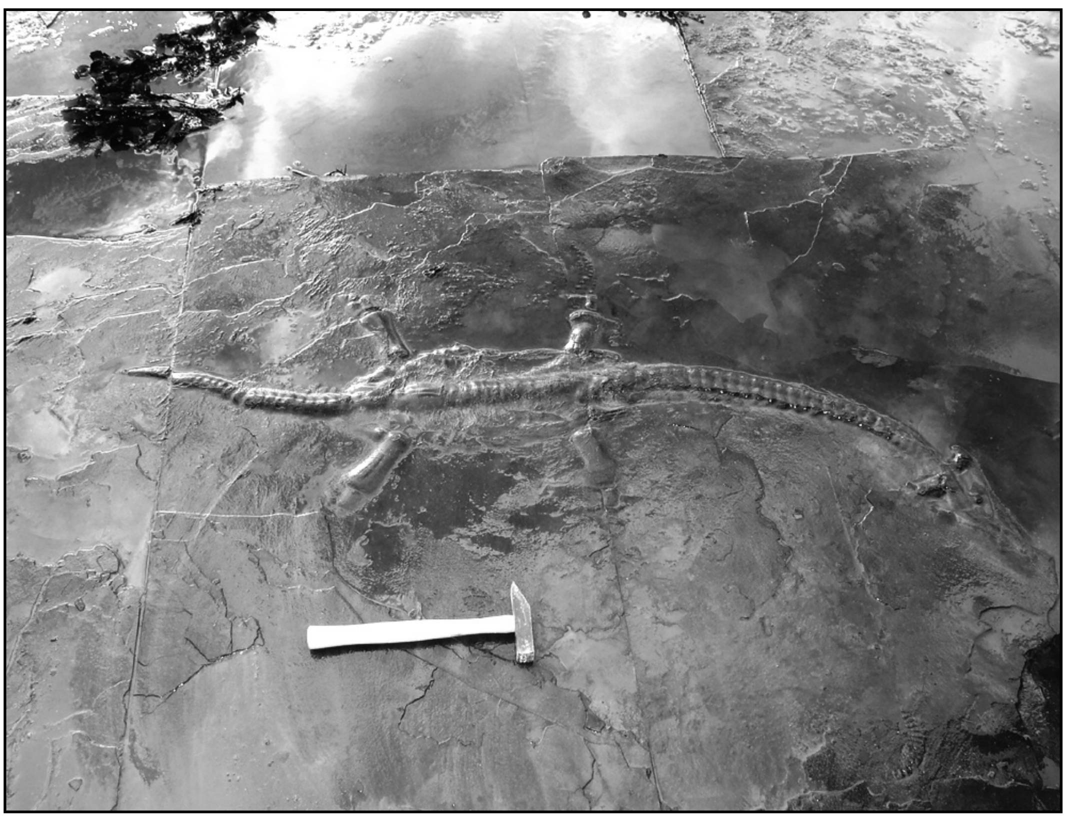

FOSSIL PREPARATION:

TOOLS, TECHNIQUES AND PROJECTS

GEOLOGICAL CURATORS' GROUP

Registered Charity No. 296050

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: The Collard Plesiosaur (TTNCM: 146/2003) as found in Bridgwater Bay National Nature Reserve near Hinkley Point on the Somerset coast before excavation. It is lying 'belly-up', and the head is to the right of the picture. The geological hammer is approximately 290 mm long. See paper by Larkin *et al*. inside.

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FOSSIL PREPARATION: TOOLS, TECHNIQUES AND PROJECTS

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GEOLOGICAL CURATORS' GROUP - September 2010

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EDITORIAL

The contents of this issue arise almost entirely from a Preparators' session at the Society of Vertebrate Paleontologists (SVP) first meeting held outside of North America. Hosted by Bristol University and jointly run with the European based Symposium of Vertebrate Palaeontology and Comparative Anatomy (SVPCA) and the Symposium of Palaeontological Preparation and Conservation (SPPC it was a significant occasion. Whilst the two continents are reverting to their normal pattern of meetings this year, this journal issue provides a lasting record of that meeting. The Geological Curators' Group is proud to be associated with this venture, making a durable addition to the relatively sparse existing literature on preparation of fossils.

I would like to thank Remmert Schouten for kickstarting the idea. Many people have helped get this publication completed, and I would like to thank Paolo Viscardi, Gareth Dyke, Matthew Brown, Leslie Noè along with many people who reviewed papers, often at speed. Although there were a few unfortunate delays with the production (with my apologies to the authors involved), it has been rewarding to see the volume take shape. I hope you, the reader, will get equal value from the contents.

Matthew Parkes, August 2010.

DISCOVERY AND PREPARATION OF A LARGE MASS OF ARTICULATED EARLY JURASSIC CRINOIDS FROM BLACK VEN (DORSET AND EAST DEVON COAST WORLD HERITAGE SITE, SOUTH-WEST ENGLAND)

by Simon Carpenter and Jonathan D. Radley

Carpenter, S. and Radley, J.D., 2010. Discovery and preparation of a large mass of articulated Early Jurassic crinoids from Black Ven (Dorset and East Devon Coast World Heritage Site, south-west England). *The Geological Curator* 9(3): 103 - 106.

Early Jurassic marine mudrocks on south-west England's Dorset and East Devon Coast World Heritage Site are well known as a source of spectacularly preserved examples of the fossil crinoid *Pentacrinites fossilis* Blumenbach. This paper outlines the geological and palaeobiological contexts of a recent find, and the measures taken for its preparation, conservation and preservation.

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Introduction

The Dorset and East Devon Coast World Heritage Site, south-west England, comprises globally important exposures of Triassic, Jurassic and Cretaceous strata (House 1993; Brenchley & Rawson 2006; Boylan 2008). Palaeontologically, the marine Lower Jurassic mudrock formations of the West Dorset coast are an outstanding feature, having yielded innumerable well-preserved vertebrate and invertebrate fossils to generations of collectors. Internationally important specimens are preserved within numerous museum collections, and significant new discoveries are made every year.

During the autumn of 1995, David Sole, a professional fossil collector, collected a spectacularly large accumulation of the Lower Jurassic pseudopelagic crinoid, *Pentacrinites fossilis* Blumenbach, from a large mass of slipped shale on the classic coastal landslip of Black Ven, west of Charmouth, in West Dorset. Black Ven has yielded many well-preserved ammonites, marine reptiles and other fossils, including articulated, exquisitely preserved specimens of *Pentacrinites*, now seen in many museums and private collections (Simms 1986, 2004; Figure 1). David Sole safely stored his crinoid material in an essentially unprepared state for a number of years, before it was acquired by one of us (SC). This paper outlines the collection and ongoing preparation of the crinoid material, and how the inferred life mode of *Pentacrinites fossilis* allowed it to be preserved in such detail.

Both authors first became interested in fossil crinoids during childhood family holidays in West Dorset (Figure 2). Trips along the beaches between the village of Charmouth and the town of Lyme Regis allowed collection of worn fragments of limestone containing portions of articulated *Pentacrinites* (Figure 3), derived from the wave-scoured seaward edge of Black Ven, and cliffs below Stonebarrow further east. These originated from the so-called 'Pentacrinite Bed' within the Black Ven Marl Member (Sinemurian; Stellare Subzone) of the Sinemurian up to Pliensbachian Charmouth Mudstone Formation (Simms 1986, 2004). In reality this is not so much a bed as an interval of organic-rich mudstone (approximately 2 m thick), that largely lacks benthic macrofauna.

As time went on, one of us (SC) became enthused by stunning specimens of *Pentacrinites* displayed in various museums including the Earth Sciences gallery of the National Museum of Scotland (part of the Hugh Miller collection), and the Oxford University Museum of Natural History (Figure 1). So several years ago, SC began to make enquiries concerning acquisition of material that would rival these spectacular museum specimens, and subsequently met with David Sole with a view to purchasing his Black Ven specimen.

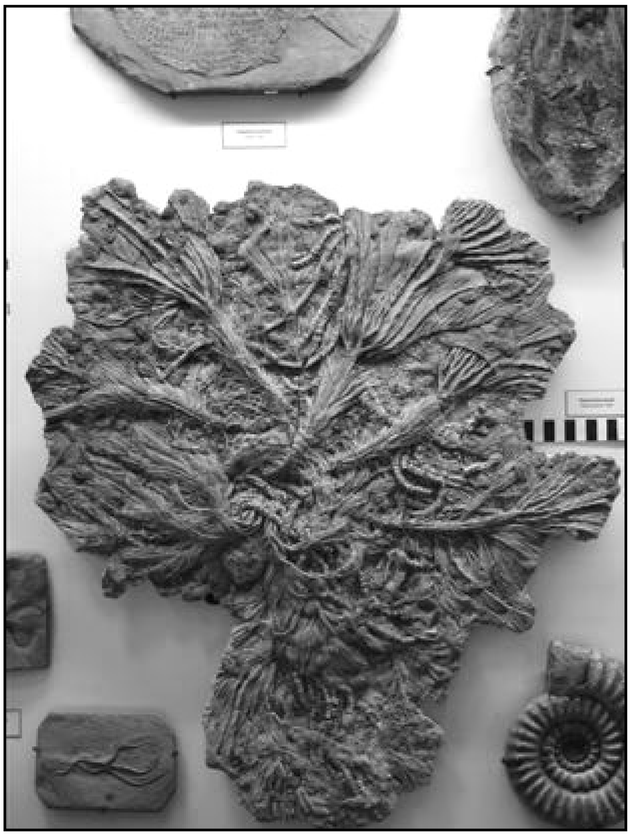

Figure 1. An articulated example of the Lower Jurassic crinoid, **Pentacrinites fossilis** *Blumenbach, on display at the Oxford University Museum of Natural History. The provenance is unrecorded but the specimen is almost certainly from the Black Ven Marl Member of the Charmouth Mudstone Formation, Lyme Regis - Charmouth coast of West Dorset. Scale bar is marked in centimetres.*

Figure 2. Simon Carpenter aged 7 (3rd from left), with some of his family, hunting for fossils on the Dorset coast.

David's crinoid material was largely unprepared, and remained within the bags he had collected it in at Black Ven. From inspection of David's field notes and in conversation with him, it was apparent that the crinoid mass had covered an area of several square metres. The remains were evidently not pyritised, nor enclosed within limestone nodules. Pyrite is commonly associated with *Pentacrinites* material within the Black Ven Marl, and can enhance the appearance

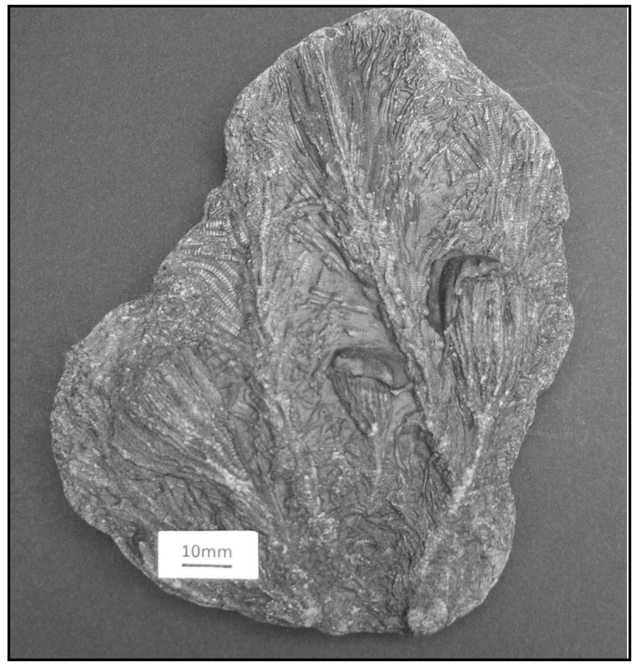

Figure 3. Worn fragment of limestone preserving **Pentacrinites,** *from the foreshore at Black Ven, West Dorset (Simon Carpenter collection). Specimen collected in 1972.*

of these fossils by imparting an attractive brassy lustre. However, it is commonly unstable, potentially damaging the appearance and integrity of the fossils. The fact that David's crinoid material was unprepared was an added bonus, as it would allow SC to carry out this painstaking work to his own satisfaction.

Palaeobiology, taphonomy and preservation

Recent crinoids occupy a range of marine environments from shallow-water to deep marine settings. They commonly bear a stem attached to a substrate, but some live attached only as juveniles and become free-swimming as adults. There are only a few hundred known modern species, but crinoids were much more abundant during the geological past, notably the Palaeozoic. Regionally extensive crinoidal limestones ('encrinites') are made up of the disarticulated remains of countless billions of crinoids. More rarely, articulated crinoid fossils, such as the West Dorset Jurassic *Pentacrinites fossilis*, can be exquisitely preserved and are much sought after by collectors (Hess *et al.* 1999).

As long ago as 1836, William Buckland recorded groups of *Pentacrinites fossilis* associated with coalified fossil wood, and noted that the wood was nearly always preserved in contact with and above the crinoid fossils. This suggested that the crinoids were attached in life to driftwood, floating on the surface of the Early Jurassic sea. It wasn't until the 1980s that research by Michael Simms confirmed Buckland's original theory and went further by describing the relationship between larval and adult forms and their association with, and colonization of driftwood (Simms 1986). It now seems likely that as the crinoid colonies grew and spread on their driftwood rafts they eventually sank, overwhelmed by their own weight. The crinoids descended first, followed by their driftwood raft, and perished in the dysaerobic (oxygen poor) water on the Early Jurassic sea floor. The soupy mud would have been a perfect preservation medium, supporting the ossicles after death and arresting decay and disarticulation. Also, the stagnant conditions would have prevented scavengers from disturbing or destroying the perished crinoids. These conditions ensured a favourable environment for preserving intact crinoids, resulting in the spectacular fossils found today.

Collection

David Sole discovered the mass of fossil crinoids during a collecting expedition to Black Ven during the autumn of 1995. The raft of shale which yielded the fossils had already detached itself from the main body of the cliff and had begun moving seaward down the slope. David collected the broken-up crinoid-bearing rock from the shale raft over a period of two weeks. The shale overburden was removed from above the crinoid-bearing material and small areas of the fossiliferous rock were carefully bagged, to keep associated fragments together. David numerically coded them and produced a simple drawn plan to show how they interrelated (Figure 4). From SC's initial inspection of the bagged fragments, it was evident that the crinoid remains had not constituted one continuous sheet, but had occurred as a ramifying mass of lenticles at one level within the shale bedrock. Some crinoids were apparently preserved together in large tangled masses, forming the thicker and more substantial lenticles. Others were preserved as relatively dispersed masses, making up thinner lenticles.

Acquisition

The purchase agreement was a collaborative one. It was agreed that if SC were to lose interest in the preparation project or find the task too demanding, David Sole would have the option of purchasing the material back - paying interest on the original purchase price to compensate for the preparation carried out to that date. This arrangement reflects David's continued interest in the specimen and his desire that the preparation is completed.

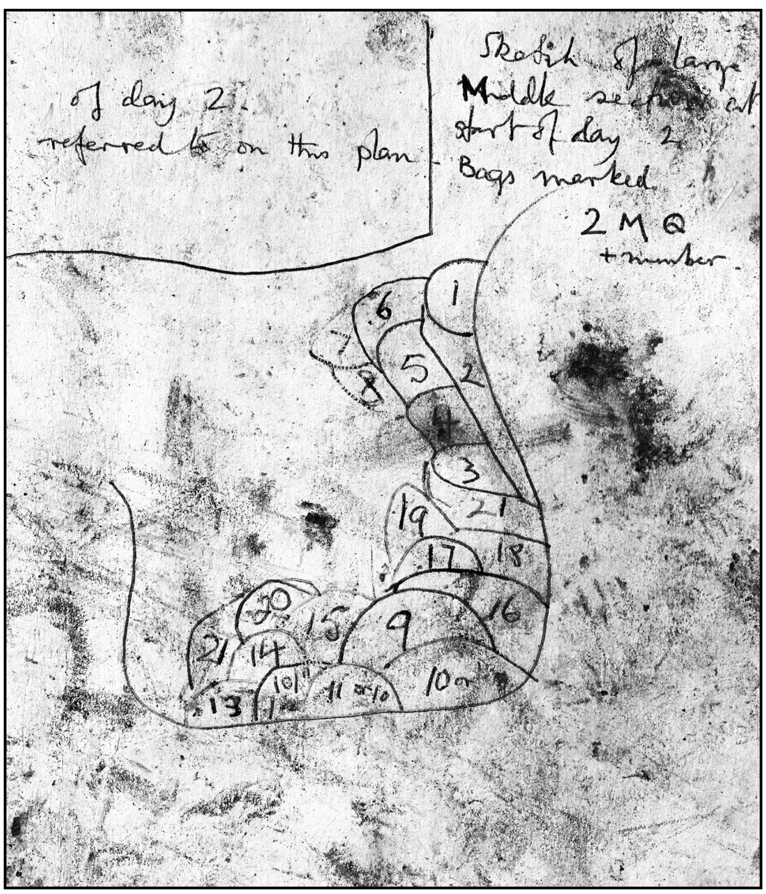

Figure 4. A section of David Sole's field site plan showing the relative positions of crinoid-bearing limestone fragments in shale bedrock, prior to removal.

Preparation and preservation

One of SC's first tasks was to clean the hardened, dried-out clay and small amounts of fibrous calcite from the surfaces of each broken slab of carbonate-cemented crinoid remains. This was undertaken by soaking the specimens in warm water, and then carefully removing the hydrated clay with a soft scrubbing brush. Harder, more resilient rock matrix and fibrous calcite would have to be removed at a later date without damaging the surface detail of the fossils. A range of scalpels, picks and needles would be used for this task. Careful and sensitive preparation takes time and patience. SC estimates that it will take another five years to complete the project - possibly longer. One critical factor during the cleaning process has been to maintain the integrity of David Sole's bagging and coding system, to prevent information loss. This information would be essential if future reconstruction of the fossil was to be attempted. Once the soft clay had been removed, the fragments were placed together in shallow trays along with

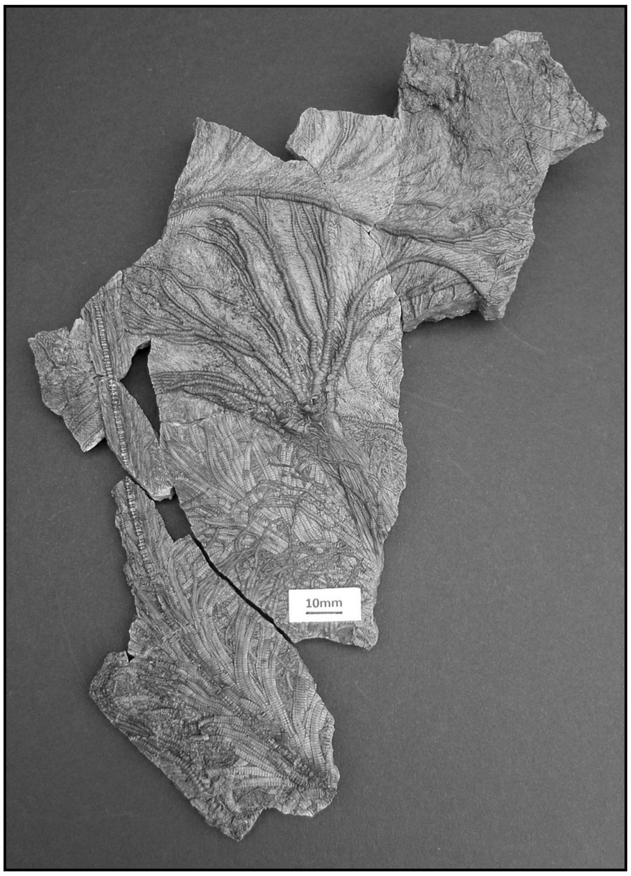

Figure 5. A fragment of the cleaned, prepared and partly assembled* Pentacrinites *material collected by David Sole from Black Ven, West Dorset (Simon Carpenter collection).

their unique codes. As more bagged specimens were cleaned in this way, more associations became apparent. Ultimately, it is envisaged that the separate crinoid 'rafts' will be reunited as related and interconnecting slabs.

At the time of writing (late Autumn 2009), several trays of prepared crinoid fragments have been cleaned and partially reconstructed (Figure 5) and this work continues. It is always tempting to start gluing pieces together at an early stage in a preparation project. SC has already undertaken some preliminary adhesion, once satisfied that this would not compromise the future attachment of adjoining slabs. Paraloid resin (B72), dissolved in acetone, is being used for this purpose. It provides a strong bond, allowing edges to knit closely together. Excess glue can be removed with a sharp blade without risk of damage to the surface of the specimen. The process is also reversible, if at a later date missing fragments are found (Paraloid B-72 will re-dissolve in acetone). The material is already revealing itself to be truly spectacular, and it would be a tragedy if it were to languish in a cabinet drawer for the next decade. SC has always provided access to his private collection for geological research as a fundamental part of his collecting ethic, as well as donating scientifically important material to museums. The final phase of the reconstruction will witness the assembly of manageable portions of the crinoid layer, which will fit into shallow cabinet drawers. If at a later date the material is offered for public display, it could be easily assembled on a flat surface in its entirety.

In many ways this has been a partnership project. Without David Sole's experience, perseverance, and meticulous attention to detail, this wonderfully complete specimen might never have been discovered and rescued. Without SC's time and effort, this material may have remained unprepared for many more years. Ultimately, it will pass with the rest of SC's collection to a museum or other recognized institution where it can be enjoyed and studied more freely.

Acknowledgements

We would like to thank David Sole of Axminster, Devon, for allowing access to the crinoid material, and for facilitating its purchase. Gratitude is also expressed to Phil Powell and Juliet Hay (Oxford University Museum of Natural History) and Sean Porter (Frome, Somerset) for their invaluable assistance with photography. Michael Simms (Ulster Museum) kindly commented on the manuscript.

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THE VIRTUAL AND PHYSICAL PREPARATION OF THE COLLARD PLESIOSAUR FROM BRIDGWATER BAY, SOMERSET, UK

by Nigel Larkin, Sonia O'Connor and Dennis Parsons

Larkin, N., O'Connor S. and Parsons, D. 2010. The virtual and physical preparation of the Collard plesiosaur from Bridgwater Bay, Somerset, UK. *The Geological Curator* 9 (3): 107 - 116.

The 'Collard Plesiosaur', found in 2003 in Bridgwater Bay on the Somerset coast is the only complete and fully articulated plesiosaur skeleton to have been found in Britain for over 100 years. The 1.5 metre long specimen was preserved in the fine-grained and thinly laminated Lower Liassic Kilve Shales. This lithology is susceptible to fluctuations in humidity, severely compromising the integrity of specimens once dry. The priorities for the project were to arrest shale delamination caused by environmental fluctuations and to prepare the specimen for research. The specimen appeared to be mostly well fossilised in a homogeneous, un-cemented matrix, offering excellent potential for non-destructive recovery of fossil information using conventional X-radiography and Computed Tomography before the preparation commenced. Despite the skeleton being variably mineralised, the analyses yielded very detailed images. This 'virtual preparation' helped to inform the subsequent physical preparation, with the conventional radiographs proving most useful. In addition, the project demonstrated that such analyses are not just useful for guiding preparation but also for recording material that might be removed during preparation and highlighting details not visible to the naked eye or that remain buried. During preparation, experimental attempts to consolidate matrix samples were unsuccessful - the shale layers distorted and delaminated. However, the adhesive Paraloid B72 was successfully applied to the sides of the specimen blocks in liberal quantities, providing a useful partial barrier to future changes in atmospheric relative humidity. Scalpels were found to be the most appropriate tools for preparing the specimen, removing one paper-thin layer of shale at a time.

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Introduction

Fieldwork

The Collard Plesiosaur (Somerset County Museums Service Accession number TTNCM: 146/2003) was found within an intertidal section of Bridgwater Bay National Nature Reserve near Hinkley Point on the Somerset coast by Nicholas Collard. Hardly any bones of the skeleton were actually visible, but an outline of a complete skeleton just under the surface was quite clear, with layers of fine sediment draped over the bones (Figure 1). Had the last few layers of protective sediment been eroded before the skeleton was found, the bones would have rapidly been destroyed by stones scouring across it with every tide.

Mr Collard swiftly contacted Somerset County Museums Service at Taunton Museum who sought permission from the landowner and English Nature to excavate the skeleton immediately as the specimen was vulnerable. The site was washed clean of mud to expose the whole specimen and facilitate its detailed examination, planning and photography. Drainage channels were cut to maintain visibility because when it rained the area was flooded with muddy water. Natural joints in the rock defined the blocks on which the specimen would be contained. Excess rock was trimmed from the sides and underneath the four blocks to reduce weight. The blocks were lifted onto wooden boards, loaded on to the padded rear of a six-wheeled tractor and removed from the beach.

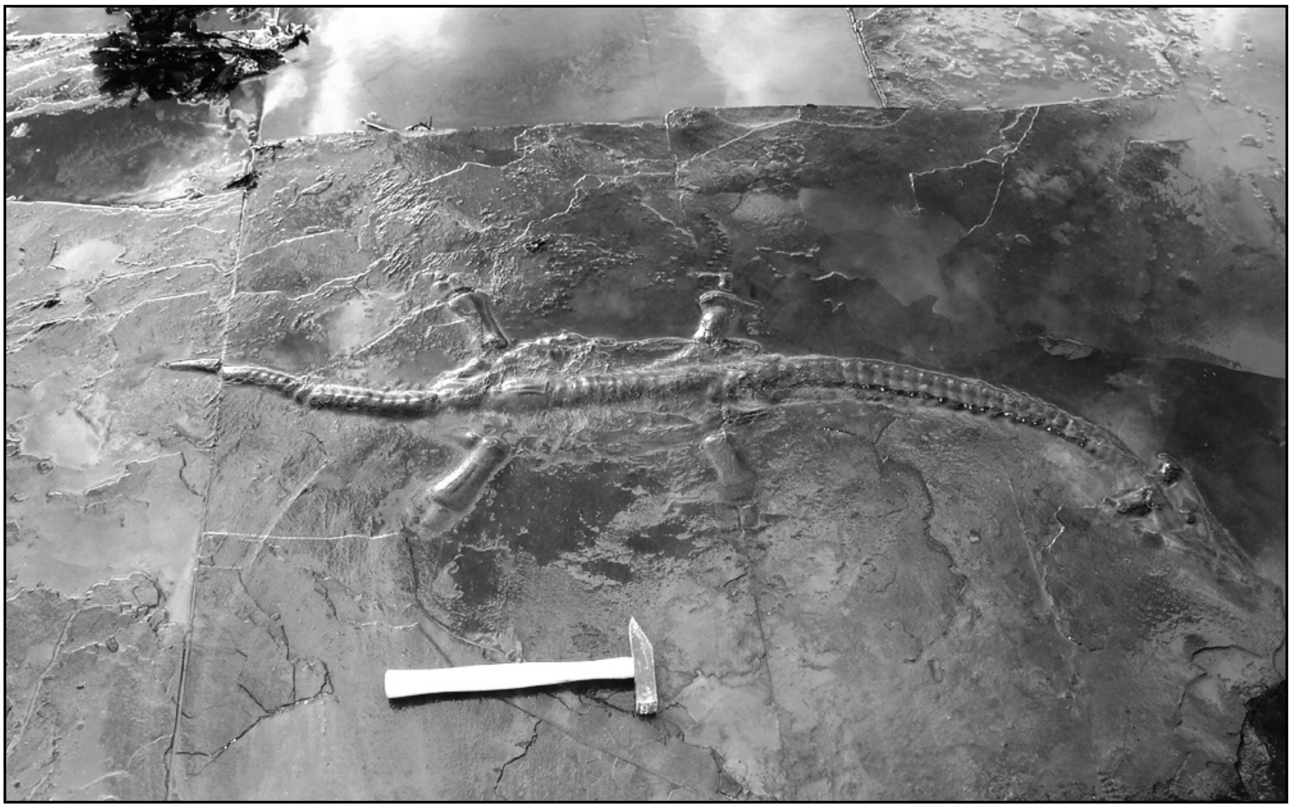

Figure 1. The Collard Plesiosaur (TTNCM: 146/2003) as found in Bridgwater Bay National Nature Reserve near Hinkley Point on the Somerset coast before excavation. It is lying 'belly-up', and the head is to the right of the picture. The geological hammer is approximately 290 mm long.

Stabilisation

The skeleton was preserved in the *Bucklandi* zone of the Lower Sinemurian Kilve Shales of the Lower Liassic (Lower Jurassic) (Palmer 1972; Whittaker and Green 1983; Parsons 2002). The shales are a fine-grained, thinly-laminated marine sedimentary rock containing little or no cement. Held together by compression, this lithology is susceptible to damage from fluctuating humidity, which can severely compromise the integrity of a specimen during drying and once it has dried out.

At the Somerset County Museum, the specimen was placed into large tanks and continuously flushed with fresh water each working day for three weeks to remove as much salt as possible. However, there were no facilities to dry the material under controlled conditions. Therefore it remained in water until it was transported to the Palaeontology Conservation Unit of the Natural History Museum in London for drying and stabilisation. Here, a barrier film tent was constructed around the specimen and it was allowed to dry out slowly.

Once stabilised, the aim was to prepare the specimen as soon as possible. Whilst funding was arranged, however, it was put on display for eight months at Somerset County Museum due to public interest. Possibly as a consequence of being on open display and experiencing diurnal fluctuations in temperature and relative humidity, the material began to delaminate and split (Figure 2). This process had to be arrested before the preparation of the material could commence. Experiments were therefore conducted on separate test pieces of the host rock with different dilutions of consolidant. In every case this resulted in the shale layers swelling, causing dramatic distortions and delamination. The least dilute, most viscous consolidants were the least damaging but did not really penetrate the rock. These experiments showed that consolidation of the blocks containing the skeletal material was not a practical option. Instead, the methacrylate co-polymer adhesive, Paraloid B-72[1] (see Appendix), was applied liberally around the vertical edges of all the blocks both to act as a barrier to future changes in relative humidity and to physically deter the fine layers from separating. Paraloid B-72 adhesive has been tried and tested over more than 25 years and shown to be a stable conservation adhesive and remains easily removed by dissolution in organic solvents (Down *et al.* 1996, Koob 1986). This approach was successful, and the specimen has not delaminated further in the ensuing four years.

Initial preparation

Once stabilisation was achieved, the next process was to remove the underburden from each of the

Figure 2. Cross-section of the abdominal block of the Collard Plesiosaur (TTNCM: 146/2003), showing delamination after display. Cross-sections are visible of a vertebra (near the top of the block in the middle of the picture) and a large but flattened ammonite (at the lower right) that created a weakness across the block. The height of the cross-section shown here is about 70 mm.

blocks to make them lighter and, therefore, less prone to mis-handling and subsequent damage. To achieve this, the fragile specimens had to be turned upside-down. To prevent damage, a close fitting support was made for the upper surface of each block. To prepare this surface a sealing layer of Paraloid B-72 dissolved in acetone (25% Paraloid B-72 granules to 75% acetone weight by volume, which was viscous enough not to cause the sediment to warp and delaminate) was applied. When this layer was dry a water-soluble putty, made from polyethylene glycol (PEG) and French chalk (Rixon 1976), was used to fill the vertical cracks in the specimen. This was to prevent penetration by the fine moulding compound (Wacker silicone rubber[2], see Appendix) that was liberally applied to this surface to provide a close-fitting, shock-absorbing layer. When this had set, a rigid support was formed over it using Jesmonite[3] acrylic resin (see Appendix) reinforced with glass fibre cloth. Finally each block was strapped securely to its supporting jacket and then turned over carefully so that the underside of the block was now uppermost. The silicone rubber layer in these jackets has also taken a perfect impression of the shape of the specimen as found and can be used for the reproduction of replicas if required.

Across two of the largest blocks a very large ammonite (approx 800 mm in diameter) had been preserved, though completely flattened, about halfway through the sediment (Figure 2). This provided a major weakness in the blocks horizontally that was exploited to facilitate removal of the underburden. Elsewhere, horizontal delaminating layers were exploited to remove an appropriate amount of underburden. The large ammonite sections preserved on the underburden blocks were quite fragile, and were consolidated where necessary. Impressions of the ammonite remain on the undersides of the main specimen blocks (see below). Wooden boxes, lined with Plastazote foam[4] (see Appendix), were made for the storage and transportation of the underburden blocks.

A supporting jacket was made for the layer of newly exposed sediment on the blocks containing the skeletal material in exactly the same way as for the upper surface of the blocks. Each block, strapped between its upper and lower jackets, was again turned to bring the top surface uppermost. The temporary upper jackets were then separated from the blocks and the water-soluble putty removed with a scalpel. The lower jackets were retained as permanent rigid supports for the blocks.

Virtual preparation of the specimen

There is a long tradition of using conventional radiography in the investigation of fossils reaching back at least to 1895 (Harbersetzer 1994) and the use of computed tomography (CT) to gain three dimensional radiographic data of fossils was first published in 1984 (Conroy and Vannier 1984). Fossilised vertebrates are now commonly subjected to radiographic analyses and even some invertebrate specimens such as starfish, trilobites and crinoids within slabs of slate can be usefully studied this way (Hohenstein 2004). Radiographic images are formed by the differential absorption of X-rays as they pass through an object. The ability of a specimen to absorb X-rays will vary depending on changes in density, thickness and the minerals within it. Conventional radiography can present very clear and easily interpreted images of features hidden within fossil specimens because changes in density usually correspond to boundaries between materials or phases. However, these are two dimensional representations of three dimensional objects and features overlying each other may form unrecognisable shapes or confused detail. Even when it is obvious that, for instance, there are two or three recognisable bones overlying each other within the rock matrix, it is not necessarily possible to determine their depth within the object when viewing a single X-ray exposure. CT scanning overcomes this by taking many X-ray images from slightly different positions. These digital images can be combined and reconstructed to provide virtual sections through an object in any direction and 3D reconstructions of the object or features within it.

Although X-ray machines, techniques and operators vary and are constantly improving, the relative success of applying these processes is determined largely by the nature of the specimen. Many facilities cannot accommodate large or heavy specimens, dense matrices may be impenetrable and, most important of all, there may not be enough contrast between the fossil material and the host rock. Industrial radiography equipment and techniques, such as that used in the inspection of pipe welds, are more suited to the examination of fossil specimens than medical facilities as the image quality of the latter is compromised by restrictions relating to patient safety. In order to minimise exposure duration and X-ray dose, general medical radiographic films have very fast emulsions and these produce lower resolution and lower contrast images than slow, high definition, industrial films. In addition the medical X-ray beam is heavily filtered to remove the lower energy X-rays, as these are the most damaging to living cells, and this also reduces image contrast. In consequence, medical images may not capture the finest details and low contrast features may not be distinguishable against the grey image of the host rock. However this loss of information may only be apparent when medical and industrial X-ray images of the same object are compared (Buckberry and O'Connor 2007). The change from film to digital image capture has improved the contrast obtainable with medical radiography but resolution is still an issue.

Radiography can be costly and even if offered for free, funds will still have to be found for transporting the material to and from the facility (Clark & Morrison 1994). Industrial CT scanning is available but by far the most common use of CT is in a medical setting. This makes CT, on the whole, less easy to access than conventional radiography and it is very much more expensive. Fortunately high quality conventional radiography is perfectly adequate for most situations and can produce better rendering of fine detail than CT scans so it is advisable to employ this first, perhaps using several view points (from above, from below, from the side) and use the resulting images to determine whether CT scanning might add anything of significance.

Information gained through the radiography and CT scanning of specimens can be useful in many ways. The pre-preparation analysis of the contents of specimens jacketed with plaster during excavation can enable the prioritisation of work and guide the preparator's hand (Groenke *et al.* 2007). CT scanning is particularly useful for recording the position of fossil remains and details of the host material - associations and information which will be lost during the preparation process. Specimens flattened during preservation will benefit less from CT scanning and more from X-ray analysis. Importantly, both processes can reveal internal details not visible through other preparation methods. In conventional radiography, however, the X-ray beam diverges as it travels from its source and through the object to the film. This means that comparative morphological data will only be to scale where the specimen is in contact with the film or image receptor and the further away a feature is, the more it will be magnified. In some cases, where the matrix is hard but the fossil bone is extremely fragile, virtual preparation by radiography may be the best, or only, method available for preparators and researchers to work on a specimen. Furthermore, digital radiographs and CT scans can be made available readily and widely disseminated if so desired. The three-dimensional data from a CT scan can also be used to produce a replica of a fossil without removing it from the matrix, using computer aided design (CAD) software to control the formation of a solid three-dimensional scale model by techniques such as stereolithography (Clark *et al.* 2004). More importantly, this approach can be used to make a replica of a fossil specimen that has completely dissolved and left a void so that there is nothing to physically prepare. Magnetic Resonance Imaging (MRI) is another extremely useful non-destructive analytical process that can be used in a similar way to CT scanning but is not suitable for rocks containing magnetically susceptible materials (Clark *et al.* 2004).

The Collard Plesiosaur seemed to offer great potential for X-radiography as it appeared to be at least partly replaced by dense materials such as pyrite and calcite, similar to other specimens found at this locality (Parsons 2002), but was preserved in a relatively soft, homogeneous and un-cemented matrix. To test this potential and to gauge the effectiveness of CT scanning, the smallest block (containing the skull) was selected for analysis as it was the easiest to handle, would be less likely to suffer damage during transportation and would be most easily fitted into or under the relevant equipment.

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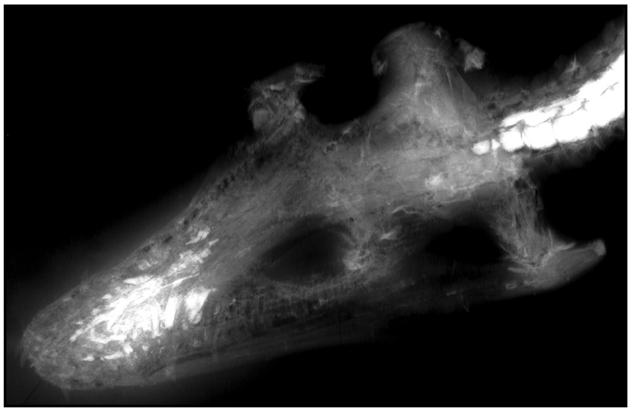

Figure 3. X-radiograph of the skull and cervical vertebrae of the Collard Plesiosaur (TTNCM: 146/2003). The tip of the snout is to the bottom left, cervical vertebrae to the top right. Note the dense mineralization of parts of the cervical vertebrae and the tooth sockets in the maxilla/pre-maxilla area.

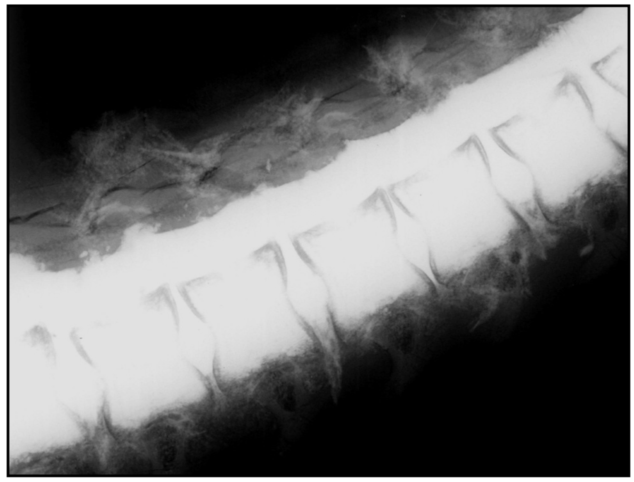

Figure 4. X-radiograph of the cervical vertebrae of the Collard Plesiosaur (TTNCM: 146/2003) with proximal vertebrae to the left and distal vertebrae to the right. This image shows a very dense region around the neural canal and the upper part of the vertebral centra, and the much lower bone density of the zygapophyses and neural arches. The neural spines are almost completely invisible on the X-ray, but the Y-shaped cervical ribs can be seen below the centra. The image has been magnified and the greyscale values adjusted to optimise the visibility of the detail captured.

Wear, a Pantak industrial X-radiography unit was used to take a variety of exposures producing high definition radiographs captured using both traditional film (Agfa Structurix D4) and digital capture by CR (computed radiography) using Agfa industrial image storage plates and an Agfa CR100 plate reader. The experimental exposures were taken between 80kV and 170 kV, and the best contrast images were gained between 100 kV and 125 kV. The film images were subsequently digitised using an industrial X-ray film scanner (Agfa SF50B) at Archaeological Sciences, University of Bradford.

The radiography, both the CR and film capture, yielded immediate and astonishingly clear results. The skull and neck appeared on the monitors in very fine detail, with many separate teeth visible and possibly even blood vessel channels and other tiny details (Figure 3). Individual vertebrae in the neck were shown clearly, detailing their internal structure (Figure 4).

From these results it seemed that CT scanning would also be fruitful and this was undertaken the next day at the Department of X-radiography at Bradford Royal Infirmary where a brand-new state-of-the-art CT scanner had just been installed. This was a GE Lightspeed VCT '64 slice' machine, one of only four in the country at that time. This CT scanner's action continuously overlapped each slice with the last to create a continuous image. The images from this machine were not so easy to interpret as the radiographs and required specialist software to work with the huge dataset produced. However both the radiography and the CT scanning worked extremely well. It was clear that these images would not only provide an invaluable guide for the preparation of the specimen but also enhance the subsequent study of the morphology and taxonomy of the skeleton and its eventual display, providing the possibility of generating a three dimensional stereolithographic model. Encouraged by the results from both approaches it was decided to extend the X-ray and CT studies to the rest of the specimen.

Radiography of the whole skeleton revealed that the only bones missing were some phalanges of the right rear limb. Intriguingly it also revealed great variation in the ability of the bone to absorb X-rays. In Figure 3, the white areas in the snout and neck indicate that in these places the bone is markedly more radio-opaque than the bone immediately around it. This range of variation was also observed in the distal bones of the limbs (see below). Given that this is a young individual this might indicate differences in the state of ossification of the bone at the time of death. The whiter areas may represent centres of calcification. It certainly indicates differences in the fossil state of the bone.

Exploration of the digital images was facilitated by the ease with which they could be magnified and the greyscale values adjusted to improve image contrast and thereby make features more visible. Figure 4 has been adjusted in this way to reveal detail in the more ephemeral areas around the centra of the vertebrae. Here, and in other places, the X-rays images suggested that there may have been soft tissue preserva-

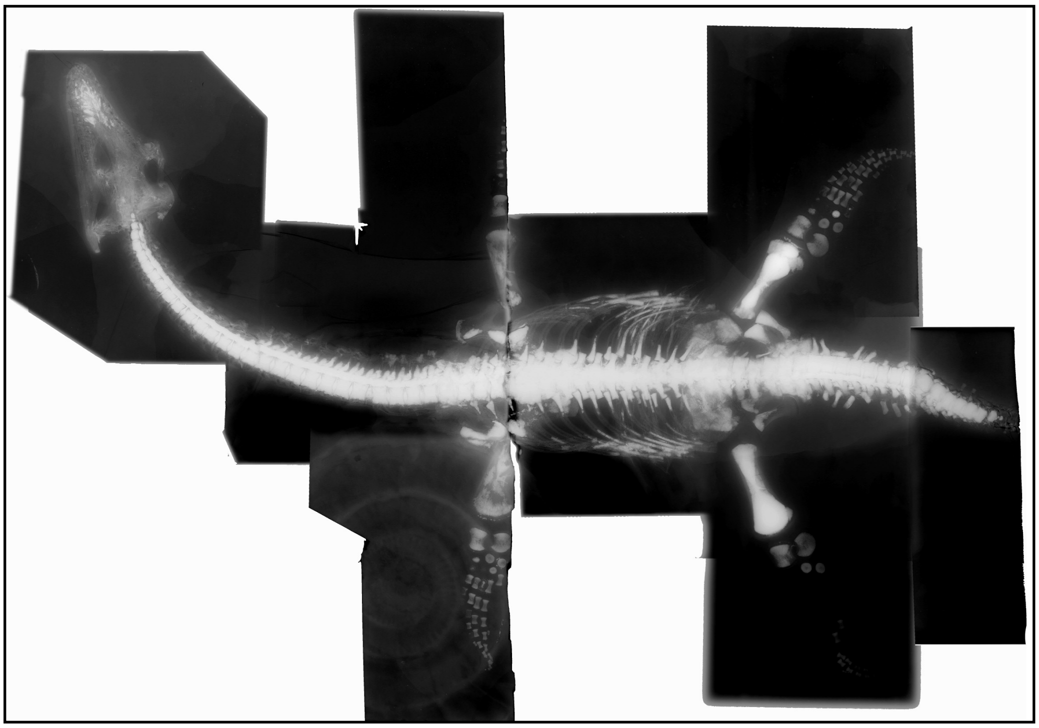

Figure 5. Composite of X-radiographs of the Collard Plesiosaur (TTNCM: 146/2003), showing the whole specimen as a grayscale image. The large ammonite impression (at the bottom of the image, in the middle) is approximately 800 mm in diameter.

tion around the bones. In Figure 5, the differences in the grey shades in the rock surrounding the specimen are due to variations in its thickness, for instance where some thin shale layers have broken off or it is deeply cracked. Also evident is the impression of the large ammonite. Again, the X-ray images seem to show possible soft tissue preservation seen as a fringe around the bone which is less dense (i.e. less radio-opaque) than the bones but more dense than the surrounding rock. It may just have been that the rock was thicker around the bone, but in some areas there did seem to be detailed features preserved in these areas. It was also possible to assign colours to different regions of the greyscale, rendering the image in false colours which made features stand out that otherwise could have been overlooked in greyscale images.

Physical preparation of the specimen

The physical preparation of the specimen was carried out with constant reference to the conventional X-ray and CT images. Due to the nature of the rock and specimen, the use of a scalpel blade to tease the layers of sediment away from one another proved to be more controllable, more gentle and generally more effective than mechanical preparation using airabrasives and percussion tools. Some bones, such as the smallest tail vertebrae, were found to be poorly preserved with little surface detail. There was a very small gap between the very last layer of sediment and the bone itself, where the surface of the bone might once have been but had since deteriorated. Fortunately, this type of preservation affected only a small fraction of the skeleton.

Each of the blocks was tackled in turn with a succession of fresh scalpel blades, teasing the layers of sediment off one another to expose the bones within. Body outlines and gut contents were searched for, but none observed despite the tantalising X-ray images. The preservation of the bone surfaces varied, and it was noted that some of the bones of the limbs were extremely porous and friable with no coherent surface (in particular the phalanges), whereas the upper limb bones exhibited fine surfaces in their middle portions but the bone surface was particularly poorly preserved at the proximal and distal ends. This differential preservation of the bone surface did not exactly match X-ray images of the rear limbs, see below.

Once a bone had been exposed as best as it could with scalpel blades (Figure 6), it was gently swabbed clean with cotton buds dipped briefly in acetone and a small amount of water to remove as much of the remaining sediment as possible. Acetone helped the water to evaporate more quickly, limiting penetration of the specimen and reducing the risk of the matrix swelling and distorting.

As well as occasionally being friable and crumbly, the bones were often riddled with tiny cracks. Therefore, once prepared and cleaned these bones were consolidated with two or three applications of Paraloid B-72 (5% Paraloid B-72 granules to 95% acetone by weight) using either a very small brush or a pipette, so that the consolidant did not affect the matrix. This was followed swiftly by a few drops of more concentrated consolidant (10% to 15% Paraloid

B72 to 90% and 85% acetone respectively, weight by volume) that was drawn down into the bone by capillary action to give a better and deeper consolidation than would otherwise have been achieved. When appropriate, Paraloid B-72 adhesive was applied straight from the tube if an area was particularly friable or if a break needed repairing.

The preservation of the specimen

The skeleton is almost complete. The only bones known to be missing are some of the phalanges in the middle of the right rear paddle. The skeleton is preserved upside-down with the skull at a slight angle. Part of the lower jaw (dentary, left side) was broken and folded over the rest of the underside of the skull and mandible during the burial process (Figure 6). This allows us to see more teeth than we might otherwise have done. The upper parts (as preserved) of some of the bones, particularly the vertebrae, symphysis of the pelvic girdle and the skull, are less well preserved. These areas were possibly more prone to damage during the burial process as they would be the last parts of the body to be covered by sediment and therefore would be potentially subject to more decay and sea floor processes. There is no evidence of scavenging, and the carcass was largely undisturbed.

The surfaces of the main limb bones seemed relatively soft, especially at their distal and proximal ends. At first glance these differences in preservation might seem to correspond with the differences in density recorded by the radiography (Figure 7). However, closer inspection comparing the radiograph to the actual specimen (Figure 8) reveals that only the interior of the limb bone is mineralised, not the external portions. As this is a young individual, there are obvious questions one can ask about the diagenesis and differential preservation of the bone and what this might tell us about how the limb bones grew. However, it is also interesting to note that two carpal bones in the x-ray image (Figure 7) are hardly discernable and one phalange is not recorded at all, compared to the same limb after preparation (Figure 8). This demonstrates that X-ray images should be interpreted and acted upon with caution.

Many of the smaller bones are highly fractured and have little or no integrity. If the removal of individual bones had been attempted, they would certainly have crumbled. The gastralia and some of the vertebrae in the abdominal area were particularly poorly preserved and very brittle. This area possibly suffered more chemical and/or biological damage than other areas due to the gut and stomach contents acting upon the bone during initial putrefaction of the body. When the specimen was found, it was clear that with each tide stones had been rolling back and forth over the skeleton, damaging the upper surface of some of the bones that had become exposed (particularly the pectoral girdle and skull). Also, cracks

Figure 6. The prepared skull, lower jaw and cervical vertebrae of the Collard Plesiosaur (TTNCM: 146/2003). Although the rest of the body has been preserved ventral side up, this image shows how the skull has not been preserved in a simple 'plan' orientation but has been flattened at an oblique angle. The ventral aspect of the right side of the skull and lower jaw can been seen towards the bottom of the image, and above this the left dentary, a row of interlocking teeth and part of the dorsal surface of the left maxilla.

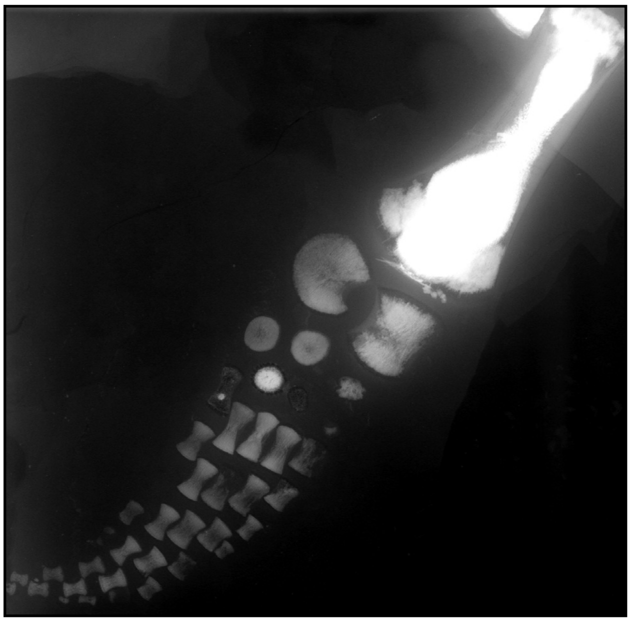

Figure 7. X-radiograph of the left rear limb of the Collard Plesiosaur (TTNCM: 146/2003) showing differential preservation between bones and, in the case of the femur (at the top of the image), within a bone.

Figure 8. Photograph of the rear left limb of the Collard Plesiosaur (TTNCM: 146/2003) after preparation, showing the bones either hardly revealed or not revealed by X-radiography (marked by 'X's).

had developed along the spine and salt water had penetrated the specimen, though this does not seem to have adversely affected the material.

A very hard, white crystalline infill - possibly calcite - was found between the vertebrae. Not all this was removed and the remainder could be investigated with X-ray diffraction techniques as part of any investigation into diagenetic processes. Many small flattened ammonites and a few fish scales were found preserved in the sediment as well as the very large ammonite in Figure 5. Most of the sediment was saved for further analysis or handling/teaching sessions.

Discussion

The usefulness of X-radiographs and CT scans

The X-rays were extremely useful in providing an accurate map of where the bones were located, so that preparation could take place more effectively than might otherwise have been the case. They also provided a surprisingly detailed permanent record of the specimen, including morphological details that remain unavailable and preserved phenomena that might not be visible to the naked eye and which may or may not have been removed by the physical preparation. It was hoped that the dark outline extending out from the postcranial skeleton (Figure 5) might be the remains of a body outline preserved or at least a microbial mat. The physical preparation has revealed no body outline so far. However, the lower halves of the bones are still embedded in the matrix and it is possible that something of this nature could be preserved within the unprepared sediment at a lower level. Further X-radiography would reveal if the outline is still there or not.

Figures 9 and 10 are respectively horizontal and vertical sections through the skull reconstructed from the CT scan and demonstrate that CT scanning does not immediately reveal a specimen in unadulterated detail. Both images suffer from scanning 'artefacts' due to X-ray reflection and scattering (pyrite inside the bones may have been partly responsible), the subject being very different in its radio-opacity to the human tissues for which both the hardware and software of the CT scanner are designed. To make full use of the CT scans would have required specialist software and much specialist help in processing the scans to produce 'cleaner images' and interpret them. Unfortunately, this could not be undertaken in time for the preparation of the fossil. However, having relatively little access to detailed CT data did not hinder the preparation process as the X-ray images were of such high quality. The CT images that were available did give a useful indicator of the depth of the bones under the surface of the shales (which the X-rays do not provide). In both the X-ray and CT images, it is clear that there is little difference between the matrix and bone in many places.

This image processing will be invaluable for the research stage as the CT data will add much to study of the anatomy and taxonomy of the specimen. For example, CT images of the skull show the phyloge-

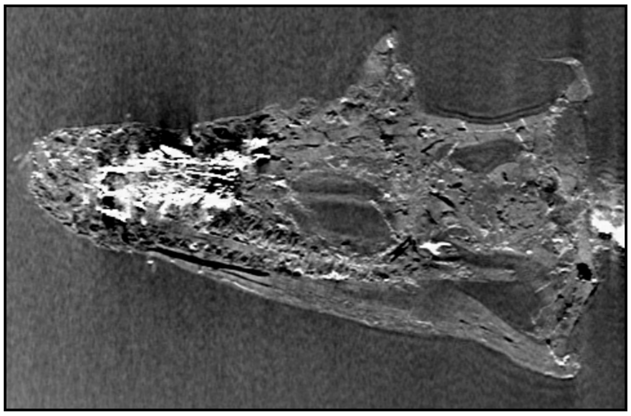

Figure 9. A CT slice of the skull of the Collard Plesiosaur (TTNCM: 146/2003), seen in horizontal cross-section. The tip of the snout is to the left, the rear of the skull to the right. As in Figure 3, the densely mineralised cervical vertebrae can be seen to the right, and to the left is the densely mineralised area of the front of the skull.

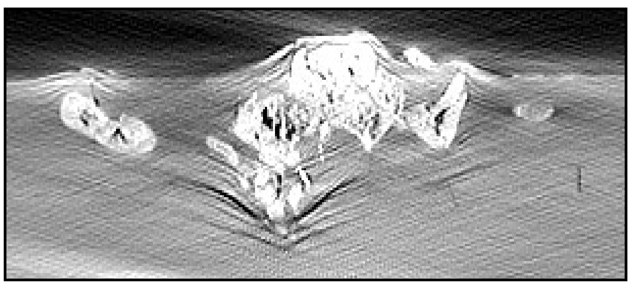

Figure 10. A CT slice of the upside-down skull of the Collard Plesiosaur (TTNCM: 146/2003), seen in vertical cross-section.

netically significant shape of the parietal, which is impossible to see on the X-rays because of all the overlapping structures. Similarly, the structure of the sphenoid and basioccipital can be studied. No single CT image offers a perfect view of these structures but by moving backwards and forwards through the slices in sequence they can be studied and their morphology measured (Mark Evans *pers. comm*.).

Display

Data gathered either by X-raying or CT scanning a fossil specimen has the potential of making a valuable contribution to an interpretive display. The digitised X-ray images from an entire skeleton can be 'stitched' together and explored in detail on a monitor in a gallery or on the internet. The CT data could be used to create a virtual 3D model for an interactive exhibit where users could rotate the skeleton in any direction and magnify specific features. The same data could be used to make full-size solid stereolithographic replicas.

Such uses of the data are constrained by many limiting factors: primarily budget, but also the physical space available, the prioritisation of certain themes within an exhibition and the technical expertise available. However, they may not even be necessary. Extremely well preserved and almost complete skeletons such as the Collard Plesiosaur are very readily and intuitively interpreted by the public.

The Collard Plesiosaur will be on permanent display from mid-2011 in the Great Hall of Taunton Castle, the new Museum of Somerset.

Conclusions

Although a delaminating specimen may look as if it requires remedial conservation, including possible consolidation, attempting this could damage the specimen. In all cases experimental consolidation should initially be undertaken on unwanted test pieces of matrix. This highlights the importance of collecting additional matrix with a specimen.

Working on this fossil in conjunction with its radiographic record provided a unique opportunity to be forewarned of the position of the bones, variations in their condition and of the possible existence of soft tissue preservation or potential microbial mat.

The X-ray images were extremely useful for guiding the physical preparation of the specimen. The CT scans, had they been processed to improve the visibility of features, would also have been of some additional use, to help judge the depth of individual bones within the specimen. However, the skeleton was preserved in an uncomplicated horizontal position, the locations of the main bones were obvious from the outset and a complete set of X-rays were available. Therefore the preparation of the specimen may not have proceeded very differently even if cleaned CT images had also been available. Other, more complicated specimens that are less easy to interpret in the field and in the preparation lab would benefit much more from both analyses.

This project, however, demonstrates that the employment of these analytical techniques is valid for recording in detail the unpredictable preserved phenomena that are either invisible to the naked eye or remain inside the specimen and unavailable even after preparation.

Acknowledgements

The following people provided invaluable advice and discussion: Richard Forrest, Mark Evans, Arthur Cruickshank, Amy Davidson and Leslie Noè. Without the generosity of spirit of the following people, much of the work above would not have been possible: Argos Inspection Ltd who X-rayed the specimen and the staff at Bradford Royal Infirmary undertook the CT scan. The project was financed by The PRISM (Preservation of Industrial and Scientific Material) Fund, the Geologists' Association Curry Fund, Somerset County Museums Service and donations made by the public.

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Appendix

The materials used in the preparation and conservation of the Collard Plesiosaur

1. **Paraloid B-72** (also known as Acryloid B-72). A stable and reversible ethyl methacrylate co-polymer used as an adhesive and consolidant (as a consolidant, it requires the addition of a suitable solvent, e.g. acetone, toluene or isopranol).
Supplier: Conservation Resources (U.K.), Ltd., Unit 2, Ashville Way, Off Watlington Road, Cowley, Oxford OX4 6TU, U.K.

2. **Wacker silicone rubber**. Room-temperature vulcanizing silicone polymer, flexible and resistant to aging. Used for making moulds of delicate objects.
Supplier: South Western Industrial Plasters, 63 Netherstreet, Bromham, Chippenham, Wilts. SN15 2DP, U.K.

3. **Jesmonite acrylic resin**. Jesmonite is a casting and laminating system that provides a safe alternative to polyester and fibreglass resin systems. It is durable, flame proof and does not warp when applied in large quantities.
Supplier: South Western Industrial Plasters, 63 Netherstreet, Bromham, Chippenham, Wilts. SN15 2DP, U.K.

4. **Plastazote foam**. A chemically inert, low density, closed cell, cross-linked polyethylene foam of archival quality available in sheets at various thicknesses.
Supplier: Paulamar Company Ltd., Woodilee Industrial Estate, Woodilee Road, Kirkintilloch, Glasgow, G66 3TU, U.K.

THE SECOND WESTBURY PLIOSAUR: EXCAVATION, COLLECTION AND PREPARATION

by Judyth Sassoon, Roger Vaughan, Simon Carpenter and Leslie F. Noè

Sassoon, J., Vaughan, R., Carpenter, S. and Noè, L.F. 2010. The second Westbury Pliosaur: excavation, collection and preparation. *The Geological Curator* 9 (3): 117 - 126.

The Lafarge cement works at Westbury, Wiltshire is an important exposure if the Lower Kimmeridge Clay and yields a variety of marine vertebrate fossils. This paper describes the excavation, preparation and taphonomy of a remarkable pliosaurian skeleton discovered in the quarry during the summer of 1994. The find includes a skull, crushed dorso-ventrally, with a well preserved palate and a complete mandible, as well as postcranial material. The specimen, housed in the Bristol City Museum and Art Gallery (BRSMG Cd6172), is currently undergoing a detailed study.

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Introduction

The cement works at Westbury, Wiltshire (NGR ST 8817 5267) provides one of the few inland exposures of the Lower Kimmeridge Clay (Cox and Gallois 1981). This quarry is of considerable interest and value to geologists and paleontologists, yielding marine fossils from between 155 and 150 Ma (Table 1). The Westbury works has been operating since 1962, under the name Blue Circle Industries plc, extracting clay as a source of alumina in the cement manufacturing process (Hudson 1984, Pugh 1988). In 2001 it was purchased by the French company Lafarge and "Blue Circle" became Lafarge's cement brand name in the UK.

The "old quarry" to the west of the main works was developed for the combined use of clay extraction and disposal of excess dust from the cement manufacturing process. Dust disposal was discontinued in 1981 and clay extraction ceased at the old quarry in 1992. After this, the old quarry was used for disposal of domestic and light commercial waste products. The "new quarry", to the northeast of the main works, operated after the closure of the old quarry (Grange *et al.* 1996). However, in 2009, the Westbury cement works closed and the pumps controlling water levels in the pits were switched off. Consequently, over an unpredictable period of time the pits will fill with water and the site will be lost to the geological community (Carpenter 2009).

Active quarries and clay pits create new exposures when excavating machinery scrape out rims or "benches" on the working quarry faces. These activities at Westbury frequently revealed fossils. Both the old and new quarries at the Westbury works have yielded a diverse micro- and macro-fossil fauna at many horizons and a number of valuable marine fossils were collected between 1980 and 2009 (Figure 1, Table 1, Grange *et al.* 1996).

Here we present an account of the excavation and preparation of one significant find from the Westbury cement works: the cranial and post-cranial remains of a well-preserved pliosaur. This specimen is referred to as the Westbury Pliosaur II, because it was the second major pliosaurian find at Westbury. The first (Pliosaur I) emerged from the old quarry in 1980 and was identified as *Pliosaurus brachyspondylus* (Crane 1980; Taylor and Cruickshank 1993; Taylor *et al.* 1993; Taylor *et al.* 1995). Pliosaur I has been on display at the Bristol City Museum and Art Gallery (BRSMG) since the 1990s (Taylor *et al.* 1995; BRSMG Cc332). In 1994 the new specimen was identified as a pliosaur on the basis of its elongated mandibular symphysis (Tarlo 1960) but a reliable identification to species level has not been made to

Taxon	Date	Location	Comments
Class: Sauropsida Order: Ichthyosauria	June 1994	New quarry	Partial cranial and postcranial elements of *Opthalmosaurus*. sp. (*eudoxus* biozone).
Class: Sauropsida Order: Crocodylia	1999	New quarry	Vertebral column from *Steneosaurus* sp.
	Mar. 2000	New quarry	Articulating vertebra, teeth and post-cranial fragments (*eudoxus* biozone).
	Jul. 2005	New quarry	Post cranial elements, mandible, teeth of *Dakosaurus carpenteri* found 2 m below *Crussoliceras* limestone (*eudoxus* biozone). (Wilkinson *et al*., 2008)
Class: Sauropsida Order: Plesiosauria Sub-order: Plesiosauroidea	1994	New quarry	Rib and vertebrae with associated neural processes of *Plesiosaurus* sp. Damaged during clay extraction (*eudoxus* biozone). Donated to Bristol City Museum and Art Gallery, 1994. (BRSMG Cd3426).
	1998	Old quarry	Large propodial element of plesiosaur (?). Very weathered, damaged by quarrying machinery. Some associated invertebrates (*eudoxus* biozone).
	2005	New quarry	Large propodial element of plesiosaur (?).
	2006-2007	New quarry	Associated bones and teeth found at same locality on several visits.
	2008	New quarry	Vertebrae and several post-cranial elements. 10 m below *Crussoliceras* "limestone" horizon (eudoxus biozone).
Class: Sauropsida Order: Plesiosauria Sub-order: Pliosauroidea	May 1994	New quarry	Partial skeleton of *Pliosaurus* sp. located 7 m below the *Crussoliceras* "limestone" horizon (*eudoxus* biozone). Westbury Pliosaur II. Donated to Bristol City Museum and Art Gallery, 1994. (BRSMG Cd6172).
	Aug. 1994	New quarry	Ribs, vertebrae, limb elements and scapula of *Pliosaurus* sp. Located 0.38 m below the M18 "limestone" horizon (*mutabilis* biozone).
	1995	Old quarry	Vertebrae and associated neural processes from *Pliosaurus* sp. Located 3.66 m above *Crussoliceras* "limestone".
	1996	Old quarry	Partial postcranial skeleton (*eudoxus* biozone).
	2000	New quarry	Teeth, articulated vertebrae and paddle digit collected over several visits (*eudoxus* biozone).
Class: Actinopterygii	1994	Old quarry	Cranial material from *Caturus* sp. Crushed skull with separate associated mandible and teeth (*mutabilis* biozone). Donated to Bristol City Museum and Art Gallery, Nov. 1994. (BRSMG Cd3574).
	1995	Old quarry	Cranial and post-cranial elements from *Lepidotes* sp. (*mutabilis* biozone).
	Oct. 2000	New quarry	Complete skull of *Caturus* sp. (*eudoxus* biozone) (donated to Oxford Museum, Aug. 2005).
	2000	New quarry	Mandible elements of *Aspidorhynchus* sp. (*eudoxus* biozone).
Class: Chondrichthyes	Sept. 1995	New quarry	Mid portion of dorsal fin spine of *Asteracanthus* sp. damaged by quarrying machinery (*eudoxus* biozone).
	2000	New quarry	Mid-portion dorsal fin spines of *Asteracanthus* sp. found on several separate visits
	May 2001	New quarry	Partial postcranial skeleton from Rhinobatidae. Associated material found on loose block of clay *(eudoxus biozone)*
Class: Sauropsida Order: Pterosauria	1995	New quarry	Pterosaur limb bone fragment.

Table 1: Vertebrate discoveries from the LaFarge cement works, Westbury.* In situ *finds since 1994 are listed. Loose bone fragments of uncertain stratigraphic origin from spoil heaps or deposited following mudslides are not considered. Primary collector since 1994, Simon Carpenter.

date. The Westbury Pliosaur II (BRSMG Cd6172) is currently under study by the Department of Earth Sciences, Bristol University and a full description is pending (Sassoon in preparation).

Stratigraphy

In the UK, the Kimmeridge Clay crops out as a continuous, narrow strip from Dorset on the south-west coast to Yorkshire in the north-east, and Westbury provides one of only a few inland exposures. Other inland sections include a small number of transient landfill sites. The Kimmeridgian Stage of the Upper Jurassic is dated from 155.7 + 4 Ma to 150.8 + 4 Ma (Gradstein *et al.* 2004). The type sections of the Formation and Stage are found on the south Dorset

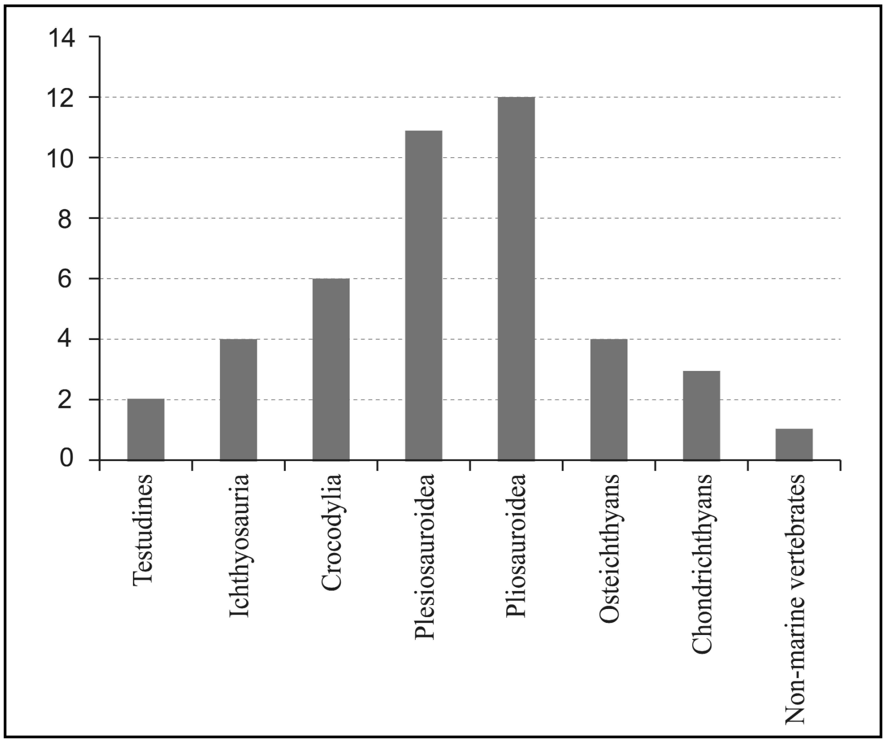

Figure 1. Chart showing the number of taxa discovered* in situ *at the Westbury cement works, old and new quarries, between 1980 and 2009. Main collectors: Steve Etches and Simon Carpenter. Data for 1980 to 1994 from Grange* et al. *(1996). For details of subsequent finds see Table 1.

coast between the Isle of Portland (National Grid Reference SY 680 730) and Kimmeridge Bay (SY 901 790) (Gallois and Cox 1976). Kimmeridgian sediments are made up of dark argillaceous shales and comprise a sequence of organic rich and calcareous mudstones, divided into 48 beds on the basis of palaeontological and lithological data (Cox and Gallois 1981). These richly fossiliferous mudrocks accumulated as shallow marine deposits during a global highstand (Haq *et al.* 1987; Hallam 1988 2001). In the Late Jurassic, the sea levels rose, reaching a high point in the Kimmeridgian, probably due to basin subsidence following a phase of crustal extension (Taylor *et al.* 2001; Taylor and Sellwood 2002).

A detailed biostratigraphical and lithostratigraphical study of a 40 m section, extending from the upper *Rasenia cymodoce* biozone (3 m) through the whole *Aulacostephanoides mutabilis* biozone (*mutabilis* biozone) (22.3 m) into the lower *Aulacostephanus eudoxus* biozone (*eudoxus* biozone) (14.5 m) (Cox and Gallois 1981), was produced for the Kimmeridgian succession at the old quarry (Birkelund *et al.* 1983). This stratigraphical framework has been used to locate the fossil discoveries at Westbury (Grange, *et al.* 1996; Grange and Benton 1996).

The Westbury Pliosaur II discovery lay on a thin level of shell material, a "pause" in sedimentation and several of these shell-beds were visible on the excavated bank, probably representing cycles of sedimentation (Oschmann 1988). Ammonite samples were collected from just above the specimen, and the stratigraphic position was located within the *eudoxus* biozone (E4) (Table 1) occurring about 10.5 m above the M18 reference marker horizon and about 7 m below the E6/KC30 *Crussoliceras* limestone marker horizon (Birkelund *et al.* 1983; Grange *et al.* 1996).

Excavation

The Westbury Pliosaur II was discovered in the new quarry, by fossil collector Simon Carpenter in May 1994, during a period of active quarrying. A section of the northeast face had been graded back by quarry machinery, to form a stable rim. In the process, the machinery had exposed several vertebrae and a line of nodules 3 m below the rim (Carpenter 1995). When this was reported to quarry manager, David Beatty, he kindly agreed to do everything possible to prevent further disturbance. Staff from the Bristol City Museum and Art Gallery and Bristol University took responsibility for the excavation. They included Dr. Peter Crowther (BRSMG Geology Curator in 1994), Roger Clark (Assistant Curator), Roger Vaughan (Geology Conservator) and Glenn Storrs (Department of Earth Sciences, University of Bristol). Thanks to the cooperation of the Blue Circle management and staff, the specimen was successfully collected over a period of two months, following the cessation of quarrying in June 1994.

Initially, layers of clay above the bone concentration were removed with small hand tools to reveal the skeleton. Several bony elements were tagged and lifted and the margin of a large carbonate concretion, crushed and distorted by the weight of the overlying sediments, was uncovered. Adjacent to the concretion, a section of cranium was revealed (Figure 2) covered in layers of clay and shell bed. It had many small fractures and appeared to have been grazed posteriorally by site machinery. The cranium was quite badly crushed dorsoventrally. As the skull was being uncovered, it began drying out and the surface began to fracture. To avoid further damage, it was decided to leave the bones covered in sediment until they could be prepared under controlled laboratory conditions.

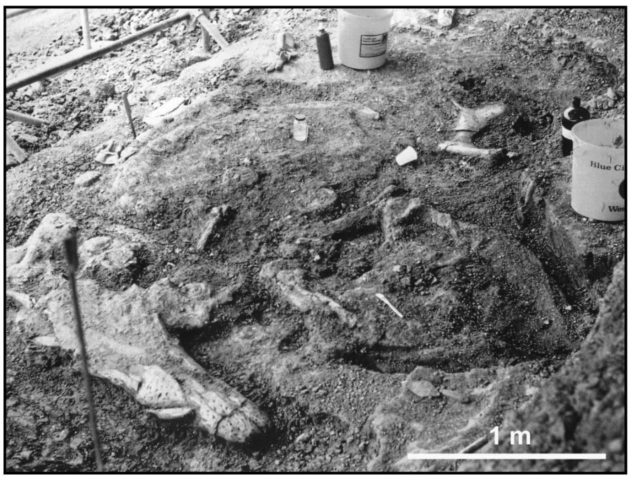

Figure 2. The arrangements of bones at the Westbury cement works excavation site 1994. The pliosaur skull is visible bottom left with the mandibles lying to the right. North to top right. Refer also to Figure 4. (Photograph courtesy of David Beatty, Blue Circle Industries, plc).

A tarpaulin cover on supporting poles protected the specimen from extremes of weather. During the excavation, the site was subjected to both torrential rain and high temperatures (31^{o} C in the shade). It was therefore important to act promptly to protect the specimen. To minimise shrinkage and cracking in the warm dry conditions, water and solvent-based adhesives were applied to consolidate the skeletal fragments. A solution of 5 % weight by volume (wbv) Paraloid B72 in acetone was used to stabilise the most vulnerable areas. However, overenthusiastic consolidation in the field was not encouraged, as the consolidant would then have to be removed with acetone in the laboratory, prior to preparation.

One of the first tasks was to remove the upslope overburden and to create a working surface. The specimen was protected with newspaper, polythene sheeting and a layer of clay blocks. Spades and pick-axes were used to cut out blocks of clay, allowing them to fall onto the covered area and afterwards the blocks of overburden were thrown downslope into the main quarry. A working surface approximately 7 m by 3 m with a 2 m high back wall was excavated. The immediate area around the specimen was trenched and divided into clay pedestals with the bones perched on top. The clay between the pedestal blocks was removed to a depth of 0.75 m (Figure 3A). Isolated bones between the major blocks were removed separately. The exposed bones were then encased in "bandages" soaked in plaster (Figure 3B).

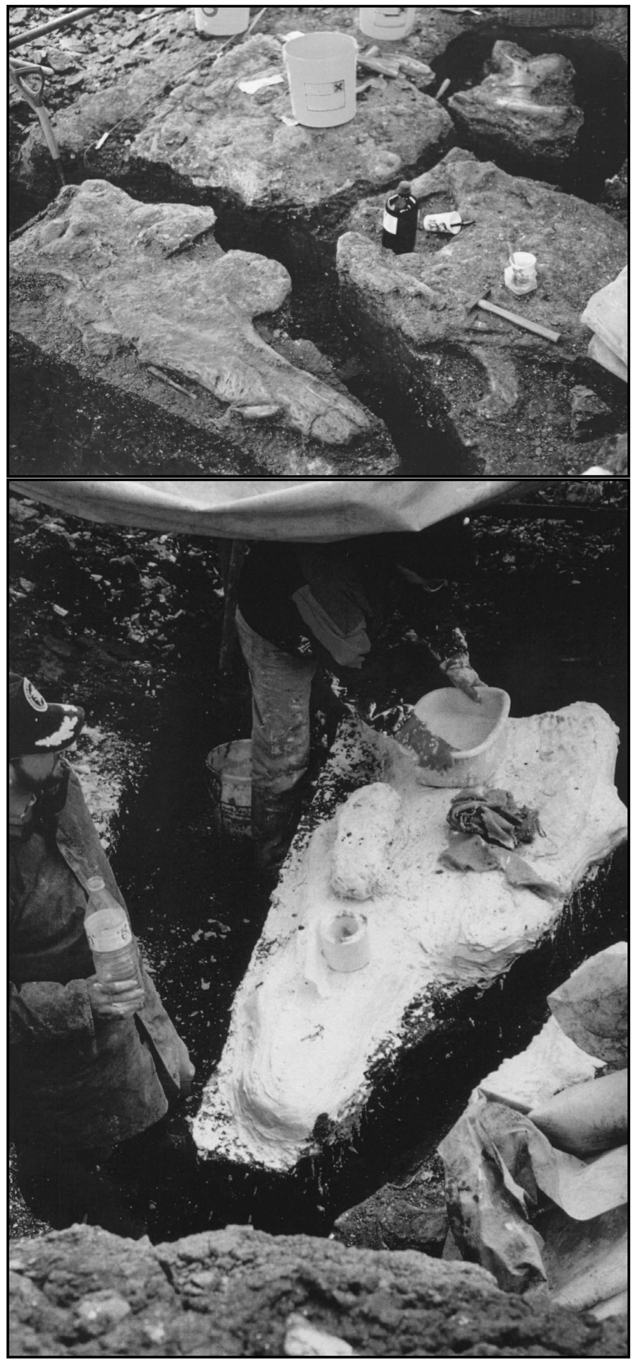

Figure 3. The pliosaur excavation site divided into bone clusters. (A) Clay between the clusters was removed leaving bone elements on pedestals. North to top right. Total length of skull (bottom left) = 1.7 m. (B) Elements were encased in foil followed by bandages soaked in plaster of paris. The plastered elements were then crated and transported from the site. North to bottom left. Total length of encased skull (centre of image) = 2 m. (Photographs courtesy of David Beatty, Blue Circle Industries, plc).

Aluminium foil was used as a barrier between the plaster and bone, to prevent moisture loss and to facilitate the subsequent removal of the plaster from the bone surface in the laboratory. Some of the larger bones, such as the skull and mandible, had timber batons set into the plaster for additional rigidity and protection. The largest of the encased bone, such as the cranium, were covered in glass fibre resin "tops", to strengthen the packaging.

Once the major bones had been exposed and encased, the original excavation site was enlarged to cover a total area of c.64 m^2. A bulldozer was employed to clear an access road for a Poclain bucket digger, which trenched down to approximately 0.5 m above the bone-bearing horizon, behind the back wall of the excavation. The remainder of the back wall was periodically pushed into the trench behind, so as to avoid collapse onto the excavation and was cleared manually. Exposed bone was given extra protection with newspaper, tarpaulin and clay padding.

The bone pedestal-blocks were removed as units in custom-built crates, which were inverted over the pedestals. To make the crates fit the blocks, and to eliminate void space within, two-part polyurethane insulation foam was injected into the crates, and timber strips pressed down onto any gaps to force the foam to expand down into the crate. The foam set hard within minutes and was very effective, penetrating right into the bedding planes of the clay and thereby giving the highest possible support. As isocyanates are components of polyurethane foam, it was noted that extra care would have to be taken later on when the crates were opened. Isocyanates can induce respiratory problems and adequate ventilation is required with their use (Zummo and Karol 1996). Remaining clay at the base of the pedestal was chipped away to undercut the block and allow wooden boards to be fitted underneath. Crates were strengthened with extra lengths of 4" x 2" (100 x 50 mm) timber nailed to the top and then turned upside down so that the extra timber formed a palate. The freestanding crates could then be lifted by crane onto trucks and transported from the quarry.

After removal of the major blocks from the excavation site, an area of consolidated shell bed around 2 m in diameter was mapped and reduced to large blocks (lettered a to n, Figure 4). Bony elements were wrapped in tinfoil and scrim, then plastered and transported back to the BRSMG preparation laboratory. The blocks have taken many years to prepare and yielded much post-cranial material (Table 2). The crates containing the largest of the bone clusters were stored in the Bristol Industrial Museum and over a period of 15 years the elements were gradually transported to BRSMG for preparation. The crates were broken open at the Bristol Industrial Museum and the elements transported in their fibreglass trays. Some sections of the specimen were particularly large, and the jacket carrying the lower jaw had to be sawn in half to facilitate movement within the museum building.

Taphonomy

The skull of Westbury Pliosaur II measured 1.7 m in length along the midline from the tip of the snout to the most postero-dorsal point of the squamosal, and 820 mm at its widest point across the quadrates. Estimates of the total size of the animal were made at the excavation site and it was thought to be around 5.3 m long from tip of snout to tail and 1.4 m wide. The cranium, mandible and teeth appeared to have been preserved in a similar fashion to Westbury Pliosaur I (Taylor and Cruickshank 1993) while postcranial elements were mostly preserved in nodules. The skull was turned towards the bank and the body lay parallel to the bank with the posterior section curving back. The body was therefore originally preserved curved into a semi-circle (Figure 4).

The skull was dorso-ventrally flattened with numerous fractures over the preserved surfaces, frequently obscuring surface features such as sutures. Dorsally, the premaxillae and maxillae were well-preserved. However elements around the orbits and the temporal bars were fragmented or missing and the squamosals were folded and crushed. Most of the brain case was lost as a result of flattening of the dorsal portion of the skull. The ventral surface of the cranium, however, was well preserved and fairly complete with considerable detail preserved on the palate. The mandibular elements were also well preserved and largely complete, with many functional and replacement teeth preserved *in situ*. Some of the postcranial material was distorted due to overburden pressures.

Both dorsal and ventral surfaces of the bones were encrusted with invertebrate epibionts suggesting that the specimen remained exposed on an oxygenated or at least partially oxic seabed prior to burial (Martill 1985; Dineley and Metcalf 1999). Such encrustations are common in Westbury specimens (Birkelund *et al.* 1983; Grange and Benton 1996; Wilkinson *et al.* 2008). Both surface scavenging of the specimen itself and scavenging between the encrusting communities was evident. Concentrations of encrusting

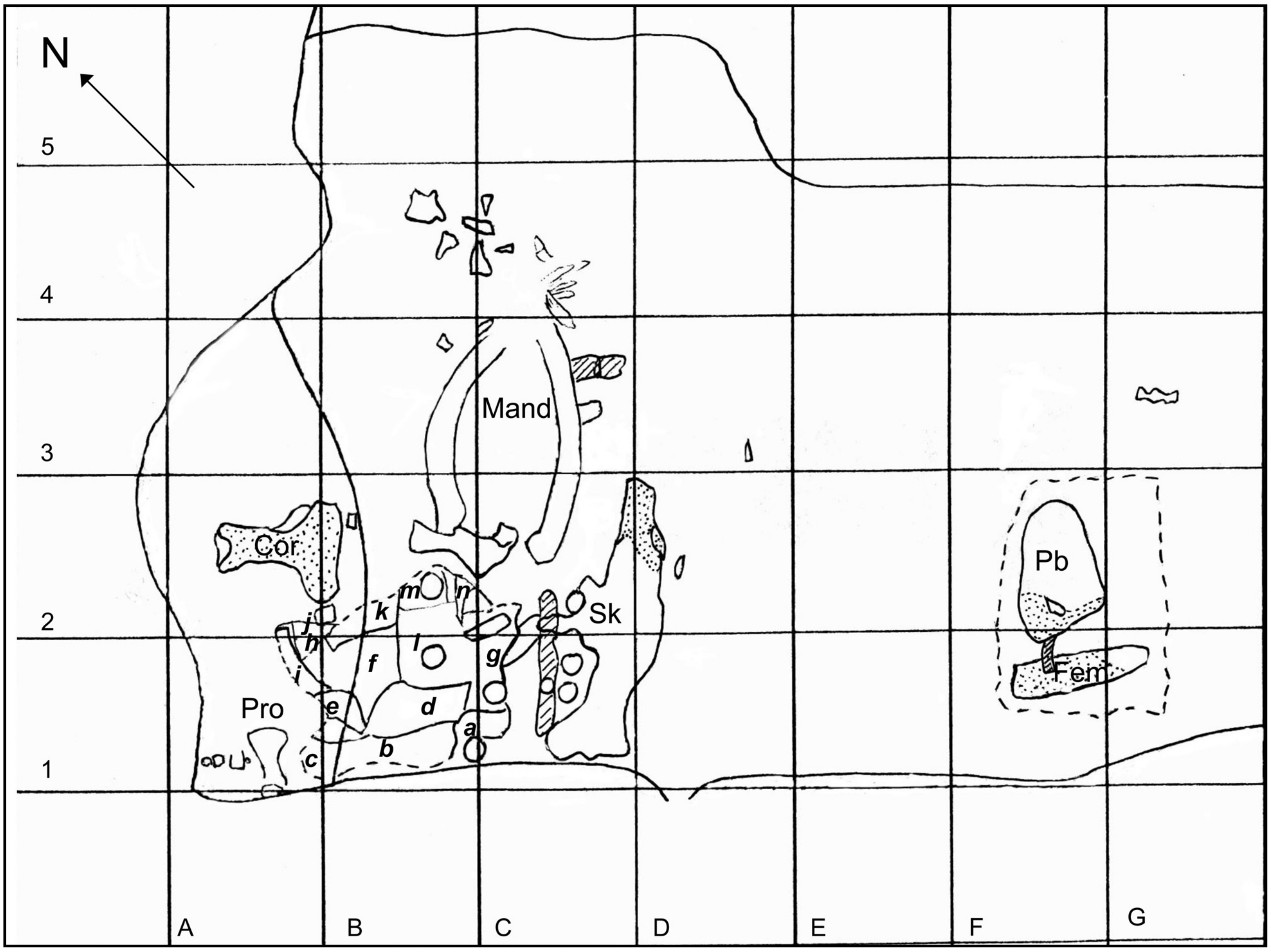

Figure 4. Schematic plan of the Westbury pliosaur II excavation site at the new quarry, Westbury cement works (1994). Cross hatched sections indicate fossil wood. Stippled areas indicate bones exposed initially, prior to excavation. Scale: Large squares = 1 m^2. Large bones: Cor, coracoid; Fem, (?)femur; Mand, mandibles; Pb, (?)pubis; Pro, propodial; Sk, skull. Major blocks were identified by their grid reference. a to n are minor blocks containing various elements (see text and Table 2 for details).

clusters have been interpreted as being the result of environmental forcing, associated with small-scale storm events within the Kimmeridge layers (Wignall 1989). Encrustrations were tentatively identified as serpulid polychaetes (white calcareous tubes, with various degrees of curvature) and various small (10 mm wide) bivalves (e.g. *Nanogyra*? sp. Grange and Benton 1996). Micro-epibionts were identified as clusters of ostracodes and foraminiferans, encrusting both bone and sediment surfaces.

The orientation of the fragmented pliosaur skeleton suggested its taphonomic history. Following death the initial disarticulation of the heavier elements such as the skull may have occurred while the body of the animal was buoyant, due to the accumulation of gases from decaying tissue (Schäfer 1972; Allison *et al.* 1991). In very deep water, the bone elements could have been scattered over great distances prior to settling. However, the presence of storm-induced sedimentary structures and benthic fauna in the Kimmeridge Clay (Birkelund *et al.* 1983; Wignall 1989) as well as the close proximity of most of the bone elements suggests that the water depth at which the pliosaur settled was not extreme. It is assumed that the skull became separated from the rest of the carcass either in the water column or on the substrate, and settled with the dorsal surface uppermost. Some of these surfaces remained exposed sufficiently to allow epibiont encrustration to occur.

Post-depositional processes, such as mass movement due to storms, current or inclined surfaces disarticulated the bones further and re-distributed them. Encrustation on both dorsal and ventral surfaces suggests flipping of the bone during sporadic storm events, for which there is abundant sedimentological evidence (Wignall 1989). It has been suggested that the skeleton could have been exposed to intense sediment-laden storm-current activity, which caused the somewhat randomly distributed disarticulation, before the skeleton was completely covered in sediment and subsequently deformed by overburden pressure (Martill 1986).

Grid location in site plan	Blocks /surrounding sediment	Elements	Comments
A1	A1	propodial, paddle elements	-
	h	-	-
	i	rib	-
A2	A2	coracoid	See Fig. 6a.
	j	-	-
B1	*a*	ribs, vertebrae and neural processes	Ribs fragments and gastralia were welded into the limestone. Ribs were recovered as fragments and reassembled. Gastralia were broken into fragments, extracted, prepared and reassembled.
	b	vertebrae and associated neural processes, ribs, unidentified small bone fragments, section of gastralia	
	c	-	
	d	ribs, vertebrae and associated neural processes, phalangeal elements, section of gastralia	
	e	-	
	f	-	
	l	vertebral centrum	
B2	*k*	-	All the blocks in this section formed part of the shell-bed platform.
	m	vertebral centrum	
	n	-	
	surroundings	rib	
B4	surroundings	ribs, bone fragments	-
C1	C1,2	skull elements, vertebrae, teeth	Skull coated with clay, limestone and shell-bed (see main text). Several vertebrae and teeth were pressed into the main skull structure.
	a	ribs, vertebrae and neural processes	
	g	sagittal crest, phalanges	
	surroundings	paddle fragments, phalangeal elements	Sagittal crest (*g*) removed from very tough shell-bed in fragments and reconstructed following preparation.
C2	surroundings	sagittal crest, teeth, vertebrae, scapula	See Fig. 6b for more details of scapula preparation.
C3	BC2,3,4	mandibles and unidentified larger bone element at B2 (still undergoing preparation).	Anterior section of mandibles in tough limestone and shellbed. Posterior section in softer shelly clay with small plant rootlets growing into the clay.
	surroundings	teeth, phalangeal elements, vertebrae	
C4	C4	teeth	-
D1	surroundings	teeth	-
D2	surroundings	teeth, rib	-
D3	surroudings	teeth	-
F1	F1,2	propodial (femur?) pubis (?)	Block still in storage at BIM awaiting preparation. Elements not identified with certainty.
F2	F1,2	pubis (?)	

Table 2. Details of finds from the 1994 pliosaur excavation site, new quarry, LaFarge cement works, Westbury. Grid co-ordinates refer to the site plan illustrated in Figure 4. Large blocks were identified by grid reference. a to n refers to smaller blocks. Large blocks were stored at the Bristol Industrial Museum (BIM) and all blocks were prepared at the Bristol City Museum and Art Gallery (BRSMG).

Preparation and conservation

All finds were marked on a map of the site (Figure 4) with a grid reference and block reference (if applicable), which aided in the correct anatomical reconstruction of the specimen. Conservation record cards are kept in BRSMG. The following elements have been completely prepared to date: the whole cranium, the anterior part of the lower jaw up to the coronoid process (containing 11 teeth *in situ*), the left mandibular ramus up to the hinge and at least 18 loose teeth (mostly complete). Prepared postcranial elements include ribs (7 large elements and numerous fragments), vertebrae (at least 17 complete) some with associated neural processes, one half of a propodial element, 2 epipodial elements, several paddle elements at least 20 phalanges, gastralia (Figure 5), part of the right scapula, 2 possible pelvic elements, the left coracoid and left scapula (Figure 6A,B).

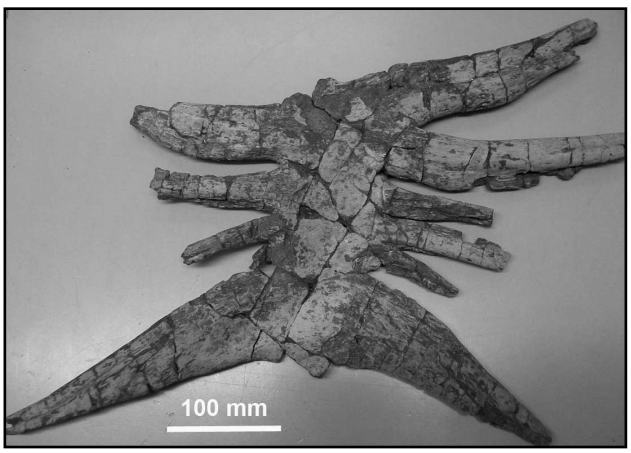

Figure 5. Gastralia of Westbury pliosaur II in ventral view. The complete gastralia were recovered over 9 years, the elements being finally reconstructed in September 2004. Broken pieces of the gastralia were found in several blocks (mainly blocks b and d. See Table 2; Figure 4). The elements were prepared out of very tough limestone and were initially mistaken for separate ribs until they were reconstructed. (Photograph: J. Sassoon).

The process used to clean the larger bony elements such as the skull occasionally necessitated breakage of the elements into smaller pieces, which were then prepared individually prior to reconstruction. The most effective tools were scalpels, used to remove limestone or shell-bed material, a vibrating airpen for more stubborn encrustations and an airbrasive tool, to give the surfaces a final finish. As the work progressed, the fossil bones were set up in a sand-tray to aid with three dimensional reconstruction and the skull pieces were supported in two, precisely shaped fibreglass mounts, made so that the reconstructed skull could be viewed from both sides. Following

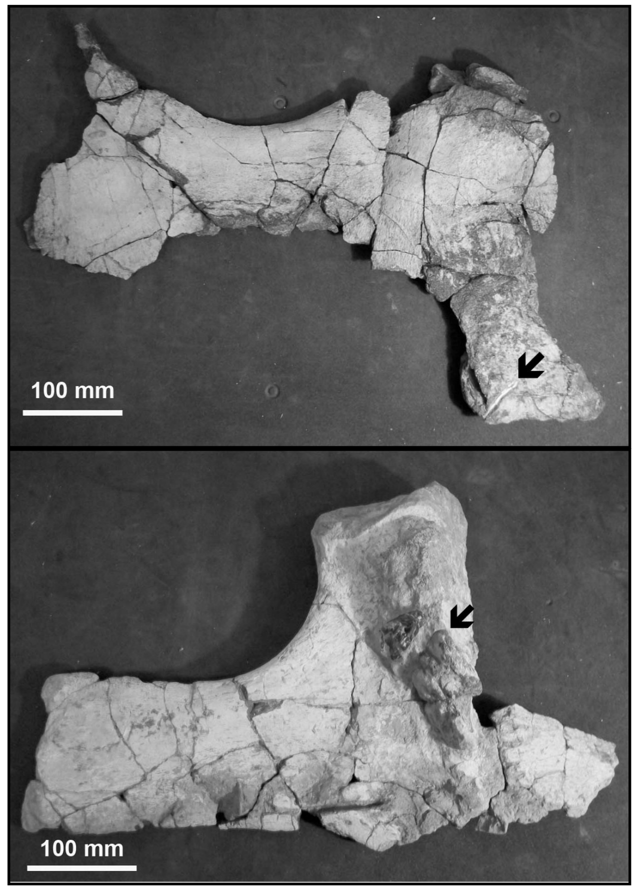

Figure 6. (A) Left coracoid, ventral view. This element was re-assembled from many fragments, extracted from shell-bed. Shelly material was pressed into the bone and was removed with an air-pen. Arrow shows a piece of shell still embedded in the bone. (B) Left scapula, ventral view. Found beneath the skull at C2 (see Figure 4) straddling tooth sockets. Maxillary tooth no. 45 remains embedded in the element (arrow). (Photographs: J. Sassoon).

this initial preparation work, the skull and other bony elements were consolidated and gradually reconstructed. A solution of Paraloid B72 dissolved in acetone was used for both surface consolidation (10 % wbv Paraloid in acetone) and as an adhesive (60 % wbv Paraloid in acetone).

Larger bones manifested several types of preservation, which required slightly different preparation techniques. For example, the first 150 mm of the skull was preserved in clay, easily removed with a palette knife and scalpel. Distilled water and a brush were used to wash away the remaining dirt from the bone surfaces. Beneath the clay layer, the exterior bones were covered with a soft white powder coating, up to 0.5 mm thick in places and easily removed. Beneath this layer was a darker brown layer of bone. It is possible that the paler surface reflected the differential reaction products with the surrounding clay, from inorganic or organic degradation acting on the exterior compact bone compared to interior surfaces.

The larger, posterior area of the skull and many other bones were preserved in a shell-bed, which had been pressed into their surfaces, making removal difficult. Airbrasive techniques were not appropriate for the preparation of such elements as they also removed much of the bone exterior. Experiments with 10 % ethanoic acid proved destructive to the bone and were not employed after initial tests. Bone preserved in shell-bed material tended to be brittle but it was nevertheless better to prepare such regions without using consolidant to prevent sediment from being accidentally consolidated onto the bone. When there was no alternative, excessive consolidant could be removed using acetone. The most effective way of removing the shell-bed from delicate areas involved wetting the surface, allowing sufficient time for the moisture to penetrate into the clay (e.g. 12 hours for small, hand-sized specimens and 24 hours for larger specimens such as vertebrae). Tooth sockets in the upper and lower jaws were also prepared in this way, with a damp sponge left in the sockets for one hour prior to removal of sediment with a scalpel or airpen.

Conclusion

During the past 15 years the Westbury cement works has yielded a fantastic variety of Upper Jurassic fossils, which makes it one of the major Kimmeridgian vertebrate localities. The numerous finds provide substantial evidence for the existence of diverse vertebrate marine communities during that part of the Upper Jurassic. One of these specimens, the Westbury Pliosaur II, is currently undergoing a detailed description and will provide much information on pliosaurian anatomy and palaeoecology, when studied against the backdrop of the locality and fauna with which it was found. However, the potential for future discoveries at the Westbury quarries may now have been curtailed with the closure of the LaFarge cement works. This is because the finds were closely dependent upon active, mechanised quarrying taking place at the pit, the continuous control of water levels with pumps and diligent inspection of fresh exposures.

Acknowledgements

The authors express their gratitude to David Beatty and the quarry staff of the LaFarge cement works at Westbury, whose generous and continuous cooperation aided excavation work and also for kindly providing some of the photographs used here. The1994 excavation team included: Dr. Peter Crowther (Geology Curator in 1994 and supervisor of the excavations), Roger Clark (Assistant Curator), Roger Vaughan (Geology Conservator) and Glenn Storrs (Department of Earth Sciences, University of Bristol) as well as numerous volunteers who helped with the excavation and preparation work. We thank Simon Powell (Department of Earth Sciences, University of Bristol) for help with formatting photographs and images. We also convey our thanks to Professor Mike Benton for comments and suggestions on the manuscript.

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THE TAUNTON PROJECT

by Melissa Schiele, Lorraine Cornish, Dennis Parsons

Schiele, M., Cornish, L. and Parsons, D. 2010. The Taunton Project. *The Geological Curator* 9 (3): 127 - 132.

This paper describes the palaeontological conservation carried out at the Natural History museum London, from 2008 until 2010, on the Taunton Museum's marine reptile collection. Taunton Museum is located in the county of Somerset and is governed by Somerset County Council. The collection of specimens encompassed ichthyosaurs, plesiosaurs, and chelonia (turtles) all found in and around the Taunton and Somerset area. A few select specimens were conserved and prepared for wall mounting in the museum's new exhibition space. The other, smaller specimens were conserved and readied for placement into the newly built storage space back at Taunton Museum. This paper also focuses closely on the conservation and minor preparation of a large ichthyosaur, which was found in Lyme Regis (Lower Lias). This specimen was complete, though piecing it back together and stabilizing it for display proved much more challenging then one would expect.

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Introduction

Somerset County Council is currently engaged in two key projects to improve the delivery of its new Heritage Service. The new Museum of Somerset is a Heritage Lottery funded project refurbishing Taunton's historic castle and providing an enlarged home for the county's museum with all-new facilities. The Somerset Heritage Centre is a County Council funded project providing new premises for the Heritage Service. These include: County Records Office and Museum stores; also design, workshop and conservation facilities. The new museum will provide greatly improved physical and intellectual access to Somerset's heritage resources, high standards of collections care and an excellent visitor experience. It is due to open in Spring 2011.

The Project

Using a portion of the Heritage Lottery fund a project was established to conserve and restore 80 specimens of marine vertebrates, mainly from the Lias, making them accessible for research, display and education. Many specimens come from small, hand-operated quarries that no longer exist and as such form an important resource that cannot be replaced.

The Taunton Project was awarded to the Natural History Museum in November 2008. A project plan was produced and the work was divided into two phases, one to be completed by summer 2009 and the second to be completed by July 2010.

The collection

The fossil vertebrate collection is owned by the Somerset Archaeological & Natural History Society and managed by Somerset County Council's Museums Service.

The county collection contains the remains of fish, turtles, ichthyosaurs and three plesiosaurs. One plesiosaur, collected from the Somerset coast in 2003, is probably the most complete specimen recovered in Britain for over 100 years. It will be going on display for the first time in the new exhibition space.

Methods and materials

All but seven of the specimens were conserved for placement back into Taunton museum's collection space. The main aim for all specimens was to remove any non conservation grade packaging or mounts and to conserve the fossils to increase their stability and longevity. New mounts were produced to ensure that each specimen could be safely accessed and handled by researchers and other users of the collections. The seven larger specimens selected for inclusion in the exhibition areas required more work including minor preparation and bespoke mounts suitable for safe display. A more detailed account of the treatment processes of one of the larger ichthyosaur specimens has been outlined toward the end of this paper

Initial condition

Eighteen of the specimens arrived in their original

Victorian wooden boxes, (figure 1) with an infill which consisted of plaster, often accompanied with small parts of cork, wood and newspaper. The frames were constructed using tongue and groove joints with hand crafted nails.

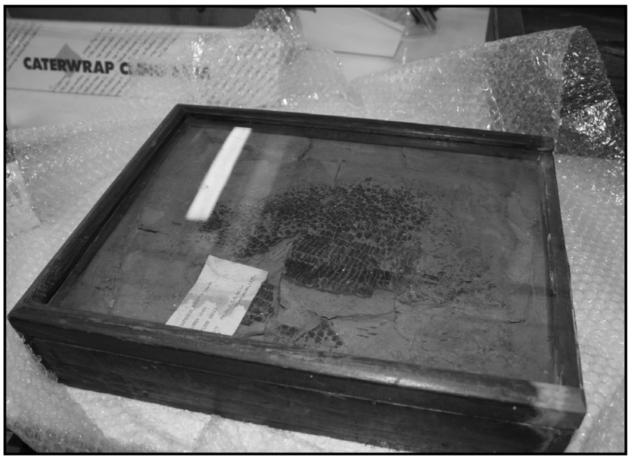

Figure 1. Victorian wooden box containing **Diapedium** ***sp.***

The larger specimens presented logistical problems. One of the plesiosaurs which arrived in three limestone blocks weighed half a tonne when reassembled. An ichthyosaur which was around a metre and a half long proved to be difficult to mount in fibreglass as it had taken on longitudinal curving during its period of disassembly and storage.

Many of the specimens were dirty and fragmented and 5 exhibited pyrite oxidation problems.

Treatment outline

All specimens were condition checked and a treatment schedule for each was produced. A summary of the work is outlined below.

Specimen cleaning

Smoke sponges and brushes were used to remove surface dirt. A variety of dental picks and metal sculpting tools were utilised for matrix removal on areas with fine detail.

One of the mechanical cleaning methods involved air abrasion, using sodium bicarbonate on specimens with a less resilient matrix or delicate fossil bone. More resilient specimens required the careful usage of crushed glass as the aggregate. For removal of tough plaster filler from the matrix, an air pen was used, as well as a micro motor (NSK) with either a rotary diamond saw or abrasive-cap fixture.

Chemical treatments

For consolidation, a 5% solution of Paraloid B-72 in an IMS (industrial methylated spirit) and acetone mixture was used with a 50/50% (w/v) mix of IMS and acetone. Higher concentrations of paraloid (20%) were used in instances where the specimen was highly fragmented and stronger consolidation was required. The adhesive used was 60-80% Paraloid B-72 in acetone.

In order to fill gaps and improve strength to the specimen, glass micro balloons were mixed with Paraloid B-72 and acetone in order to create a malleable paste.

Pyrite decay (Figure 2) treatment involved the use of ammonia.(Waller, R. 1989). This involved combining ammonia and PEG (polyethylene glycol) in a polypropylene box, and placing it, with the fossil, into an air tight chamber for one day. The fumes neutralised the active decay process. These specimens were then placed into an oxygen-free micro environment to ensure future stability (Figure 3).

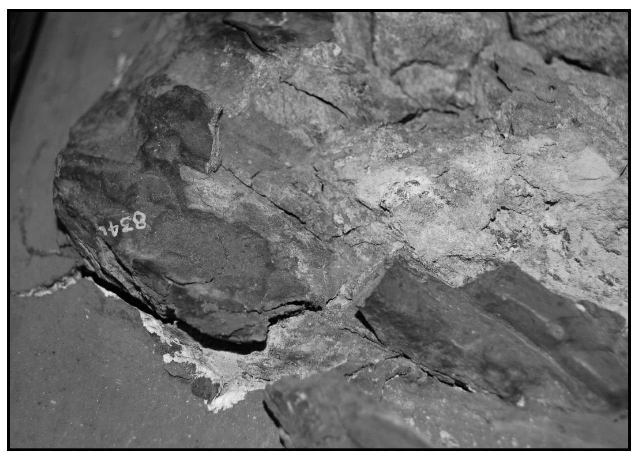

Figure 2 White sulphuric deposits from pyrite decay.

Figure 3. Oxygen-free storage.

Preparation

In order to remove matrix carefully from the fossils, the air abrasive unit was used, with an average pressure of 200bars and an aggregate of sodium bicarbonate. This process is delicate enough to use on friable fish scales. An air pen was needed to remove tougher limestone from around bones such as the larger plesiosaurs. In some cases, an angle grinder was used to cut away limestone in order to reduce the weight of certain specimens.

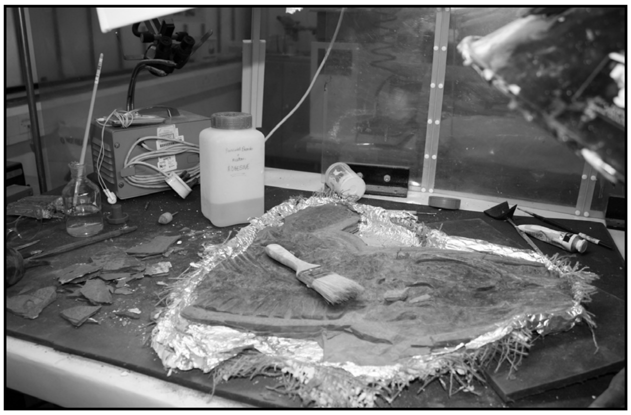

Figure 4. preparation using a plaster jacket.

Specimen re-housing

For all specimens arriving in existing frames the first task was to remove each frame using mechanical methods ranging from sawing and prying to opening with a hammer and chisel. Many were surface protected with a plaster of paris jacket (Figure 4) so that they could be inverted for safe removal of old bases. New base mounts were produced using Epopast epoxy mix lined with plastazote foam.

Documentation

Throughout the project all processes were documented resulting in each specimen having its own condition form plus a portfolio of photographs, in both hard copy and digital format.

A more detailed account on the treatment of *Ichthyosaurus* sp. 8373

Initial Condition Survey

The specimen was a complete fossilised skeleton of an ichthyosaur which was around 1.3m long. It was found in the Lower Lias formation in Lyme Regis.

A condition survey was carried out and accompanied with many photographs documenting the current state of the specimen. The ichthyosaur arrived in 15 broken pieces (Figure 5); each part wrapped in acid free tissue paper which had been adhered to the fragments using a paraloid and acetone consolidant, for protection during its storage period. There was evidence that a consolidant or lacquer had been applied to the specimen as a whole also, with the lacquer yellowing in places as a result of exposure over time. This material is also visible in some joints and cracks, having being used as an adhesive.

The specimen lacked any supportive boxing and no original labelling was to be found, aside from the reference number on the specimen itself. The pieces varied in size and weight, with the cause of total disassembly being unknown.

Figure 5. Specimen prior to treament.

Methods

Total reassembly of the specimen was required as the specimen forms part of the display in the new palaeontological exhibition due to open in late 2010 on a vertical wall within the exhibition hall. The tissue was removed using either mechanical methods such as scraping with a scalpel or a chemical method using a poultice dipped in acetone. Some of the smaller and finer bones were delaminating from the shale in areas such as the ribs and gastralia, and there was a large amount of museum dirt covering the whole specimen. The delaminating parts were very fragile, and needed immediate attention using a consolidant and adhesive, even before conservation cleaning ensued.

Figure 6. Detail of the gastralia and ribs.

As a base to build on, plasticine was rolled flat onto the workbench. The centre pieces of the specimen were laid out in the middle, which included the dorsal ribs and the gastralia (Figure 6). The adjoining parts were replaced respectively. Over time, it was clear that in order to make clean joins, the pieces would have to be at various angle to each other. Plasticine and plastic building blocks were used to support these pieces. After more assembly, it was evident that the whole specimen had a curve not originally observed from the original display in plaster many years previously (Figure 7).

Figure 7. Reassembled specimen shows slight curvature.

The base support for the fossil would need to be strong enough to hold it vertical whilst being attached to an exhibition wall. It was decided that the epoxy glass material epopast 400 would be used as the main support material. In order to apply the jacket onto the back of the fossil, it was required to be inverted onto its front so the back would be accessible.

All the gaps on the face of the specimen were filled with water soluble putty (Rixon 1976) Then a layer of silicone rubber was applied to the surface (Figure 8). Once this was dry, any pockets and undulations were filled with silicone filler putty. The purpose of this layer was for it to act as a protective and shock absorbing layer between the fossil and the actual supporting structure. The silicone layer, when dry was liberally coated with Vaseline also which acts as a separator.

Polyester resin was mixed and coloured red. Strips of fibreglass sheeting were dipped into the resin and applied to the silicone layer to form a rigid support. This structure was supported by wooden base (Figure 9). A spirit level was used to ensure a level platform was created. The support was lifted from the ichthyosaur and upturned and then placed in the large grinding booth. The silicone rubber layer was also

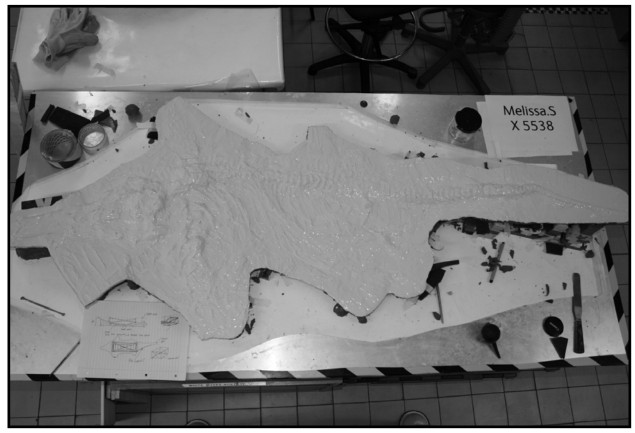

Figure 8. Specimen coated in silicone.

Figure 9. Support structure on silicone.

removed and then replaced into the red support.

The fragments of the fossil were then easily replaced, face down, into the silicone rubber layer. Each of the reverse sides were individually cleaned using the air abrasive unit, with number 4 sodium bicarbonate powder. Once all the pieces were back in place, the opportunity was taken to finally adhere them together using Paraloid B-72 in acetone. After this, small squares of fibreglass cloth were applied directly to the back of the fossil and attached using Paraloid B-72. Onto this layer, the epopast was applied to create the main support cradle. This was applied to a thickness of approximately 2cm (Figure 10)

Figure 10. Epopast support on specimen.

Figure 11. Finished mounted specimen ready to be exhibited.

Applying epopast in this way meant that the fossil was literally adhered into the epopast cradle. In this respect, there was no worry that it may fall out of the support. The fibreglass consolidant layer meant that subsequent removal of the specimen from the cradle would be possible if required in the future by the application of acetone.

A method of attaching the fossil to the wall was devised using two fibreglass tubes (square in cross section) and six bolts. The fibreglass tubes had six holes drilled through them along its length, which enabled the bolts to be threaded through them. These tubes were then adhered to the back on the ichthyosaur using more epopast. A spirit level ensured that the structure was level. Once dry the finishing touches were applied, which involved a final 'sanding down' of the fibreglass and touching up it's the black paintwork, using the NSK and acrylic black paint (Fig 11).

Conclusion

The Taunton Project involved a wide range of conservation and preparation methods and materials. Each specimen had differing conservation requirements and the challenge was to apply the most appropriate techniques to stabilise and enable greater access to this unique collection.

References:

Waller, R. 1989. Pyrite Oxidation Studies. *Canadian Conservation Institute Newsletter* **10**.

Rixon, A.E 1976. *Fossil Animal Remains, Their preparation and conservation.* Athlone Press, London. 304pp.

Suppliers List

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http://www.epakelectronics.com/

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REAPPRAISAL OF THE GASTRIC CONTENTS OF A LOWER JURASSIC ICHTHYOSAUR

by David E. Valente, Amanda L. Edwards and John E. Pollard

Valente, David E., Edwards, Amanda L. and Pollard, John E. 2010. Reappraisal of the gastric contents of a Lower Jurassic ichthyosaur. *The Geological Curator* 9 (3): 133 - 142.

Re-examination of cephalopod hooklets preserved within the gastric mass of several Lower Jurassic ichthyosaurs reveals that these reptiles fed mainly on phragmoteuthids, rather than belemnites as previously proposed. This conclusion matches the findings of recent research on ichthyosaurs and well-preserved coleoids from the Lower Jurassic (Toarcian) Posidonia Shales of southern Germany. A greater variety of belemnoid species known in the Posidonia Shales includes complete belemnites with bite marks; these provide evidence of predation from large vertebrates such as ichthyosaurs. However, no belemnite rostra have yet been found in the gastric contents of any ichthyosaurs from either Germany or the UK. Examination of the phragmoteuthid hooklets from the gastric mass of a small ichthyosaur in the Manchester University collections reveals that they have a layered fibrous ultrastructure comparable to that of Triassic phragmoteuthids from Austria. These hooklets show pitting and possible abrasion which may be related to gastric processes.

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Introduction

In 1963 the skeleton of a small ichthyosaur with discrete associated gastric contents was discovered in Lower Jurassic (Hettangian) shales near Lyme Regis, Dorset (Pollard 1968). Based on detailed analysis of cephalopod arm hooklets preserved within the gastric mass of this specimen and comparison with similar ichthyosaur specimens, soft-bodied 'belemnites' and coprolites, Pollard (1968) discussed the dietary habits of these extinct reptiles. He identified four hooklet types (A, B, C and D) and made suggestions relating to the nature of prey, volume of food eaten and digestive mechanisms.

In the past four decades several similar specimens of ichthyosaur have been described and analysed from the Lower Jurassic (Toarcian) rocks of Germany (Keller 1976; Böttcher 1989) and major advances have also been made in the understanding of arm hooklet morphology and diversity among Lower Jurassic dibranchiates (Donovan 1977, 2006; Weisenaur 1976; Riegraf and Reitner 1979; Riegraf and Hauff 1983; Reitner and Urlichs 1983; Seilacher 1983; Engeser 1987; Doyle and Shakides 2004).
These new discoveries and advances prompted us to review the literature and re-examine specimens. In particular this paper reviews the gastric mass of an ichthyosaur specimen from the collections of the University of Manchester (MGSF1) (Pollard 1968), using new techniques such as computer enhanced imagery and SEM analysis (Valente 2007). Ichthyosaur specimens with associated gastric contents preserved in the collections of the Manchester Museum, Oxford University Museum of Natural History and Bristol City Museum & Art Gallery are also considered herein.

Materials and Methods

Five ichthyosaur specimens were examined in this study.
MGSF1 (Figure 1) - Manchester University ichthyosaur specimen from Lyme Regis, Dorset, analysed by Pollard (1968);
MM LL 11835 (Figure 2) - An ichthyosaur in the Manchester Museum collections from Street, Somerset (Pollard 1968, p.381) which preserves a gastric mass of hooklet types A, B and C (*sensu* Pollard (1968, text-figure 2)) just posterior to the pectoral girdle;
OUMNH J12125 (Figure 3) and J13593 - The Oxford University Museum of Natural History houses a number of ichthyosaur specimens which contain gastric contents including both fish remains and cephalopod hooklets (Buckland 1836; Pollard 1968).

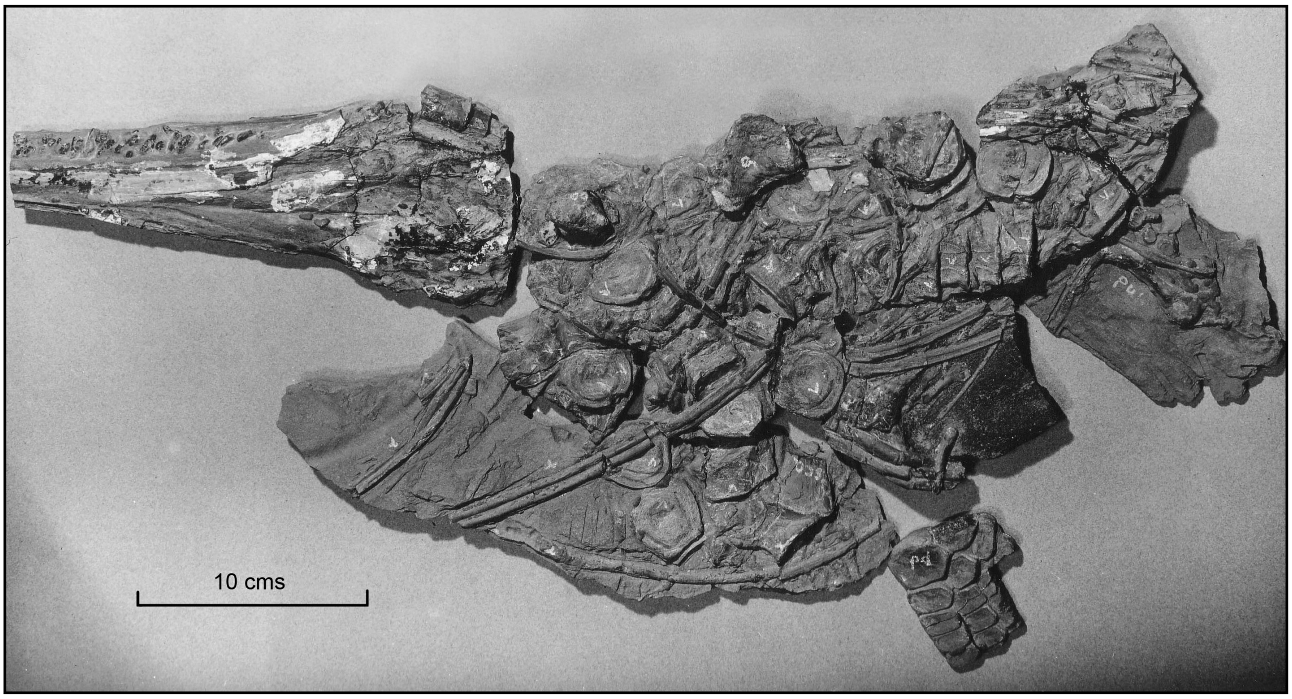

Figure 1. Dorsal view of the skeleton of an ichthyosaur with the gastric contents preserved as the dark mass at centre right. Lower Jurassic (Hettangian) Planorbis Zone near Lyme Regis, Dorset. MGSF1. Collections of School of Earth, Atmospheric and Environmental Sciences, University of Manchester (see Pollard (1968) for details).

OUMNH J.12125 contains an assemblage of diverse cephalopod hooklets between the ribs (Figure 3). Buckland (1836, pl.14) figured the first ichthyosaur with an associated gastric mass, OUMNH J.13593. It contains fish remains in the stomach contents, together with a sparse scattering of type C hooklets over the dorsal surface of the gastric mass (Pollard 1968);

BCMAG CE 16611 (Figure 4) - The Bristol City Museum and Art Gallery houses an undescribed but nearly complete ichthyosaur skeleton from the Lower Jurassic near Street, Somerset, which contains an embryo and stomach contents (Figure. 4). The gastric contents are preserved between the ribs as a black oval mass extending almost 30cm along the underside of the vertebral column. Type A, B and C hooklets are clearly visible in this mass but the accumulation is less dense than in the Manchester specimens (MGSF 1 and LL 11835).

We also examined two phragmoteuthid specimens.
MM L6108 (Figure 6) - A specimen housed in the Manchester Museum consists of several incomplete arms associated with a crushed pro-ostracum and ink sac. It is suspected that these components may be falsely associated, hence the specimen may be a composite (Donovan 1977 and 2006). However, the

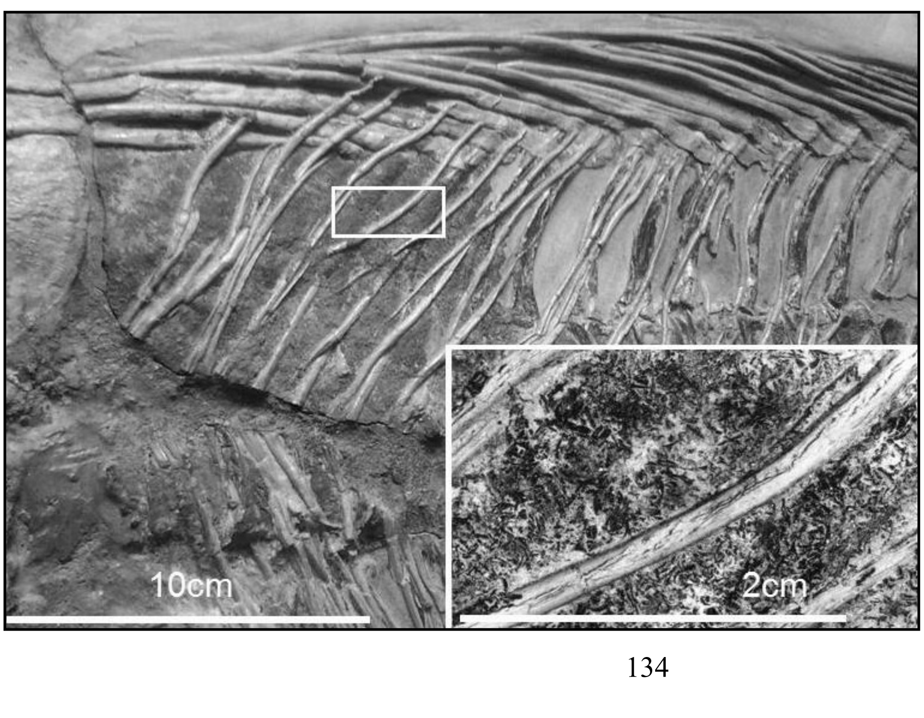

Figure 2. Gastric mass of hooklet types A, B and C among the thoracic ribs of an ichthyosaur with a close up image inset. Lower Jurassic, (Hettangian), Street, Somerset. LL 11835. Manchester Museum Collections.

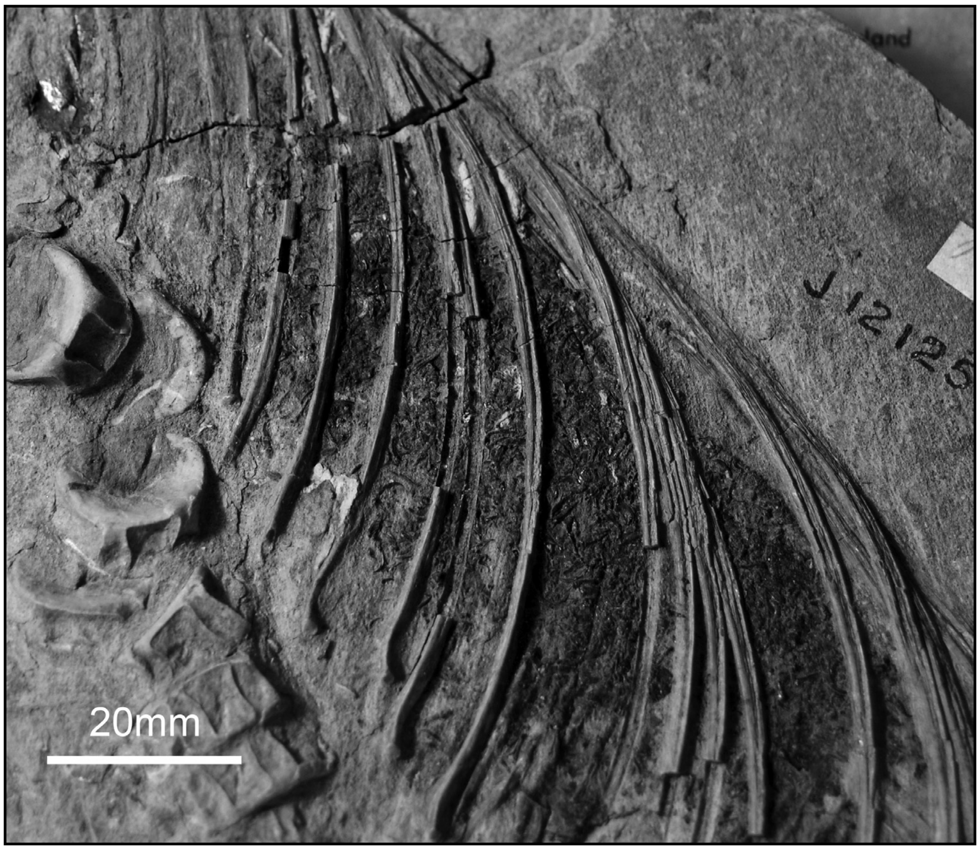

Figure 3. Diverse types of hooklets preserved between ribs of a Lower Jurassic ichthyosaur. J12125. Philpot Collection, Oxford University Museum of Natural History.

nature of the hooklets (types A, B and C) confirms they belong to *Phragmoteuthis montefiore*; PH1 - *Phragmoteuthis montefiore* from Dr Peter Hardy's private collection, loaned to the University of Manchester. The specimen has incomplete arms with types B and C hooklets *in situ*, with a pro-ostracum and ink sac. This fossil is from the *Psiloceras planorbis* ammonite zone, the same horizon as MGSF1, although it was collected from Watchet in Somerset.

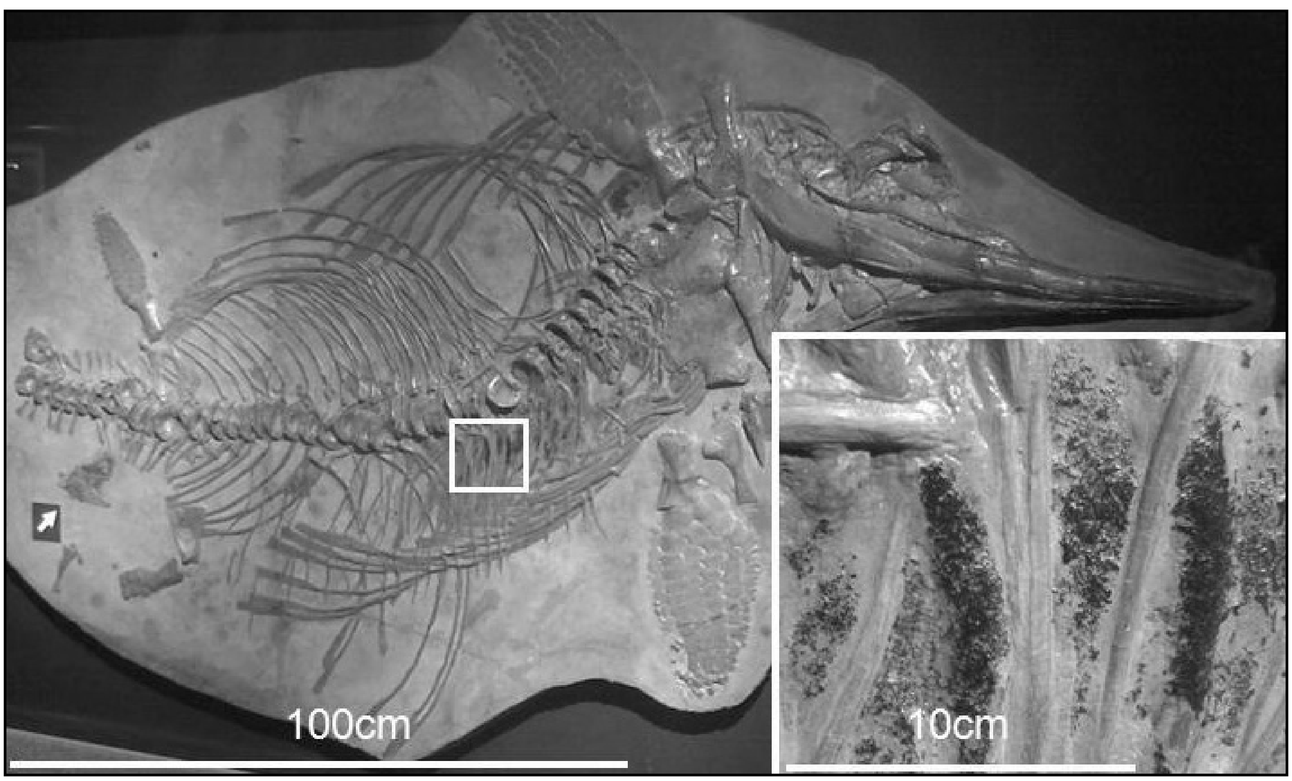

Figure 4. Patches of diverse hooklets between ribs of an ichthyosaur with a close up image of the stomach contents inset. Lower Lias, Lower Jurassic, Street, Somerset. CE 16611. Bristol City Museum and Art Gallery collections. Inset close up view of hooklet mass.

All specimens were observed in hand specimen. The dorsal and ventral surfaces of the gastric mass of MGSF1 were examined under the binocular microscope, and then photographed with a digital camera. The photographs were enhanced using the digital image layering software, CombineZ (Figure 7). This specimen and in particular the gastric mass were prepared without the use of chemical or abrasive agents.

Hooklets from the gastric mass of MGSF1 and the arms of MM L6108 were re-examined *in situ* using SEM analysis at a range of magnifications (100-10000x). Previous authors (Böttcher 1989; Engeser and Clarke 1988) were able to remove individual hooklets from the gastric mass to confirm details of their size and shape. However, due to the extreme cracking of our specimens it was not possible for us to do so.

Dibranchiate hooks in the gastric contents of ichthyosaurs

In his discussion of feeding habits and digestive mechanisms in 1968, Pollard suggested that the ichthyosaur MGSF1 had ingested 760 to 2430 individual cephalopods. This was based on an estimated number of hooklets in the gastric mass (478,000 ±250,000) and each cephalopod having 300 hooklets. Cephalopod hooklets have not been described within the gastric contents of any British ichthyosaur since Pollard (1968). However, comparable specimens have been recorded from the Toarcian Posidonia Shales of southern Germany (Keller 1976; Böttcher 1989). Keller (1976) examined the stomach contents of 28 specimens of the ichthyosaur *Stenopterygius*, which consisted of hooklets of the coleoid *Phragmoteuthis conocauda*. He suggested that indigestible hooklets may have been regurgitated periodically.

The stomach contents preserved in a specimen of the large ichthyosaur *Leptonectes* (previously '*Leptopterygius*') from the Posidonia Shales contained 200 vertebrae of young ichthyosaurs as well as three types of cephalopod hooklets (Böttcher 1989). The juvenile ichthyosaur vertebrae were interpreted as prey, but later conclusions regarded them as embryos (Böttcher 1990). The hooklet types recognised appear to belong to phragmoteuthid, chondroteuthid and belemnitid coleoids (Böttcher 1989).

Doyle and Macdonald (1993) described accumulations of belemnite rostra ('Belemnite Battlefields') (*Acrocoelites*) from the Ovatum Band of the Lower Jurassic (Toarcian) rocks of Yorkshire. These deposits are of similar age to the Posidonia Shales of Germany. The accumulations are also associated with hooklets and it was postulated that these 'Belemnite Battlefields' may represent reworked predation accumulations of gastric contents or regurgitates. If this interpretation is correct then an ichthyosaurian origin for the accumulations remains speculative; they could also have been produced by hybodont sharks (Pollard 1968; 1990), marine crocodiles (Martill 1986), plesiosaurs or pliosaurs. These recent discoveries have prompted this re-examination of ichthyosaur specimens.

Affinity of cephalopod hooklets preserved in the gastric contents

One of the unresolved matters in the original analysis of MGSF1 (Pollard 1968) was the precise affinity of the hooklets. This is vital for identifying specific predator-prey relationships between the ichthyosaur and the cephalopod. Pollard recognised three abundant hooklet types (Figure 5): A - short, robust trifid; B - elongate, gently curved, bifid blunt base; C - laterally flattened, 90º curve, blunt base. A possible fourth, rare small type was also identified: D - oblique truncated base, strongly recurved >90º (Figure 5). Types A - C are similar to the 'belemnite' hooklets figured by Huxley (1864) and Crick (1907) and also *Belemnoteuthis montefiore* figured by Buckman (1880). Pollard (1968) assigned the hooklets to 'belemnites' based on Huxley's and Crook's work, although he expressed suspicion of the authenticity of Huxley's 'complete' belemnite specimens as possible 'well intentioned' forgeries. This conclusion posed several possible scenarios for feeding habits and digestive mechanisms of this ichthyosaur (Pollard 1968).

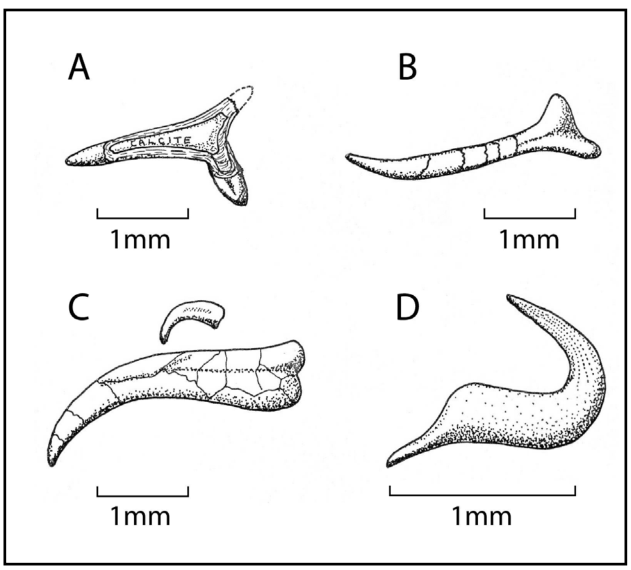

Figure 5. Hooklet types recognised in gastric contents of ichthyosaur MGSF1 (Pollard 1968, text-figure 2).

Donovan (1977) described the characteristics of phragmoteuthids which include the absence of a guard and at least eight arms, each bearing two rows of hooks. He also noted the artificial association of belemnite guards with phragmoteuthid arm crowns in several specimens from the collections of the British Museum of Natural History including those described by Huxley (1864). Riegraff and Reitner (1979) confirmed Donovan's conclusions on the British specimens and also showed that 'complete' specimens of belemnites from the Lower Jurassic (Toarcian) of Holzmaden, Germany, were in fact false associations combining the arm crowns of the phragmoteuthid *Phragmoteuthis conocauda* with the guards of the belemnite *Passaloteuthis paxillosa*.

Further work on belemnoid cephalopod hooklets, particularly from the German Posidonia Shale's in the 1980s, clarified the affinity of differing arm hooklet morphology. Hauff and Hauff (1981) figured complete arm crowns of *Phragmoteuthis conocauda*, these included hooklet types A, B and C (*sensu* Pollard 1968). Genuine soft parts of the belemnite *Passaloteuthis* showed that the animal had short arms possessing small recurved hooklets with 'spurs' and obliquely pointed bases (Riegraf and Hauff 1983; Reitner and Urlichs 1983). Engeser (1987) and Engeser and Clarke (1988) reviewed fossil and recent coleoid arm hooklets and concluded that in the Jurassic there were three distinct types: 1. phragmoteuthids with expanded bases; 2. belemnothetids with acutely pointed bases; and 3. belemnitids with pointed bases (with or without internal spurs). Engeser and Clarke (1988) also noted that the greatest diversity of hooklets occurred in the early Jurassic and belemnitid hooklet type varied along the arms. Riegraf (1996) studied isolated belemnitid hooklets from the Psiloceras Zone sediments of Germany. These were identified as *Paraglycerites* (Eisenack 1939) and it was suggested that distal hooklets were smaller and more strongly curved than the larger and straighter proximal hooklets (with or without spurs).

Doyle and Shakides (2004) reviewed recent work on the hooklets of belemnoid orders and showed that the Belemnitida possessed hooks with spurs while the Belemnothetida had hooks without spurs. They also illustrated strongly recurved hooklets of *Chondroteuthis wunnenbergi* from the Lower Jurassic (Toarcian) of Gloucestershire simililar to Pollard's rare type D hooklet. To illustrate this rare type Pollard (1968, text-figure 2d) figured a specimen OUM 14799 also from the Toarcian rocks of Gloucestershire for comparison which, therefore, belongs to *C. wunnenbergi*. However, recent re-examination of the specimen MGSF1 failed to recognise type D hooklets (Valente 2007) (see below).

Donovan (2006) provided an important redescription of *Belemnoteuthis montefiore*. The taxon, including the arm crowns described by Huxley (1864) and Crick (1907) with hooklet types A, B and C of Pollard (1968), was re-identified as *Phragmoteuthis montefiore*. He distinguished *P. montefiore* from the belemnite *Passaloteuthis* based on its shorter arms (c. 0.2 total body length v. 0.4 total body length); hooks with blunt bases; less strongly curved hooks; and the bases of hooklets situated closer together on the arms. The hooks of *P. montefiore* resemble those of *P. bisinuata* from the Upper Triassic and *P. conocauda* from the Lower Jurassic (Toarcian) of Germany (Doguzhaeva *et al.* 2007; Donovan 2006). P. montefiore possessed 10 arms, each with 20-25 pairs of hooks. The largest hook was half way along each arm (4.3- 5.8mm, types B, C) and the shorter hooks were located (c. 1mm, types A - C) towards the proximal and distal ends of the arm. There were 40-50 hooklets on each adult arm, so there were around 400 -500 per animal. Despite the similarities, of *P. montefiore* and *P. conocauda* Donovan (2006) retained them as separate species because they occur at different stratigraphic horizons. To test the conclusions derived from the above literature, two specimens of *P. montefiore* (MM L6108 and PH1) were examined in hand specimen and using SEM techniques.

Another important insight into the feeding habits of marine vertebrates was provided by Seilacher (1983) and Riegraf and Hauff (1983) based on studies of complete belemnites from Holzmaden. It was suggested that the presence of arm hooklets but not rostra in the gastric contents of ichthyosaurs supports the hypothesis that they bit off the heads before ingestion. Pollard (1968) drew similarities between the feeding habits of ichthyosaurs and modern teuthophagous whales that attack their prey from the head end (Pollard 1968; Clarke 1956). Isolated Holzmaden specimens show belemnite rostra found with associated arm hooklets, smashed pro-ostracum and phragmocone. These specimens are interpreted as being damaged by 'alveolar bites' of the predator which would cause the complete carcase to sink to sea bed for burial and preservation (Seilacher 1983).

Re-examination of ichthyosaur gastric contents

Figure 7 shows a dense mass of various sized hooklets from the gastric mass of MGSF1. They are par-

Figure 6. **Phragmoteuthis montefiore** *with arms and hooklets. Lower Jurassic. L 6108. Manchester Museum collections.*

tially buried and mostly broken or damaged so their morphology is difficult to distinguish. The hooklet masses on these surfaces are very similar to the figures of Pollard (1968, pl. 73, figures 1 and 2) but with sharper resolution. Two main discrete hooklet morphologies were observed: a form with a bifurcated base and a thin shaft which curves distally (type B of Pollard 1968) and a form with a less bifurcated base, a wider and shorter shaft, and a stronger distal curvature c. 90º (Pollard's type C). There also appear to be several larger triangular hooklets (an example of these is highlighted in the top left corner of Figure 7). In these observations, Pollard's type A, the small trifid form, was rare and his type D hooklets with a pointed base and recurvature >90º was not seen.

Examination of MGSF1 hooklets within a fragment of the gastric mass at low magnification (100x-200x) confirmed that they are intensely cracked, fractured and some cracks are infilled with calcite (Figure 8a). There appear to be at least two generations of cracks. The first generation of cracks are infilled with calcite contiguous with the internal calcite fill of the hooklet (Pollard, 1968, text-figure 2a), the second generation are wider and unfilled. The matrix consists of comminuted hooklets with clay or micrite. There is no evidence of fragmented cephalopod beaks as postulated to occur in stomach contents by Engeser and Clarke (1988). Higher magnifications (2000x) reveal a random pattern of pits and possible abrasion on the surface of the hooklets (Figure 8b, 8c). Even higher magnifications (10000x) reveal the ultrastructure of the hooklets. There are several overlapping layers, each consisting of a parallel fibrous texture. The orientation of the parallel fibrous texture differs in each

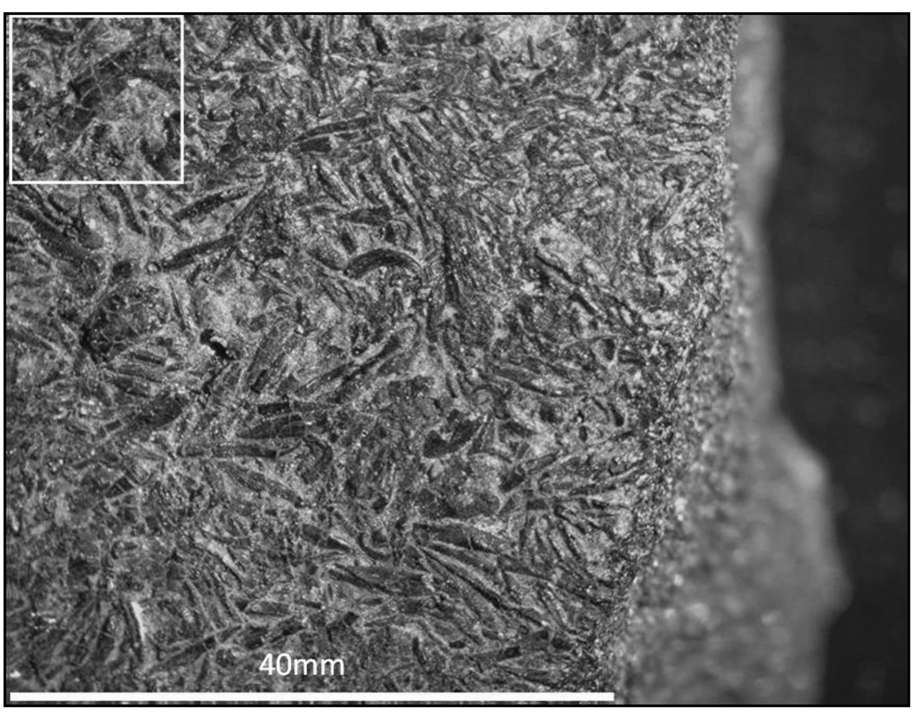

Figure 7. Digitally enhanced photograph of surface of the gastric mass showing diverse densely packed hooklets. Hooklet types B and C are most abundant with a rare larger triangular form (top left) MGSF1.

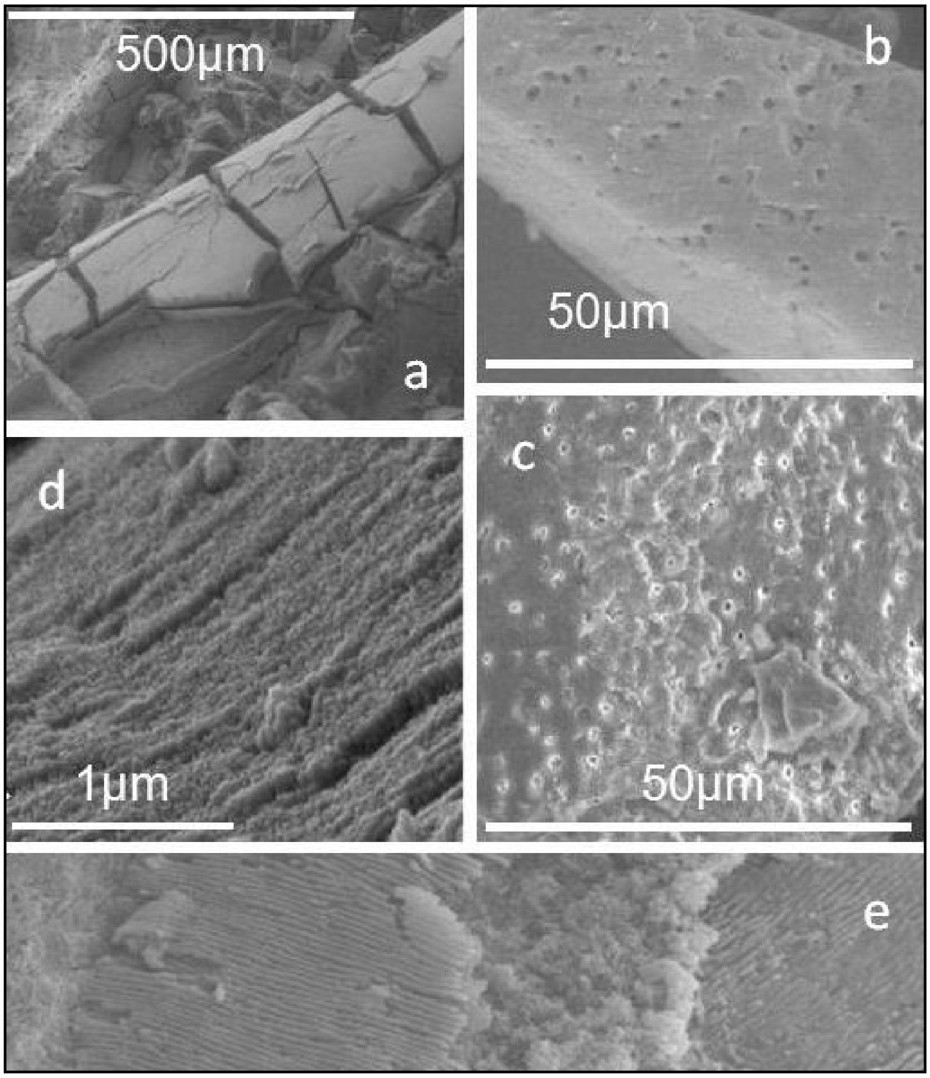

Figure 8. SEM photographs of phragmoteuthid hooklets. (a) - (c), (e) From the gastric mass of MGSF1, (d) from Doguzhaeva* et al. *2007, figure 6 with permission. (a) 3D calcite infill of a hooklet with two generations of cracks, earlier penetrating from the infill and later open surface cracks; (b) and (c) show pits on surface of hooklet fragments; (d) globular-lamellar ultrastructure of a hooklet of* **P. bisinuata,** *Triassic, Austria; (e) layered parallel fibrous ultrastructure which compares with (d).

layer (Figure 8e). This structure closely resembles the "globular-lamellar" ultrastructure of carbonized hooklets seen in *Phragmoteuthis bisinuata* from the Triassic rocks of the Austrian Alps (Doguzhaeva *et al.* 2007, figure 6) and Figure 8d. The surface pitting and apparent abrasion of these hooklets, and the exposure of the layered ultrastructure pose the question as to whether these structures are a function of etching by ichthyosaur stomach acid or are they a preservation artefact?

To answer this question, hooklets from the arms of a 'complete' specimen of *P. montefiore* (MM L6108) were examined using SEM analysis. A complete hooklet type A is intensely cracked and infilled with shale (Figure 9a). This suggests that the hooklet was brittle and hollow, and became crushed and infilled with mud. This differs from the 3D preservation of a type A hooklet with a calcite infill figured by Pollard (1968, text-figure 2a) and Figure 8a herein. At higher magnifications (400x; 3000x) (Figure 9b, 9c) the surface of the hooklet shows no signs of pitting or abrasion, as seen on the hooklets in the gastric contents (Figure 8b, 8c). However, very fine hierarchical infilled cracks were visible, as well as larger open surface cracks, this confirms the presence of at least two generations of cracks as seen in the 3D specimen from the gastric mass (compare Figures 8a and 9b). The ultrastructure of the hooklet revealed at the highest magnification used in this study of MM L6108 (3000x) showed linear surface features and layered minerals on the broken edge, suggesting a layered internal structure (Figure 9c). The presence of a detailed "globular-lamellar" ultrastructure was not confirmed and surface pitting was not observed.

Discussion

Based on the above literature review and descriptions we know that Pollard's (1968) hooklet types A, B and C belong to *P. montefiore*, not contemporary belemnites. Hooklet type D of Pollard (1968) is of belemnothetid type, probably from *Chondroteuthis wunnenbergi*. This species is restricted to the Toarcian so it is unlikely to be present within gastric contents of MGSF1 of Hettangian age, although it is present in Toarcian age ichthyosaur gastric contents from Holzmaden (Böttcher 1989). *P. montefiore* hooklets

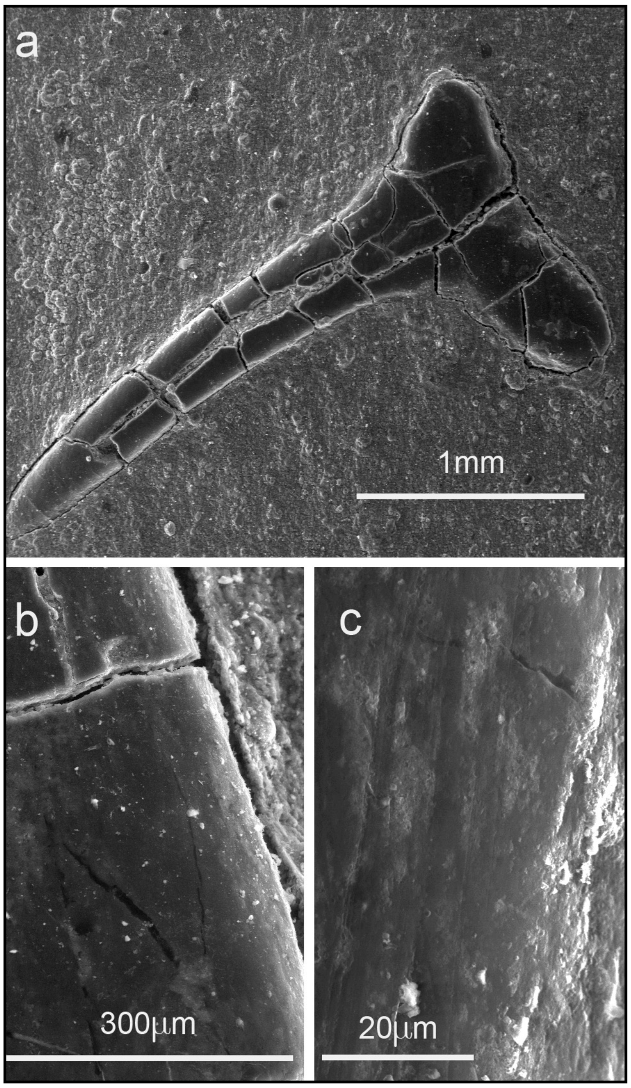

Figure 9. Surface features and ultrastructure of hooklets of* P. montefiore *imaged using SEM. L6108. Manchester Museum collections. (a) Complete but crushed, cracked and shale filled type A hooklet; (b) unpitted surface of hooklet showing two generations of cracks; (c) linear surface features and broken edge of hooklet suggesting internal mineral layering.

may be larger than the sizes given by Pollard (1968) (i.e. A 1-1.9mm; B 0.7-3.0mm; C 0.9-2.9mm) and Donovan (2006) (i.e. A 1mm; B, C 4.3-5.8mm). This species had 10 short arms with 20-25 pairs of hooks, and therefore 400-500 per animal (Pollard 1968, maximum 26-32 per 40mm arm = c. 300 per animal). Based on this number of hooklets per animal Pollard (1968) may have overestimated the volume of food eaten. To recalculate (478,000 + 250,000 / 400 or 500 hooklets per animal not 300, gives a maximum of 728,000 hooklets = 1820 or 1564 cephalopods ingested or a minimum of 228,000 hooklets = 570 or 456 cephalopods ingested). Therefore, the number of individual prey eaten ranges from c. 450 to 1560 (for 500 hooklets per animal) or 570 to 1820 (for 400 hooklets per animal). This contrasts with Pollard's (1968) calculations (760 to 2430 individual cephalopods ingested based on 300 hooklets per animal).

True belemnite specimens (e.g. *Passaloteuthis*) where arm crowns and rostra are preserved show a crushed pro-ostracum and phragmocone. These result from the crushing of the phragmocone and the release of gas from 'alveolar' bites of predators (ichthyosaurs or other large marine vertebrates). This caused the soft body and guard to sink to sea floor where they may be subject to exceptional preservation (Riegraf and Hauff 1983; Seilacher 1983). This implies that ichthyosaurs did not swallow rostra but may have bitten off the arm crowns and body, swallowing them head first (Pollard 1968, Scenario 1). However, the above literature review and specimen descriptions suggest that Pollard's Scenario 4 was the most likely mode of feeding in Lower Jurassic ichthyosaurs; that is, ichthyosaurs fed mostly on 'naked' dibranchiates such as phragmoteuthids.

SEM analysis of hooklets from the gastric mass and isolated arm crowns appears to show that they had their organic nature preserved as a brittle black replica. Type A hooklets (at least) were hollow and frequently crushed if not infilled by minerals. The ultrastructure of the hooklets appears to be layered, probably fibrous or in a "globular-lamellar" arrangement, as seen in other species of *Phragmoteuthis* (Doguzhaeva *et al.* 2007). The pattern of pitting and abrasion observed on the hooklets from the gastric mass was not present on the isolated hooklets of MM L6108. As no chemical or abrasive agents were used in the preparation of MGSF1, this feature could be related to gastric processes prior to preservation.

Conclusions

1. The absence of rostra associated with hooklets in gastric contents is confirmed.
2. Direct evidence in MGSF1 and other ichthyosaur specimens from the Lower Jurassic (Hettangian, U.K and Toarcian, Germany), demonstrates that they fed mainly on phragmoteuthid and belemnothetid coleoids, rather than belemnitids. This confirms Pollard's (1968), Scenario 4 that the coleoids ingested by ichthyosaurs lacked rostra. Prey were swallowed whole and the soft tissues and weakly calcified organs were readily broken down in the stomach where the indigestible arm hooklets accumulated. There is no evidence for the presence of fragmented cephalopod beaks.
3. Belemnites with associated arms but crushed alveolar/phragmocones and rostra, may have suf-

fered 'alveolar' bites from ichthyosaurs before they sunk to the sea floor. This evidence supports the hypothesis that ichthyosaurs bit off or attacked coleoids from the head end, as documented for the feedings habits of modern teuthophagous whales (Pollard 1968; Clarke 1956).

4. The ultrastructure of cephalopod hooklets as determined using SEM confirms their similarity to the hooklets of other phragmoteuthid species. Several generations of cracks confirms the hollow and brittle nature of the hooklets. Pitting and abrasion present on the hooklets within the gastric contents of ichthyosaurs may indicate etching by stomach acid or other gastric processes prior to preservation.

Acknowledgements

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ARCHAEOPTERYX LITHOGRAPHICA: AN EXTREME MAKEOVER

by Lorraine Cornish, Angela C. Milner and Andrew Wahl

Cornish, L., Milner, A.C. and Wahl, A. 2010. *Archaeopteryx lithographica*: an extreme makeover. *The Geological Curator* 9 (3): 143 -148.

This contribution outlines the steps taken to improve handling and safe access of the fossil *Archaeopteryx lithographica* (London specimen) for staff and visitors to the Natural History Museum in London. A review of risks and an outline of techniques applied are included.

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Introduction

Archaeopteryx lithographica Meyer, 1861 is the oldest known bird. It comes from the latest Jurassic (Tithonian, 147 MYA) fine-grained Solnhofen Lithographic Limestone from Altmuhl Valley in Bavaria, Germany. The Natural History Museum's specimen, NHMUK 37001 was the first skeleton to be discovered in 1861 from Langenaltheim quarry. Dr Karl Häberlein, a local doctor and fossil collector, is presumed to have bought it directly from the quarry owner Johann Friedrich Ottmann (Wellnhofer 2008). Richard Owen orchestrated the purchase for the Museum of Häberlein's collection of almost 2,000 fossils for £700 (including *Archaeopteryx*) in 1862.

A remarkable specimen

Archaeopteryx was a hugely important discovery in the history of palaeontology. It exhibits both dinosaur and bird characters and it is perhaps the most famous icon of evolution in action. The 'London specimen' is the ultimate reference for the other nine specimens now known. It is, thus, of prime international research importance and multiple requests for study access are received annually. However, Richard Owen did not realize its significance in his original description and, interestingly, his figure does not depict the accurate outlines of the main slab (Owen 1863). After further preparation in the Museum, between 1916 and the 1950's, de Beer (1954) published an exhaustive, illustrated monograph. Ostrom (1976) pointed out many skeletal characters shared with small advanced theropod dinosaurs - such as sharp teeth, three clawed fingers on each hand and a long, bony tail. These characters, together with the clear impressions of fully modern flight feathers, demonstrate the importance of *Archaeopteryx* as a evolutionary link between dinosaurs and birds.

A controversial specimen

A series of accusations of forgery were levelled by Fred Hoyle and Chandra Wickramasinghe in the mid-1980's (e.g. Hoyle and Wickramasinghe 1986). They claimed that the feather impressions on the London Specimen were faked, a process supposedly begun by Häberlein and later embellished by Museum staff. These claims were comprehensively refuted by Charig *et al.*(1986). The authenticity of the London specimen as the earliest bird, although never doubted by palaeontologists, has been reinforced by the discovery of four further feathered *Archaeopteryx* specimens since 1985 (Wellnhofer 2008). A recent CT study of the detached braincase of the London specimen (Domínguez *et al.* 2004) provided further evidence that *Archaeopteryx* possessed a bird-like brain and inner ear and was capable of flight.

Previous Treatments

Preparation

The first preparator to work on the specimen was F. O. Barlow. He prepared the pubes and right coracoid in 1916. In order to expose the coracoid from below, he cut a 'window' in the back of the slab sometime before 1921. L.E. Parsons prepared out the limbs, left

Figure 1. Back of main slab showing prepared areas.

shoulder girdle, pelvis and part of the skull between 1921 and the early 1950's. Sometime during this period, Parsons cut a second window into the back of the slab that exposed parts of the cervical vertebrae and left coracoid. (Figure 1). Areas of the furcula, right femur and pubes were further prepared by P. J. Whybrow in 1973. Whybrow removed the braincase from the left-hand edge of the main slab and prepared its left side in 1980 (Whybrow 1982). The surfaces of the main and counterslabs were cleaned prior to the refutation of Hoyle and Wickramasinghe's feather forgery allegations (Charig *et al.* 1986).

Replication

Available records show that the specimen was moulded on at least 6 occasions usually after any new preparation to the specimen. Over 150 casts have been produced by NHM staff since the late 1800's and many examples can be found in museums around the world.

The box housing

No records have been found regarding when the specimen was mounted into its current mahogany box housing. The first illustration of the main slab by Henry Woodward in 1862 depicts the skeleton lying in the familiar rectangular slab but shows no kind of surround. It had been noted for a number of years that the framed lid to the boxes were becoming more difficult to remove and the glass was starting to move within the frame itself causing increasing concern when handling the specimen.

Project Aims

To improve handling and safe access of specimen for staff and visitors.

After a comprehensive review of the specimen it was agreed that the current housing was substandard and unsafe for specimen access. The glass was non-safety glass and the lids were highly unstable. Lid attachment mechanisms had become old and worn and lid attachment was becoming more difficult. New housing was required.

Project Outline:

1. Make new housing boxes for main slab and counterpart with safely removable lids.
2. Use laminated safety glass in new lid construction.
3. Ensure lids have a bead seal to help with dust control.
4. Produce "user friendly" lid attachments with additional locks for added security.
5. Produce new housing which incorporates optional access to selected prepared areas on base of main specimen slab for improved access for study.
6. Excess weight (old plaster/wood) removed from base and sides of specimen blocks.
7. Reduce specimen depths where possible to decrease overall weight of main slab and counterpart.
8. Surface edges of limestone blocks to be exposed around perimeter to a depth of 5mm
9. Design housing for both main slab and counterpart to look identical in size and finish.
10. New housing to retain a similar "historical look" in its design.
11. Rebated edge around base of wooden frame to be incorporated to allow a safer finger hold for lifting and moving main slab and counterpart.
12. New moulds to be taken of specimen surfaces. Production of new master casts.

A case specification was prepared so that all would be clear on what was required. Before any work commenced on the specimen a risk assessment was produced. (Appendix 1). Condition reports and high resolution images were taken of the specimen before during and after treatment.

As the main slab is considered to be the more significant part of the specimen its treatment is described

Figure 2. Vulnerable area protected with water soluble putty.

below. As work on the counterpart was almost identical its treatment has not been outlined to avoid duplication.

Treatment of main slab

Removal from old housing

Surface protection was applied to vulnerable areas and cracks around the specimen (Figure 2). A polyethylene glycol putty mix known as 'water soluble putty' (Rixon 1976) was applied to all individual areas requiring protection. The skeletal area was then covered in gauze coated in polyethylene glycol 4000. The sides of the box were then removed along with old plaster and wood embedding materials. A silicone rubber layer was applied to the entire surface

Figure 3. Main slab inverted showing supporting jacket and wooden base with cut out for revealing ventrally prepared area.

and sides of the specimen block. Aluminium foil was used to cover the silicone rubber surface. In addition 10mm polyethylene foam sheeting was applied over the area containing the skeleton. An epopast laminating epoxy paste jacket was built over the foil/rubber lined specimen and sides. The block was then inverted (Figure 3) and the base of the old housing was carefully removed. The small exposed area prepared on the ventral side was protected with gauze coated polyethylene glycol 4000

Block reduction

An annular diamond edged saw was used to cut grooves into the limestone at approx 10mm intervals to a depth of 5-7mm (figure 4). Once an area of grooves were cut the 'slices' of limestone were removed by gentle chiselling. This process continued until the agreed depth had been reached. Approximately 20mm depth of limestone was removed across the back of the main block. A 2mm polyethylene sheet was applied to the surface and an epopast jacket was applied over the surface of the ventral side and sides. The small prepared area on the underside was not covered to ensure future access.

Figure 4. Grooves being cut into the limestone slab.

New wooden housing

The jacketed specimen was again inverted so the specimen surface would be uppermost. The top jacket and silicone layer were removed. The bottom jacket would remain to strengthen the block. All exposed limestone block edges were cleaned. The specimen block was then placed into the new housing and checked for orientation. Epoxy resin foam was poured around the block so it was embedded up 10mm below surface. A top layer of epoxy resin was poured carefully around the block to approximately

Figure 5. Specimen blocks in new housing. Perimeter of block is now exposed to a depth of approximately 4-5mm so "true edge" of limestone block can be seen. Previously this had been embedded.

Figure 6. The mould being removed from the main slab.

5mm below surface level. The cured surface was painted with black acrylic. The housing also incorporates a cut out section in the base protected by a Perspex sheet so that access can be gained to the ventrally prepared area. All polyethylene glycol wax and putty were removed so the specimen surface was completely revealed. (Figure 5)

Replication

Both main slab and counterpart surfaces were coated with dilute Teepol an alkyl sulphate detergent which forms a temporary separator. Cracks and vulnerable areas were protected with water soluble putty. A room temperature vulcanising silicone rubber was applied in 2 layers to the surface to a depth of 4-5mm. Once the rubber had cured a supporting jacket made from glass reinforced epoxy resin was applied. The jacket and mould were removed (Figure 6) and the surface was cleaned.

An epoxy resin master cast was produced so that in the future new moulds could be produced from the master cast and not from the original surface of the specimen.

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Appendix 1

Specimen Risk Assessment for Treatment Process.

Security whilst specimen in the Palaeontology Conservation Unit (PCU)
Specific risks identified:

· Major Theft resulting in stolen and or damaged specimen.

· Isolated vandalism resulting in scratched, broken or missing pieces.

The following procedures will be adopted during the project to minimise the risk.

1. Only one part of the specimen will be in the PCU at any one time. The other specimen block will remain in the collection stores.
2. A designated member of PCU staff will be responsible for the specimen while it is in the PCU
3. The specimen will never be left out in the general PCU workspace unless it is physically being worked on. (i.e. it is never left alone)
4. When not being worked on the specimen will be stored in a secure area behind 2 locked doors within the PCU
5. The work will be carried out continually in one block of time for each part to reduce the amount of time for the main slab or counterpart to be out of the collection stores.
6. Except in emergency no contractors will be allowed to work in the PCU during the project.

Physical forces

Specific risks identified:

▪ Removal/replacement of housing causing damage by vibration

▪ Preparation activities causing damage though vibration

▪ Crushing of specimen surface during inversion of block.

▪ Poor support during matrix reduction causing specimen to crack

▪ Shock during transport to secure storage area each day while in PCU

The following procedures will be adopted during the project to minimise the risk.

1. The counterpart will be worked on first as this contains less of the specimen and appears more robust. There can then be a review of methods/processes before working on the main slab
2. The approved contractor working on the wooden housing will be supervised at all times to ensure compliance to agreed procedures.

3. Specimen slab surface and exposed sides will be protected and reinforced during treatment by silicone rubber and epoxy resin for counterpart and polyethylene glycol, silicone rubber and epoxy resin for more delicate main slab.
4. The counterpart slab will be subjected to review at every 10mm reduction in depth by Lorraine Cornish and Angela Milner. Final depth to be decided by Angela Milner.
5. The main slab is considered to be more fragile so will be subject to review at every 5mm reduction.
6. The specimen will remain on a bespoke board lined with polyethylene foam during treatment and transport

Contaminants

Specific risks identified:

- Use of inappropriate material/method on specimen surface causing damage or loss

The following procedures will be adopted during the project to minimise the risk.

1. Only conservation grade materials will be used (all materials selected have been used on the specimen in the past)
2. Specimen surface will be protected during depth reduction and re-boxing
3. Specimen surface examined and vulnerable areas protected during the moulding process.
4. No chemicals will remain on specimen surface once re-housing has been completed.

THREE DIMENSIONAL PREPARATION OF A LATE CRETACEOUS STURGEON FROM MONTANA: A CASE STUDY

by Constance Van Beek and Matthew A. Brown

Van Beek, Constance and Brown, Matthew. 2010. Three dimensional preparation of a late Cretaceous sturgeon from Montana: a case study. *The Geological Curator* 9 (3): 149 - 153.

Thorough description of an exceptionally well-preserved fossil sturgeon required nearly complete disarticulation of much of the skull, as well as preparation of fins and other very delicate structures. Preparation took place in distinct stages in order to allow for detailed photographic documentation of the structure and relationship of individual bones before they were disassociated from the skeleton. Prior preparation and application of materials presented challenges to cleaning of surfaces that were overcome using a combination of chemical and gentle mechanical preparation methods. Combinations of consolidants were experimented with until a method for stabilization for fragile parts of the skeleton was decided upon. Extreme care was required during disarticulation of the very delicate elements, and a storage method was devised to maintain relationships of individual bones after removal from the skull. Justification was made based on research needs to sacrifice certain aspects of conservation principles in selection of non-reversible adhesives and consolidants for stabilization, repair, and reconstruction.

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Introduction

The Cretaceous fossil record of sturgeons, while plentiful, has not been known for well-preserved or complete specimens. Historically, they have been fragmentary or of poor quality. When an unusually well-preserved specimen of a new, undescribed taxon (MOR 1184) arrived at The Field Museum on loan from the Museum of the Rockies in 2002, it presented an opportunity to fully prepare and describe the most complete fossil sturgeon yet known. The specimen consisted of two sections: the skull and anterior trunk region, which included a tall dorsal fin; and the posterior trunk/caudal region, which contained the rest of the dorsal fin (Figure 1). The dorso-lateral surfaces had been prepared; but fine details were either not exposed, or were covered with a thick coating of Vinac B-15 (polyvinyl acetate). The ventral surfaces were minimally prepared, and were also under a thick Vinac coating. While consolidation was necessary for stabilization of the delicate specimen, this thick coating hindered detailed examination.

On the anterior trunk section, the left side of the dorsal fin had been prepared. However, on the posterior section, the right side of the fin had been prepared. This presented a difficulty, since the descriptive manuscript required figures photographed from the left lateral side. Once MOR 1184 was fully prepared, photographed and illustrated, the skull was to be completely disarticulated into individual bones for detailed description and further illustration.

Preparation

Dorso-lateral skull

Preparation work began on the dorsal surface of the skull, but removing the thick coating of Vinac was problematic. Brushing on acetone would dissolve it, but the surface would become gummy; and if the remaining Vinac was removed mechanically with a carbide needle some of the bone surface would peel away as well. However, continuous light brushing of the surfaces with acetone alone, using a soft art brush, was effective in removing the Vinac with minimal or no bone damage. This cleaning now made the bone extremely soft and fragile. Vinac was re-applied to the bone surfaces as a very dilute solution. This method enabled surface details to be revealed without creating an undesirable glossy coating. However, this treatment alone would not give the bones enough strength to be handled.

Thin cyanoacrylate glue (Aron Alpha 201) was

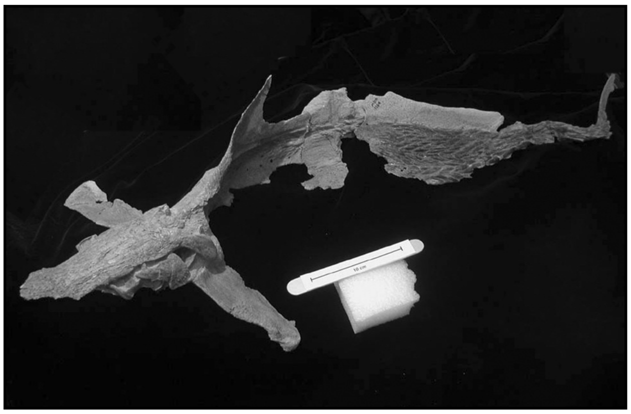

Figure 1. MOR 1184 before preparation, dorso-lateral view.

selected as a supplementary consolidant. Once a surface was completely cleaned, it was immediately treated with tiny amounts of cyanoacrylate. It was applied using a watchmakers oiler- a small spatulate tool that allowed for very precise application. The tip of the oiler was dipped into a tiny puddle of glue, and then touched to the bone surface, which absorbed it. This method is similar to the scratch technique as described by Amaral (1994:136). Once the dorsal surfaces had been treated in this manner, detailed features such as skull sutures, ornamentation and scale tubercles became visible (Figure 2). Both lateral sides of the skull were then prepared in the same manner.

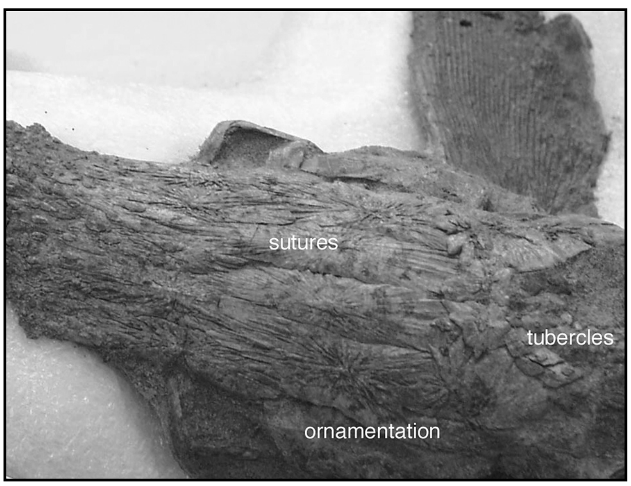

Figure 2. After stripping a thick layer of consolidant and matrix from the dorsal surface of the skull, detailed features are now visible, including sutures, ornamentation, and tubercles.

Trunk and caudal region

The next phase was preparation of the dorsal and pectoral fins, which required very delicate work with acetone and a carbide needle. After removing the thick Vinac with acetone, a few thin layers of Vinac or cyanoacrylate were applied to the surfaces. The pectoral fins and the tall sail-like anterior portion of the dorsal fin were effectively treated in this manner. After stabilization and preparation of the distal dorsal fin, work proceeded on the rest of the trunk and caudal regions.

Transfer preparation of dorsal fin

Preparation work continued on the distal portion of the dorsal fin. Since the right lateral side had been prepared already, matrix remained on the left side for stability. That matrix had to be removed, however, so that MOR 1184 could be photographed in left lateral view. The fin was extremely thin, and another stabilizing method was necessary.

First, eight layers of thin Vinac were applied to the prepared side of the fin, but this method did not provide enough support to keep the fin from collapsing during preparation. The transfer method of preparation was selected to reinforce the already prepared surface (Toombs and Rixon 1950). A wall was built around the fin using Van Aken Plastalina modelling clay, and three thin layers of Castolite AP, an optically clear acrylic-polyester resin) were applied. After the resin had set up, the clay wall was removed, and it was possible to then remove the matrix from the left lateral side without breaking the fin.

Ventral skull

After the dorsal surfaces had been prepared, the ventral surface of the skull was treated. In order to prepare the ventral surface, the anterior section of MOR 1184 had to be 'flipped' upside-down. Now inverted, the tall dorsal fin projected downward like a ship's keel, and required protection.

A hole was carved out in a six-inch deep ethafoam base, ensuring it was deep enough for the fin. A two-part plaster cradle was also built to protect MOR 1184 while it was nestled inside the ethafoam base, which would facilitate easy removal of the specimen for photography and study. The two-piece cradle was now ready to accommodate MOR 1184 in an upside-down orientation. Finally, a cradle was made for the posterior section of MOR 1184 that would orient easily with the anterior section, to enable straightforward manipulation during photography sessions.

Remaining matrix on the ventral skull was removed with a carbide needle, and bones were cleaned with acetone and a soft art brush. Because of the high-resolution photography that would come later, it was important to remove any remaining sand grains, so all bones got a very thorough cleaning treatment. Each bone was stabilized with very dilute Vinac/acetone and then cyanoacrylate glue, applied with the oiler tool.

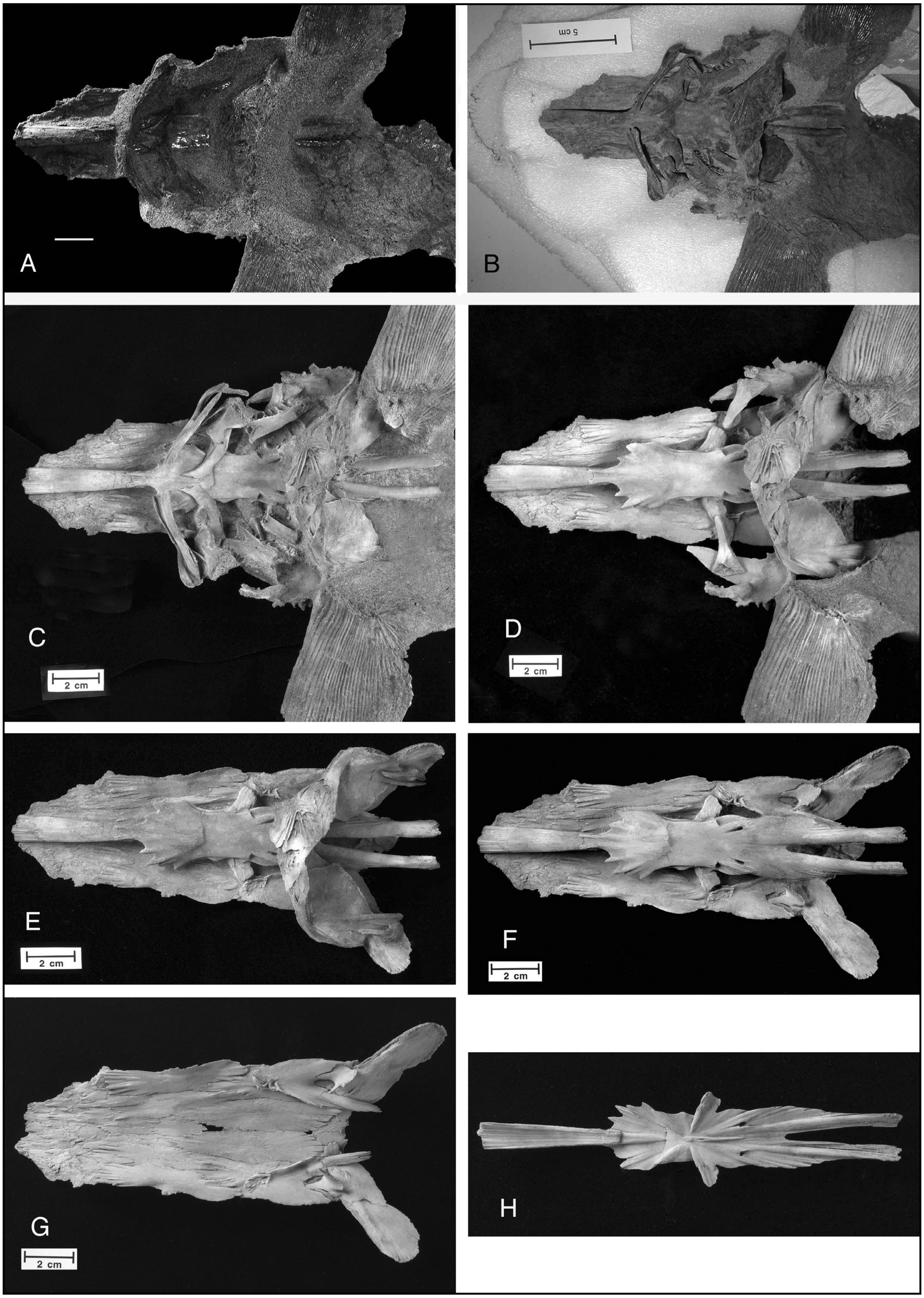

Figure 3. Preparation of the ventral skull. A. Ventral surface before preparation. B. After one hundred hours of preparation. C. Whitened with ammonium chloride prior to disarticulation. D.After removal of jaws, palatopterygoids, ceratobranchials. E. After removal of hyoid bones and subopercles. F. Parasphenoid overlying skull roof. G. Ventral surface of skull roof after removal of parasphenoid. H. Parasphenoid, dorsal view.

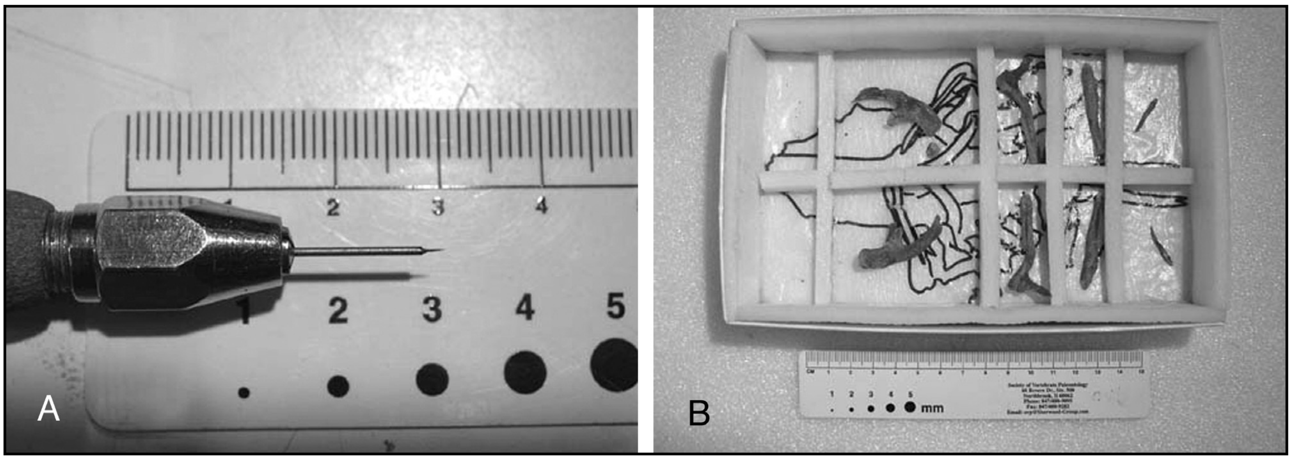

Figure 4. Techniques for preparation and organization. A. Small blades are created from carbide rod in sub-millimeter thickness to cut between very tightly packed cranial elements. B. All elements removed are stored in customized boxes with their original positions traced onto the bottom of the container and photographed.

After thorough cleaning and preparation the ventral skull elements were now clearly visible in fine detail. The first of a series of technical photographs were taken, showing all the ventral bones in articulation, before further preparation continued.

Disarticulation of skull

The final preparation phase was disarticulation and removal of all the skull bones moving ventral to dorsal, stopping at the skull roof (Figure 3). The bones were delicate and thin, and many were laid closely atop one another. Needles were sharpened into thin blades in order to get underneath delicate bones without damaging them (Figure 4a). As each bone was removed, it was placed in a labeled, compartmented, ethafoam-lined box (Figure 4b) and photographed. The relationships of the elements were traced onto transparency paper and the box was lined with the map. In this way elements removed were identified by label and by illustration, making their identity far more obvious if the box were ever to be overturned or the elements were otherwise misplaced.

The pectoral shields and fins were removed from the anterior portion of the trunk. The posterior section of the trunk and caudal was prepared in accordance with the previously described methods of matrix removal, including consolidation of the scutes, scales, and caudal fin.

Reconstruction

Curatorial direction called for several missing parts of the specimen to be reconstructed for aesthetic reasons. In one example, a previous glue join on the left pectoral fin had to be fixed. The join was taken apart, and then re-fitted with Devcon 5- minute epoxy. After re-gluing the joint, All-Game, a taxidermy epoxy putty, was used for filling in the missing areas. The neutral-colored putty was tinted with Color Match epoxy paint, added to part A to mix with the neutral-colored B.

In another example, removal of matrix in the trunk and caudal regions between scales and bones created holes after cleaning and stabilization, and the epoxy putty was added as a gap fill where necessary.

The epoxy putty was also used to bridge a gap adjacent to the left pelvic fin. To mask this fill, a paste of crushed sandstone matrix, mixed with Elmer's glue (a household brand of polyvinyl acetate emulsion) and water, was applied to the dorsal surface of the filled area. The texture blended in and did not call attention to the repair.

Discussion

Preparation of MOR 1184 took approximately 750 hours. The delicate specimen underwent frequent handling during photography, illustration, and study. However, it withstood such treatment admirably. There were many unique challenges throughout the process, and successful preparation was achieved by avoiding destructive mechanical methods and applying a combination of techniques to stabilize and protect fragile areas.

Using acetone to resolve excess Vinac B-15 instead of removing it mechanically with a needle demonstrates some of the advantages of using solution adhesives rather than reaction adhesives whenever possible. Delicate bone surfaces were preserved in areas where a more aggressive technique surely would have destroyed them. Using thin, successive applications of solution adhesive allowed most areas to be stabilized for handling. In some instances, cyanoacrylate was chosen as a supplemental consolidant, because its advantages; i.e. wicking ability, rapid and deep setting (Davidson and Alderson 2009), outweighed its disadvantages; i.e. nonreversibility, unknown longevity (Down and Kaminska 2006).

Reversibility was sacrificed in favor of greater strength several other times throughout the preparation of this specimen. Using the transfer method with Castolite resin was felt to be the only acceptable way to stabilize the fragile posterior dorsal fin. A more conservative approach would have been to leave the matrix covered side unprepared, but research needs tipped the balance and required complete preparation of that element. Likewise, use of epoxy putty allowed for the creation of very thin (< .5cm), stable fills between gaps.

Some materials used did have better alternatives that were not explored during preparation. Personal experience, anecdote, and conservation literature (Horie 1987:173) dictate that 5-minute epoxies do not have appropriate properties for use on paleontological specimens. In the future, an alternative adhesive would be selected. Elmer's Glue is also not recommended for use in fossil preparation, as it can become brittle, discolored, and insoluble over time (Davidson and Alderson 2009). Matrix fillers can be created with .more stable solution adhesives and these may be a better option.

Conclusions

The successful cleaning, preparation, and disarticulation of this specimen has resulted in two publications (Grande and Hilton 2006; 2009) establishing this specimen as the holotype of *Pristocosturion longipinnis*. Obviously the specimen could not have been described in such detail without a high level of detailed preparation, likewise the fine quality of preparation would not have been attainable without close collaboration between the research and preparation staff. Detailed input from the researchers regarding crucial anatomical features and the necessity to expose areas of certain elements, either in part or completely, helped to focus preparation and resulted in more efficient preparation. This project represents an excellent example of the benefits of curatorial and preparation staff working together as a research team.

Acknowledgements

Thanks to J. Horner and C. Ansell (MOR) for loan of the specimen and initial preparation, L. Grande (FMNH) and E. Hilton (Virginia Institute of Marine Science) who studied and described MOR 1184, J. Weinstein (FMNH) for the use of his photographs and W. Simpson, J. Holstein, L. Herzog, and A. Shinya (FMNH) for their helpful advice and support.

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BOOK REVIEW

***Amber - Tears of the Gods* Neil Clark 2010 £25.00 hardback, 128 pages, illustrated in colour. ISBN 978 1 906716 16 5.**

Amber - Tears of the Gods was a pleasure to receive and to read. It is published by Dunedin Academic Press with the Hunterian Museum and Art Gallery in the University of Glasgow. As stated in the introduction, the book draws on a 2010 exhibition of amber in the Hunterian for inspiration, but it is fully a study of amber across the spectrum and not merely a catalogue nor an opportunistic marketing supplement to that exhibition. It should stand the test of time, as an interesting addition to the amber literature, which would appear to be relatively limited.

The style is firmly in the general readership area, with an easily read flow, and some coverage of most aspects of amber, but with any more technical issues well explained in plain language. The book is well illustrated throughout with colour images of all sorts, and an attractive design standard. Despite the once mentioned exhibition in the Hunterian, illustrated pieces have a global reach, and only a handful of Hunterian specimens are used to illustrate the stories told within.

The stories that Clark tells include the origins of amber, its use in prehistoric times and the myths around amber in different European countries and cultures. A good section of the book covers the trade in amber and the shifts in political control from the fall of the Roman Empire, through the Middle Ages. It is interesting to read in these sections of the reinventions of the trade through creation of new markets for medicinal or changing religious practice, and reflect on how little has changed, with different forces grappling for control of desirable materials. Perhaps penalties are less harsh nowadays since immediate hanging for unlicensed collecting on the Gdansk coast was the norm during the Teutonic Order's control.

The 14th century Teutonic Knights and their Malbork Castle collections feature strongly, and detailed coverage of the development of the amber craft work through to the 19th century, and the illustrated material would prompts thoughts of making a visit to see for one's self. The Amber Room gifted to Tsar Peter the Great in the 1700s is a small piece of history I had not heard of, and is a fascinating mystery. A later chapter looks at amber use into the 21st century.

The latter part of the book has chapters covering medicinal use of amber, various scientific treatments and studies, and puts to bed the Jurassic Park scenario. Amber as a trap for insects and other living things is covered, and has about 12 pages of fine illustrations of the range of creatures found in amber. It is not a catalogue approach but aims to show the very fine details which can be preserved, the main groups found and the techniques used to examine them such as transmitted ultra-violet light.

The remainder of the book covers fakes and imitations, and the range of tests that can be done to be sure of what you have. Some simple guidance for a reader as to care of amber they might own is a useful closure, along with further reading and website addresses. So where does this book sit in the spectrum of existing literature? It is closest perhaps to Andrew Ross's *Amber - The natural time capsule* but its strengths are with the history of the use and trade and fantastic craft works in amber, as opposed to the detailed keys to included insects of the latter. It touches on the origins of amber in the Baltic Forest and others but for a full investigative story Poinar and Poinar's *The Amber Forest* would be an essential alternative, with its reconstruction of the vanished world which left us Dominican amber. If you wanted to identify inclusions in a piece of amber, Clark's book would help steer you, but Ross's book or Weitschat and Wichard's *Atlas of Plants and Animals in Baltic Amber* would probably step into action. So in summary, *Amber - Tears of the Gods* is a high quality publication, adding to the amber literature in a useful way, especially with the historical details of trade and craft, for both specialists (such as museum curators) and the general reader.

Matthew Parkes, Natural History Museum, Merrion Street, Dublin 2, Ireland. 5th April 2010

SKETCHING IT: USING DIGITAL PHOTOS, DRAWINGS, AND ARTIST SOFTWARE TO MAP A FIELD JACKET DURING PREPARATION

by Dennis Roth

Roth, D. 2010. Sketching it: using digital photos, drawings, and artist software to map a field jacket during preparation. *The Geological Curator* 9 (3): 155 - 159.

A field jacket was prepared from the 2008 field season, recovered by a team from the Big Horn Basin Fossil Foundation south of Douglas, Wyoming, quarry information for which is missing or unavailable at this time. Detailed mapping of fossil quarry sites is a necessity for accurate measurement and subsequent study. Often in the field, limited information is available during excavation, leaving the process of preparation of the fossils as vital to the collection of accurate data. During each day of preparation, several digital images were taken. A schematic drawing of the field jacket was also updated with new information as each fossil was uncovered and extracted. The photos were compiled using commercial artistic software (Adobe Photoshop 7.0 ™), and using notes made during preparation the fossils were outlined to create an accurate composite of a portion of the quarry floor for future study.

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Introduction

Paleontological studies require a good field record of fossil placement. Using methods such as grid and radial mapping, total station as well as field notes recording size, orientation, plunge, and surrounding geological information is routinely collected. Such information provides an invaluable aspect to taphonomic studies. When collecting and preparing plaster field jackets, some difficulties can arise with field data.

Using plaster jackets is a common practice with may museums. For storage and protection of the fossils found in the field, the jackets serve a two-fold purpose. When a jacket has more fossils than recorded in the field, the question of the position of the previously unknown fossils becomes a problem in terms of recording their original position. What are some of the steps that can be taken to correct such a problem?

A simple way would be to record the new finds on the quarry map. While this is the simplest way to record the information, it does leave a margin of error in the form of shape and size distortion. Without a frame of reference for drawing the fossils, other than the associated pieces, distortion can make this process very inaccurate.

Many fossils found in large field jackets may just be recorded as new finds - recorded, but not incorporated within final maps. If there is no accurate way to insert and record the information, it is often left out. This leads to a loss of taphonomic information from the site.

Another issue is what if the quarry has no map, or has only limited map information? In terms of considering the assemblage, removal of the fossil from the ground without any associated field information destroys most of the contextual information. Without this information, there is little to understand the taphonomy and distribution of fossils at the sites. While frowned upon, such collection does occur. If the only information gathered is from plaster jackets in association, then there needs to be a means of accurate data collection.

Here is proposed the use of a method that combines drawn schematics along with accurate photographic records of fossil excavation and preparation. Using these records, an accurate set of information about the relative associations within fossil assemblages can be recorded.

Materials

Materials for this process are simple. A digital camera with high resolution, a pen tablet, an artistic software package that uses 'layers' and notes from the preparation process. In the following sections the specific materials used in this method are elaborated on.

The specimen used for this method was WDC DMP 002, an allosaur from the Morrison Formation (Late Jurassic) of east-central Wyoming.

Methodology

At first glance, the methodology resembles an older mapping technique and could be summed up as 'a new take on an old method.' The method itself revolves around acquiring digital photographs, using an image processing software to resize and compile the images, a pen tablet to draw the fossils from the photographs, and finally the relation of the drawn image to the quarry itself. While simple, it takes advantage of computer programs and photographic manipulation in order to reduce the distortion of images when producing the schematic.

Photographs

Using a Kodak 1.0 megapixel ISO 1250 Digital IS camera and scale several images were taken during each day of preparation work. The photographs were taken between 50-70cm distance from the object, in order to get the best resolution with the camera and record the best images of the fossils after each stage of the work. Ideally, one should take photographs of small areas of the jacket. If the images taken were too large, the finer details would become lost, if they were too small, then the larger picture would be lost. When finished taking photos, select the ones that best represent the fossils in the jacket to be used later in the method.

A key precaution to take when acquiring the image, is that the angle of the camera should be perpendicular to the surface of the jacketed specimen. This will reduce the degree of visual distortion in the photograph arising from the angled view of the specimen surface.

Compilation

After preparation is completed and all photographs have been selected, some further steps are required to create creating the compilation, namely resizing the photographs to the same scale and compiling them into a lager image. The program used for this and subsequent sections was Adobe Photoshop 7.0 ™.

Since there are some discrepancies in height when taking the images, each photo had to be resized to the same scale. Various art programs allow for the creation of files of specific sizes. When selecting File > New to make a new image file, the size of the new file can be specified. In order to scale the photographs, a new image file was created at 1x10 cm. This made it possible to maintain the same scale, even though the photographs differ in size (Fig. 1).

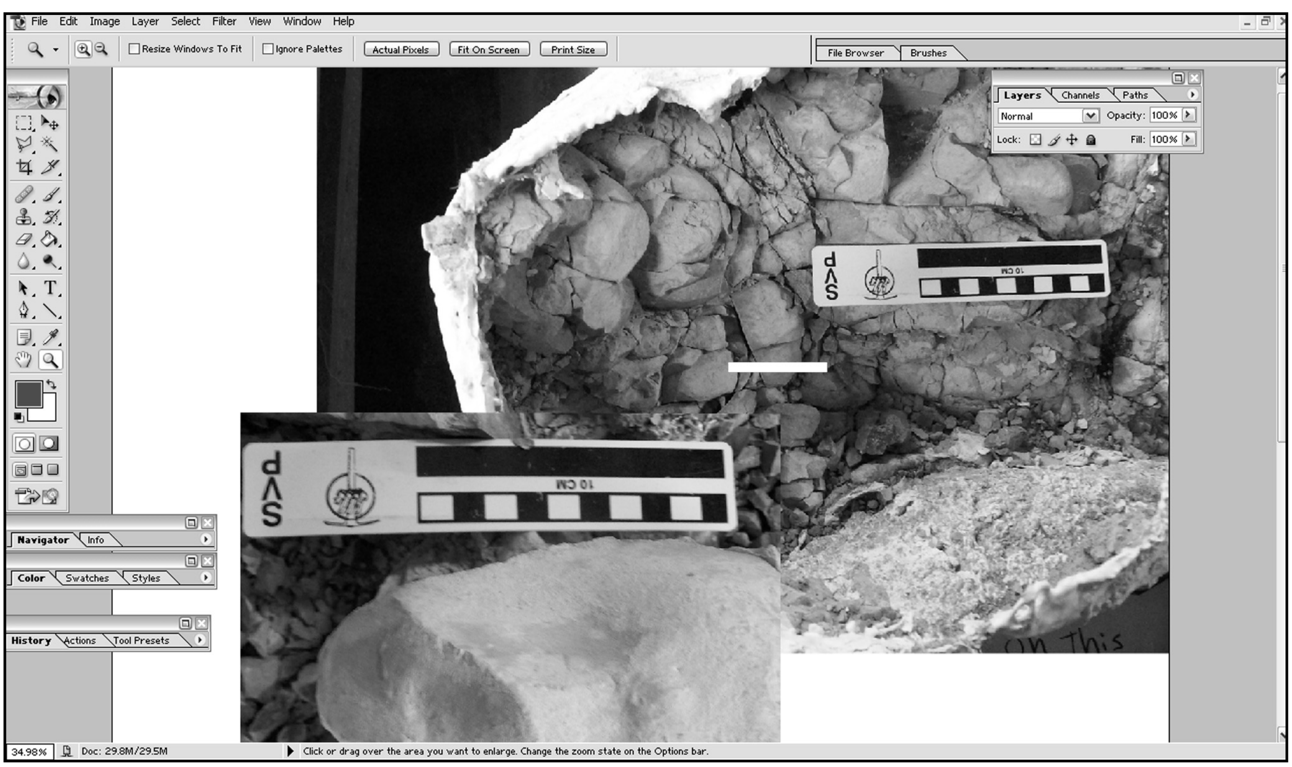

Figure 1. A screenshot of Adobe Photoshop 7.0 showing the differences in scale between two images. The bar in the centre is the 1x10 cm scale bar used to resize images to the same scale. All scale bars are 10 cm.

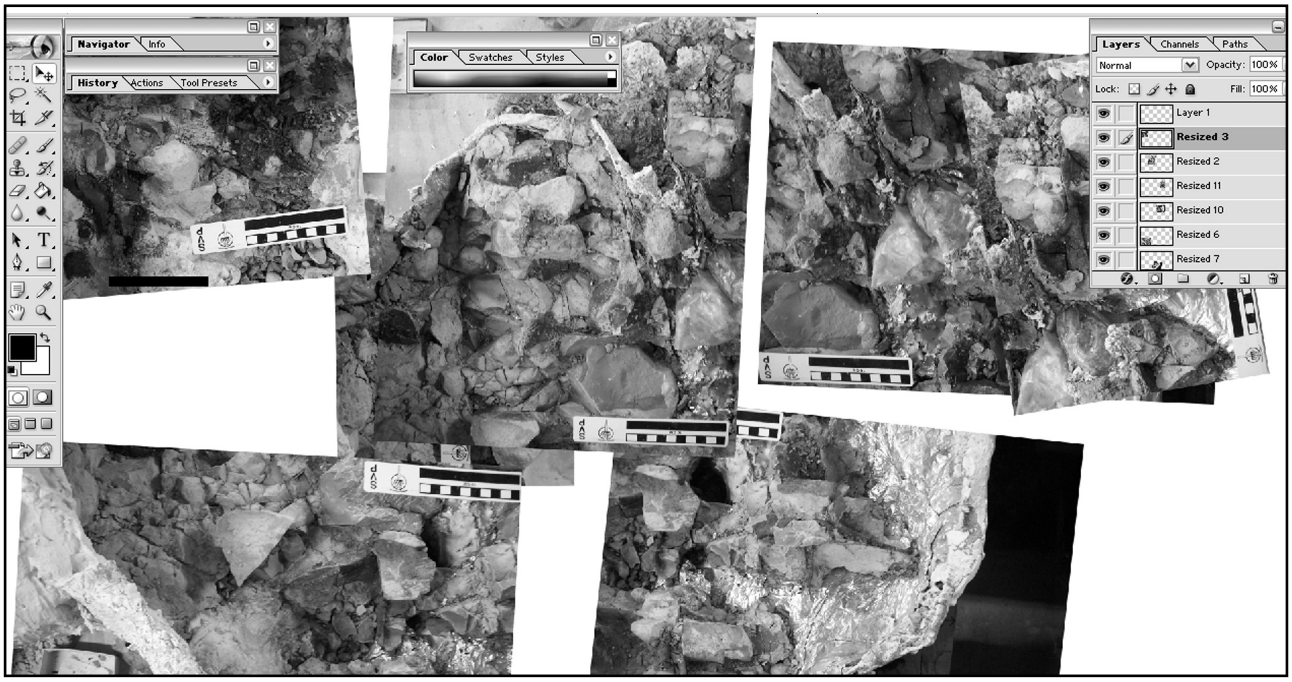

Figure 2. A screenshot of Adobe Photoshop with various images already resized to the same scale prior to piecing together the larger compilation.

Once all photographs are at the same scale, they are put together in a large compilation, using notes made during the preparation as (well as memory) to complete this stage. The final compilation should have all fossils represented well as is possible (Fig. 2).

Drawing

Once the compilation is finished, add a layer to the image to begin outlining the fossils onto. Layer, as used here, refers to the property of a variety of art programs to allow a user to change and edit something independently from the primary image. Each layer is like an individual sheet of transparent tracing paper one on top of another. Three layers were utilized in this method, one with the photo compilation, one for notes made during preparation, and the third was the layer being drawn onto (Fig. 3). The final schematic drawn should represent all the bones found during preparation of the specimen.

Relating this back to the Quarry

When the final schematic of the fossils is drawn, it can be used to try and correlate back to the quarry itself even in situations where there is little or no information available. The schematic can be overlaid on photos from the site to show the position of the bones as they originally lay in the ground. To do this, the image simply needs to be 'flipped' (thus restoring the contents of the plaster jacket to their original un-inverted pre-removal position) before placing it over any images or maps of the dig site (Fig. 4).

Conclusions

While the method is simple in design, in practice it can become complicated. Some issues that may arise when using this method are next addressed in order to illustrate some of the potential difficulties. One is the number of photos taken during preparation. While the jacket for WDC DMP 002 was 106.7x137.2 cm this method dealt with nearly 500 images taken with the digital camera.

Another important issue is the size constraints of the program being used. The version of Photoshop used in this method can only produce an image with a maximum size of 152.4 x 152.4 cm. This can limit the amount of information that can be placed into a datafile of the program. However several people who work with such programs have reported that the power of the computer using the software can be more of a limiting factor than the software itself. The brand of software being used can also be a factor. It is important to check the maximum size of file that the software can produce before starting compilation, so that if the area needed to be drawn is larger, then the scale bar can be reduced before resizing the images.

The size of the images can also cause the program to corrupt the file. This happened at least once due to the over-all size of the photographs and the information, meaning most of the resizing work had to be redone. To try and counter this problem, the photographs were separated into two parts before being

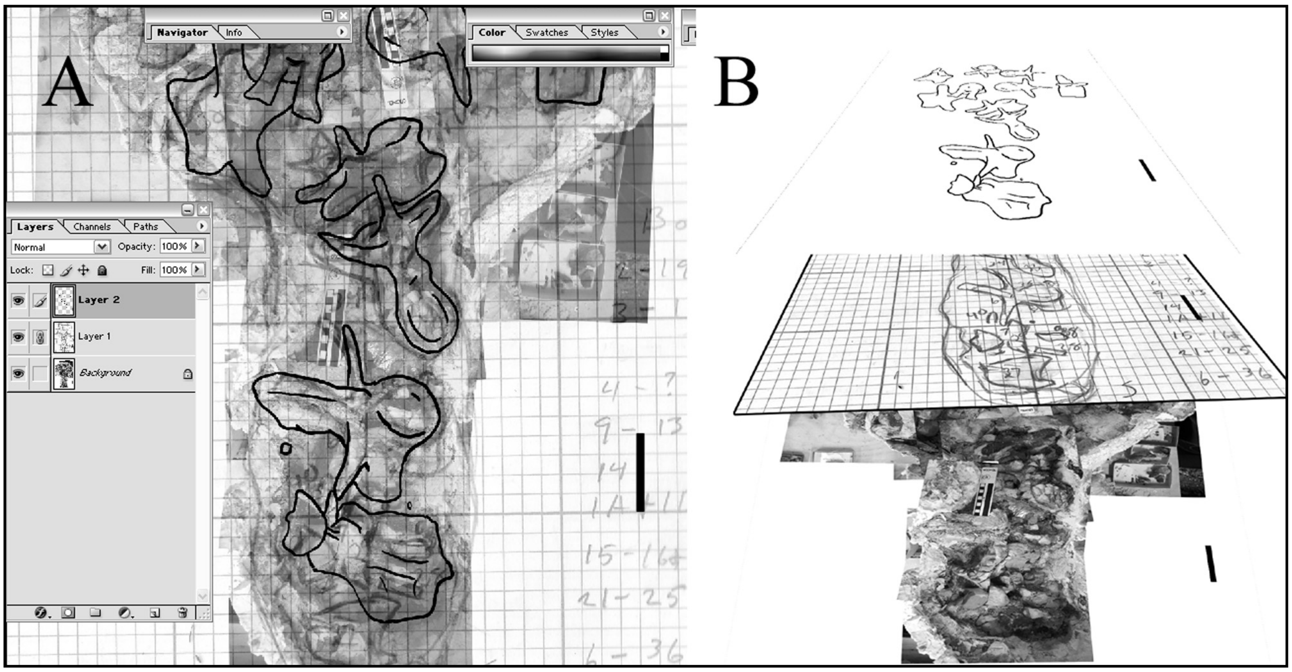

Figure 3. A) A screenshot of Adobe Photoshop showing the different layers used in drawing the final schematic. B) A three-dimensional representation of the layer system in Adobe Photoshop. This allows for the manipulation of one layer without affecting the others above or below it. Scale bar is 10 cm.

placed together for the final compilation. For large images and compilations, it is recommended to separate what will become the final image into various parts to reduce the likelihood that the file will corrupt due to its size. The file corruption could have also been due to another random factor, but splitting the compilation is still recommended.

Even when care is taken to acquire photographs perpendicular to the surface of the specimen there can still be some visual distortion when all the images are resized to the same scale. A possible solution would be to build an apparatus that could be balanced to take pictures along a horizontal plane that would minimize the chance for visual distortion. Another

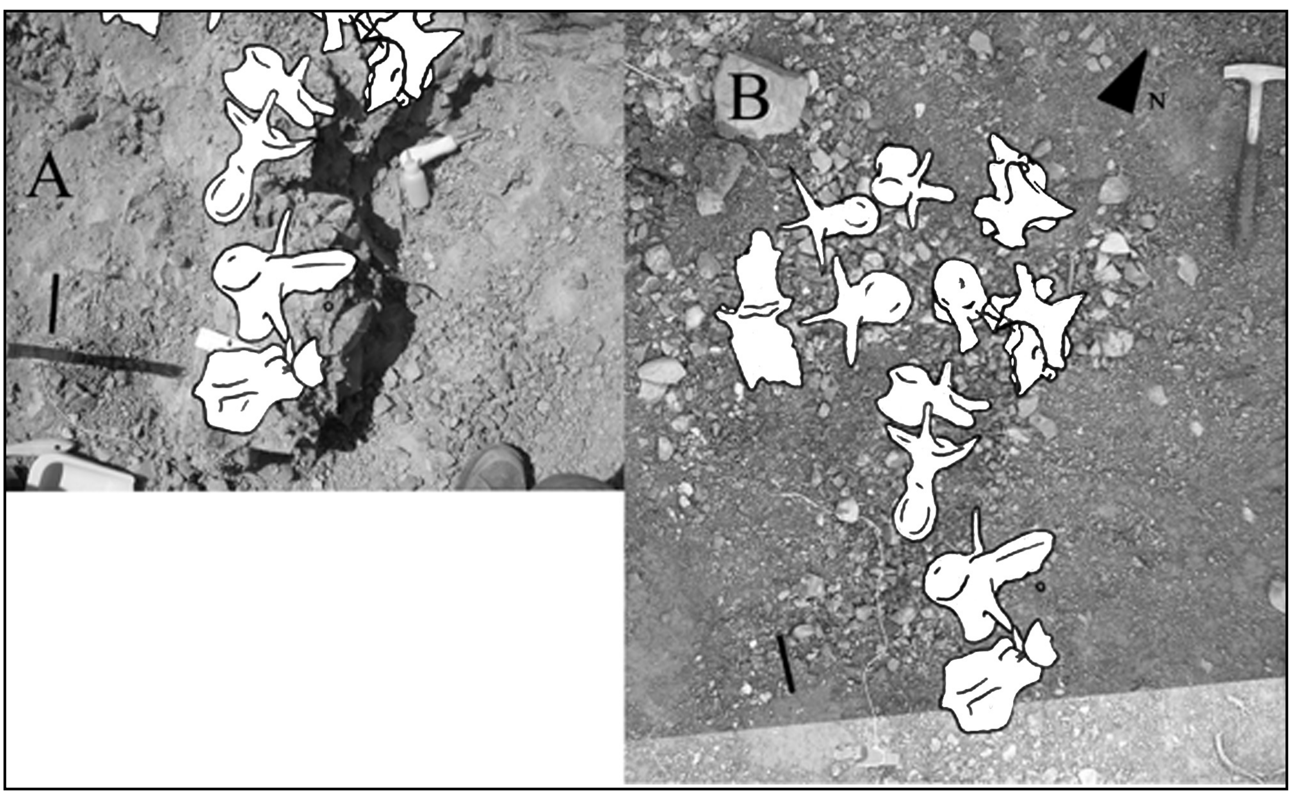

Figure 4. Using the schematic drawn with this method to replace the fossils at the quarry site. A) Before the plaster jacket was made and the fossils removed. B) The quarry site after the jacket had been removed and the final schematic placed over the site. Scale bar is 10 cm.

possible way to minimise the distortion and limit the distortion of the photographs would be to include multicoloured points on noticeable features along the fossils, such as neural arches or centra outlines. Both options should be considered for future work in order to reduce the visual distortion encountered when working with this method.

Images collected using this method could also be modified into museum displays. Using the photographs in a similar way a time-lapse photography would allow the public to see how much work goes into removing the matrix from fossils. The images could also be modified into something similar to CT (computerised tomography) scans, removing layers of matrix at a time for a sense of depth. On a larger scale, the method could be expanded to entire dig sites to keep a map on file of everything found before, and after specimen preparation.

The method presented is specifically meant for the preparation phase of fossil collection. There are some cases where there happen to be more fossils in a jacket than originally planned. For example, with specimen WDC DMP 002, field notes suggested that there were only half a dozen vertebrae in the jacket. After preparation there were 11 vertebrae recovered. This method also functions to add data to quarry maps, when there is little to no information about the quarry. While it is suggested that this method can be expanded to the entire quarry, its primary purpose is not for quarry mapping, but rather for the mapping of plaster jackets already removed from the field. Neither is it suggested that this procedure be adopted as an alternative to accurate data collection during fossil excavation.

Acknowledgments

I would like to thank the Big Horn Basin Fossil Foundation for allowing me the opportunity to work on WDC DMP 002. The Sternberg Museum of Natural History for the space and tools to prepare the specimen. William Wahl for overseeing the collection of WDC DMP 002 and subsequent discussions and applications of this method. My adviser, R. Zakrzewski, for his support and advice. Members of the Society of Vertebrate Paleontology for feedback and comments on this method. My fellow graduate students M. Calvello, J. Clare, and J. Hammond for comments, discussions, and contributions.

Materials Used

Adobe Photoshop 7.0. 2002. Adobe Systems Incorporated. San Jose, California.
Kodak 1.0 megapixel ISO 1250 Digital IS. 2007. Eastman Kodak Company. Rochester, New York.
Wacom Pen Tablet, Driver Version 6.05. 2007. Wacom Company, Ltd. Tokyo, Japan.

BOOK REVIEW

Graham Park, 2010, *Introducing Geology: A Guide to the World of Rocks*, *Second Edition*. Dunedin Academic Press Ltd, 134 pages, ISBN 10: 1906716218, ISBN 13: 978-1906716219

Graham Park's second edition of his *Introducing Geology: A Guide to the World of Rocks* is an excellent book for the novice geologist or as a preparatory guide for those thinking of studying the subject academically. As someone falling somewhere in between these two categories I find this book is right up my alley, and it achieves what it sets out to do.

At only 134 pages in length it manages to squeeze in a large amount of information, and its small size means that it can easily be carried around with minimal hassle. Its format of having short chapters on different topics means that it is the type of book one can easily dip in and out of, and so is perfect for reading on the go.

It is supplemented by an extensive glossary - which doubles as an index - allowing for free flowing reading for those acquainted with the vocabulary whilst providing definitions and additional information for those less familiar with the terms used. The language in the book is easy to understand yet does not patronize the reader, and it provides good insight into the different topics covered. It is more than just a casual introduction, and yet it leaves the reader wanting to find out more about the subject - but in a good way!

The eleven chapters cover the breadth of the subject, progressing in scale from the various properties of crystals, minerals and gemstones in Chapter One, to the uses of geology in industry in the final chapter, going over different Earth processes and aspects of Earth history in between.

For such a small book, it is surprisingly full of illustrations and helpful tables and diagrams which summarise and organise important notions in geology. The colour pictures scattered throughout the book are glossy and of good quality, and are a decent size considering the book itself is quite small. The last page of the publication is dedicated to suggested further reading and useful websites, perfect for those seeking to expand on what they have just read.

One minor gripe I have with the book is that the first chapter, which covers crystals, minerals and gemstones, perhaps deals in too small a scale to be used as the introductory chapter, and I feel maybe a chapter about broader earth processes such as plate tectonics may have been a better way to begin and then work its way down to finer and finer detail from there.

But this is just a minor complaint in an overall excellent book which serves as an ideal introduction to geology, or even as a study companion for the geology student who would like a broader view of what he or she is learning. For the price it is well worth the investment, and is an ideal purchase for the novice seeking to learn more about the science of geology.

Emmanuel Kavanagh 2nd July 2010

PIÑATAS OF THE DESERT: A COLLECTION OF 1/10 SCALE MODELS OF LATE JURASSIC MEXICAN MARINE REPTILES

by Marie-Céline Buchy and Héctor M. De La Paz Espinoza

Buchy, Marie-Céline and De La Paz Espinoza, Héctor M. 2010. Piñatas of the desert: a collection of 1/10 scale models of late Jurassic Mexican marine reptiles. *The Geological Curator* 9 (3): 161 - 168.

A decade of investigation of marine Upper Jurassic sediments in north-east Mexico has yielded a hitherto unknown marine reptile assemblage. Some of the specimens, including holotypes, are kept in collection at the Museo del Desierto, Saltillo, Coahuila, Mexico. On the occasion of the 10th anniversary of this institution, it was decided to create 3D life restorations of these animals (dubbed 'piñatas') at a 1/10 scale, consistent with current research about anatomy and life-style, using a variety of techniques and a restricted budget. The impact on the public is real and rewarding.

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Introduction

The Museo del Desierto, Saltillo, Coahuila, Mexico (Mude), is the largest Natural History Museum in Mexico. Its exhibitions explore the history of the Chihuahuan Desert, its long-gone fossil inhabitants, the archaeology of nomadic tribes and the more recent industrial past, its ecology, contemporary fauna and flora. In 2009, the Mude celebrated its 10th anniversary. Some of its original spirit may have been lost along the way, however its innovative architecture, design and location on an elevated suburb in the capital city of the State, giving an exceptional view towards the valley where the first human groups settled, all speak highly of the visionary mind of its creator, Lic. M.S. Cárdenas García and the excellence of the team she assembled around 10 years ago.

The new General Director wished to mark the 10-year anniversary of the Mude by exhibiting exceptional fossils from the region. Among these are undoubtedly the marine reptiles that populated the Late Jurassic Mexican Gulf, encountered both in Coahuila and neighbouring Nuevo León (see Buchy *et al.* 2006a, Buchy 2007, 2008, 2010, in press).

These were excavated or re-discovered during the last decade with financial support from the Deutsche Forschungsgemeinschaft (DFG), the Volkswagen Stiftung (VS) and the Consejo Estatal de Ciencia y Tecnología Coahuila (COECYT), as a collaboration between the Mude, the Universität Karlsruhe (Germany), the Staatliches Museum für Naturkunde Karlsruhe (SMNK), and the Universidad Autónoma de Nuevo León, Facultad de Ciencias de la Tierra at Linares (UANL-FCT).

Despite their scientific value, some of the fossils are fragmentary and of limited use as didactic tools, when the mission of the Mude is also to explain our science to the public, especially school children. In consultation with the Mude professional sculptor (HMDLPE), we decided to liberate ourselves from all these as much as possible, and base ourselves primarily upon the Mexican fossil remains to produce life models at a 1/10 scale to be exhibited with replicas of the original fossils and appropriate didactic material.

The 1/10 scale imposed itself when the size range of our cast of creatures was considered: from the potentially 2.5 m long *Cricosaurus saltillense* (Buchy *et al.* 2006b) to the 15 m long pliosaur nick-named 'The Monster of Aramberri' (Buchy *et al.* 2003).

When the project was in its nascent stages, these models were dubbed 'piñatas'. Piñatas may have a pre-Columbian origin as a Maya or Aztec game, and/or a Chinese origin brought to Italy and then Spain by Marco Polo; they were used by the Spaniards to christianise the Indians (Sandoval Linares 2004). Today, piñatas are colourful papier-mâché packets filled with confectionery, shaped to resemble icons from children's popular culture. The children beat the piñata during birthday parties to extract the sweets. We proudly kept this nick-name for the project because piñatas, with their hybrid origin, are very Mexican, as are these reptiles, and they enable children to have fun. Attempt at reconstructing past life is intimately bound to an epoch, its scientific and aesthetic references, and may be "beaten into pieces" by the criticism of future generations as well as of contemporary colleagues, and of course by the discovery of new fossils.

Material and methods

A variety of techniques and materials were used to produce the prototypes, according to the available material, tools and fluctuating budget. A likely reconstruction was scaled and printed on paper, in lateral and dorsal views. One was then cut out of Styrofoam; for others, both lateral and dorsal views were cut out in stiff cardboard, both pieces assembled at right angles and the voids filled with polyurethane (PU) foam; the largest ones were given a copper tube central chord, then given volume by layers of kitchen tissue and tape, or PU foam (Figure 1). The coating was a mix of polyester auto-repair putty ('Bondo') Doal and two component epoxy plasticine Bullton Hyplast 31, ground until the desired shape was attained. Generally, the 'Bondo' is softer, cheaper and dries more quickly than the epoxy plasticine, but its texture does not allow modelling. The limbs were usually outlined in cardboard, before being given volume with 'Bondo' and/or epoxy plasticine. Thin, soft tissue fins were cut out of PET foils and coated with epoxy plasticine. Several times the limbs were cut off and reglued in a better place or at a better angle. Most were held in place by inserting a metal wire between the body and the limb. Other details like teeth were modelled with epoxy plasticine. The texture of the skin was created according to the same 'whatever-we-have-here' procedure, knowing that very little is preserved in the fossil record about the skin texture of these animals. The Recent reptiles and crew of the herpetarium of the Desierto Viviente department of the Mude were also available when some details needed to be checked, like the pineal eye, the ear opening, or the mouth of live crocodiles from the inside.

Prototypes were cast using elastomer Elastosil Brenntag M 4512. Replicas were produced, either using 'Bondo' or liquid epoxy resin Plastiforma 33200 mixed with either talc or plaster (mostly to reduce costs). This is a time-consuming process because joints have to be ground, textures modelled again over the joints, teeth realigned, bubbles filled, etc.

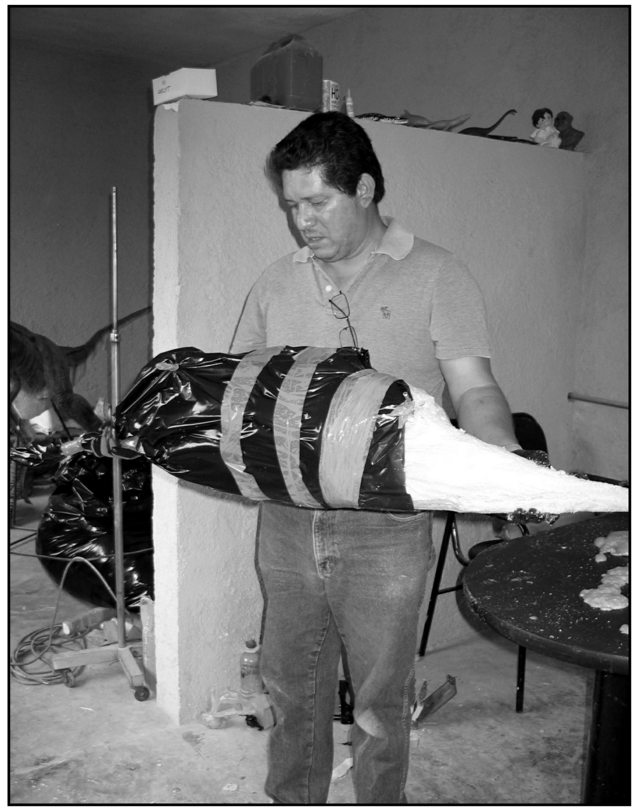


Figure 1: One of the authors (HMDLPE) and the 'piñata' of 'The Monster of Aramberri' in the making.

The replicas were painted using an air-brush and an array of colours, mostly dark-blue-grey or greenish for the back and milky-white for the belly, as Recent aquatic animals usually are, whatever their size. Patterns of fancy stripes were only allowed for the small forms, when it was considered that it is of no use to try to camouflage oneself when reaching 8 or 15 meters in length. The eyes were hand painted; for all forms, a vertical pupil was assumed, as possessed by Recent crocodiles, which allows better vision at low light levels (e.g. Walls 1942). As for the colour of the iris, we drew inspiration from Recent crocodiles for the thalattosuchians. Checking on various Recent reptiles, it appears that the eye colour matches the camouflage strategy of the body, which would have commanded painting the eyes of the remaining forms a dark blue-grey, when to our knowledge no Recent reptile has such an eye colour (but none has such a body colour either, none being exclusively marine). Moreover, it would have meant 'hiding' the eyes, and making them less obvious for the public to orient themselves, e.g. clearly with camouflaged eyes the elasmosaur head cannot be recognised as such by uneducated eyes (either in the museum of the present, or by its predators of the past). Therefore, as a didactic aid for the public, we decided on bright yellow eyes with some green and reddish stains, knowing that this very colour is unlikely to have been the real eye colour of these animals; for the ophthalmosaur, additionally, as an allusion to how fish-like it looks, a false, large 'eye' was painted on the tail fin. This is all part of the dialogue with the public when we comment upon the 'piñatas' (see Conclusions). The painted replica was coated with high-gloss varnish (Alce) to give it an aquatic feel.

The Cast

Ichthyosaurs

Some of the fossils are very visually striking, such as the large ichthyosaur from the El Sombrero Ranch south of Coahuila (cf. *Brachypterygius*, Buchy & López Oliva 2009; Figure 2); as far as explaining to children what an ichthyosaur was, it will suffice on its own once preparation is completed. Still, the forelimb of this specimen is incomplete, and was copied from the holotype *Brachypterygius* forelimb scaled to distal humerus width (see references in McGowan and Motani 2003). No hindlimb is known for the genus, so the forelimb was copied to a slightly smaller, narrower scale, according to what is known in *Ophthalmosaurus*. Based on the preserved portion of the fossil and missing parts, this 'piñata' is about 800 mm long.

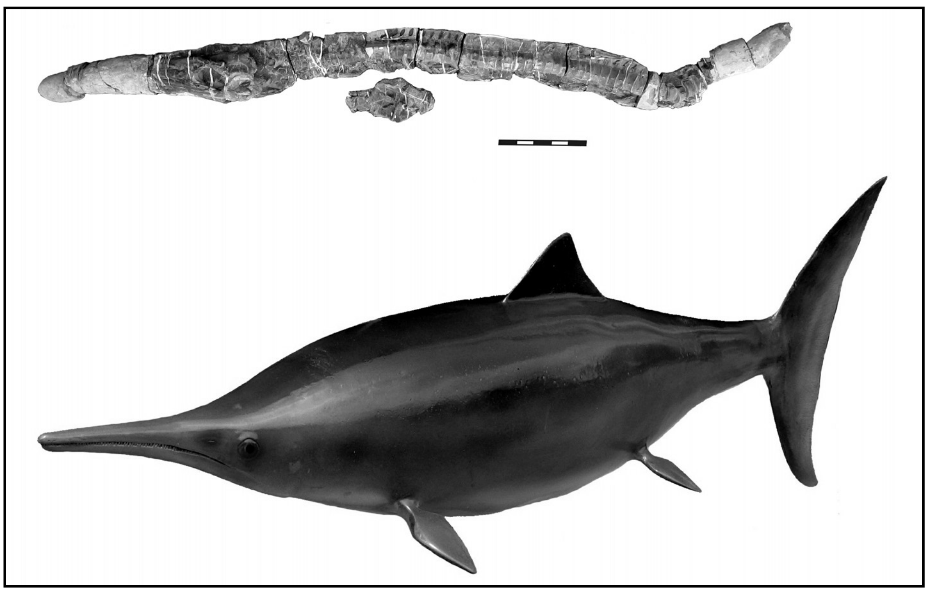


Figure 2: The El Sombrero Ranch ichthyosaur (cf.* Brachypterygius*) prior to completion of the preparation (note that preparation revealed that the last two blocks do not match anatomically the other fragments as depicted in the photo), scale 500 mm, and its 'piñata' (below), about 800 mm in length.

The ophthalmosaur skull from Gomez Farías, Coahuila (Buchy *et al.* 2006c; Buchy 2010) is complete (Figure 3), and allowed for scaling from a combination of already existing reconstructions following the review of biomechanical options and suggestions of Métayer (1995). We also modelled some new-born animals. The remains of several small individuals are known from the Gomez Farías site, which could indicate that the Mexican Gulf was a nursery for ophthalmosaurs (Buchy 2010). As for the size of these babies (70 mm in length), they were scaled to the size of the mother 'piñata' (about 400 mm) from complete new-borns from Holzmaden preserved associated with their mother (Hauff 1953).

Crocodiles

Other fossils are equally visually striking, but only to the experienced eye, such as *Cricosaurus saltillense* (Buchy *et al.* 2006b). The fossil comprises the post-orbital portion of the skull, and a few other bits (Figure 4). It was enough to create a new species, but too cryptic to introduce the general public to the marvellous realm of thalattosuchian crocodilians. Therefore, the body was taken from more complete fossils from Germany (Fraas 1902; Andrews 1913; and MCB *pers. obs*.), and the head modelled according to the fossil - or rather to an interpretation of the head of the fossil and more complete related forms (Andrews 1913; Vignaud 1995). Actually, the forelimb is too long according to the known preserved fossil material from abroad, which will have to be corrected in future copies. It is also to be noted that the Mexican species is characterised by its extremely long upper temporal fenestrae (Buchy *et al.* 2006b); possibly when the rostrum is found, it will prove to be longer than that of our reconstruction.

Mexican dakosaurs are known from two very fragmentary skulls (Figure 5), however, a reconstruction of the Argentinian 'Godzilla' (Gasparini *et al.* 2006, Pol & Gasparini 2009) published in print and on the Internet by the magazine National Geographic (in its December, 2005 issue) gave international fame to this poorly known genus (e.g. Young 2006; Andrade pers. com. 2009). From what is known of the Mexican forms at present, little can be said about them being similar to or different from European and Argentinian forms (Buchy *et al.* 2007; Buchy 2008). However, Mexico does have its own equivalent 'Godzilla' and it is expected that if it actually repre-

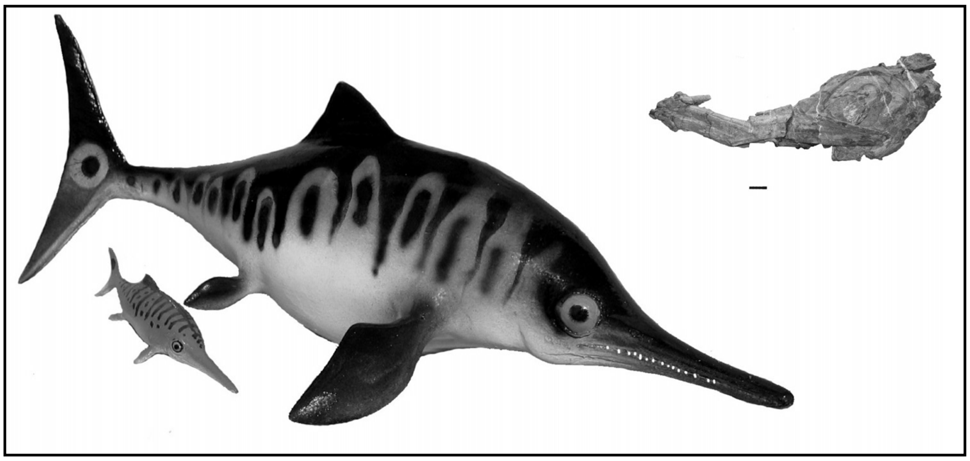
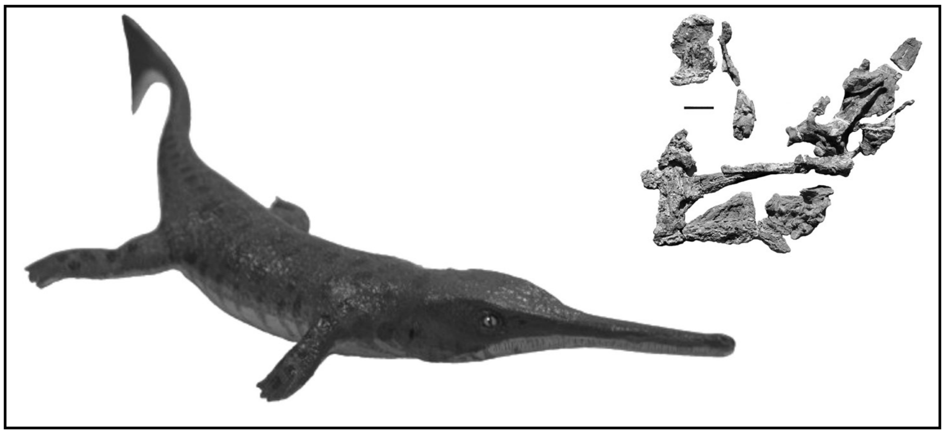


Figure 3: The Gomez Farías **Ophthalmosaurus** *cf.* **icenicus** *skull in left lateral view (top right, scale 50 mm), and our 'piñatas' (left): an adult (likely female, 400 mm) and new born (70 mm).*

Figure 4: **Cricosaurus saltillense**, *holotype CPC 218 in dorsal view (top right, scale 50 mm). The 'piñata' (left) is about 250 mm in length. The forelimb is too long and will be corrected; the rostrum might be too short (see text).*



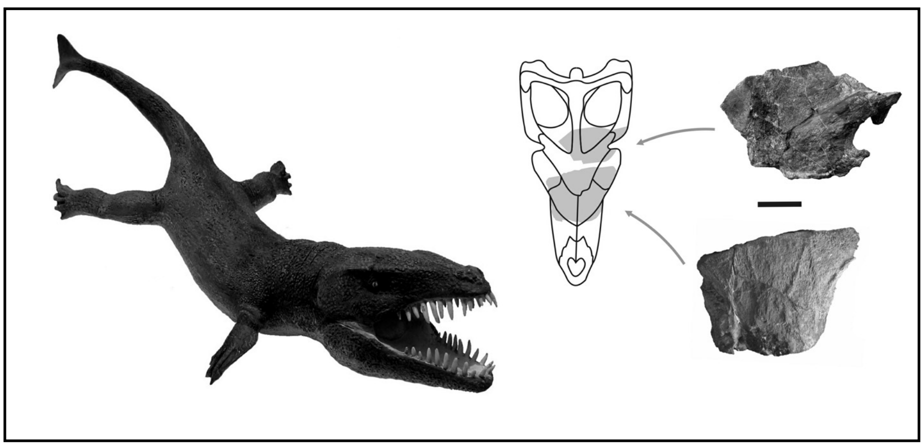


Figure 5: The two Mexican dakosaurs (scale 50 mm): UANL-FCT-R29 (top right) and CPC 201 (bottom right); their location on a sketch in dorsal view of the Argentinian form (middle, after Gasparini **et al.** *2006, not to scale). To the left is the Mexican Godzilla 'piñata', about 400 mm in length.*

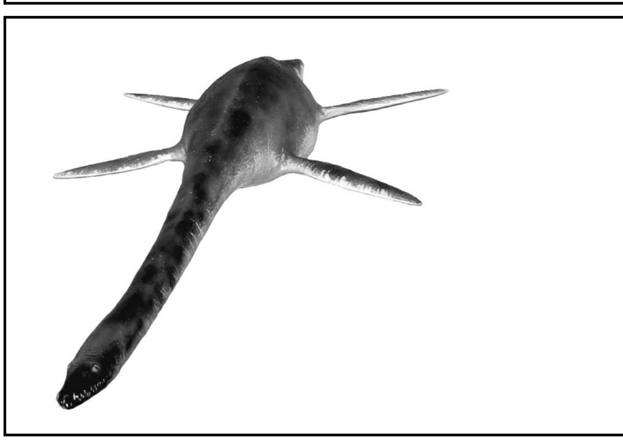


Figure 6: The elasmosaur 'piñata' (550 mm in length). The only known fossil material from the Late Jurassic Mexican Gulf are a few partial vertebrae.

sents a new species, it will differ in features that would not be easily visible on a life-reconstruction for a general audience at a 1/10 scale. Our reconstruction is mostly based on a partial skeleton described by Fraas (1902) and is in accordance with that produced by National Geographic after the discovery of Gasparini *et al.* (2006), which was based on the same scant fossil post-cranial material (Gasparini *pers. com*. 2009).

Plesiosaurs

Mexican elasmosaurs (Figure 6) are known from very fragmentary material (a few isolated vertebral centra; Buchy *et al.* 2006a, c). As for cryptoclidids, a fairly complete skull and partial neck discovered in Gomez Farías is currently under study, and repre-

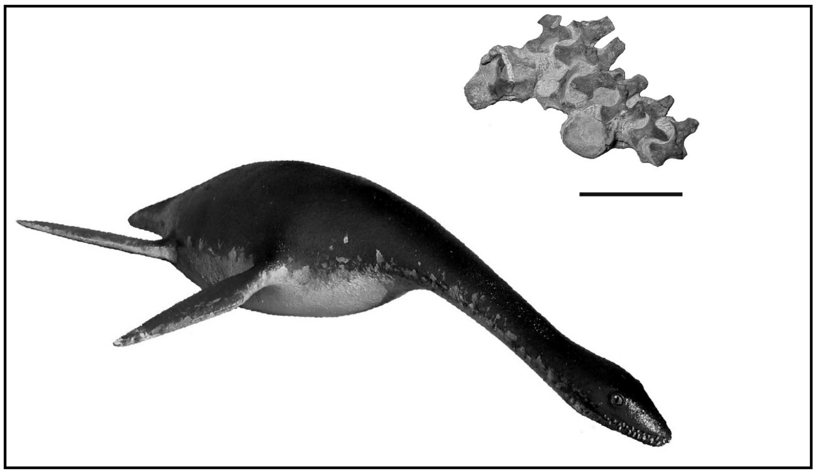


Figure 7: Three cervical centra and six articulated neural arches of the Gomez Farías cryptoclidid (and only Mexican one to date), scale 10 mm. Our 'piñata' of a cryptoclidid plesiosaur (below, 350 mm).

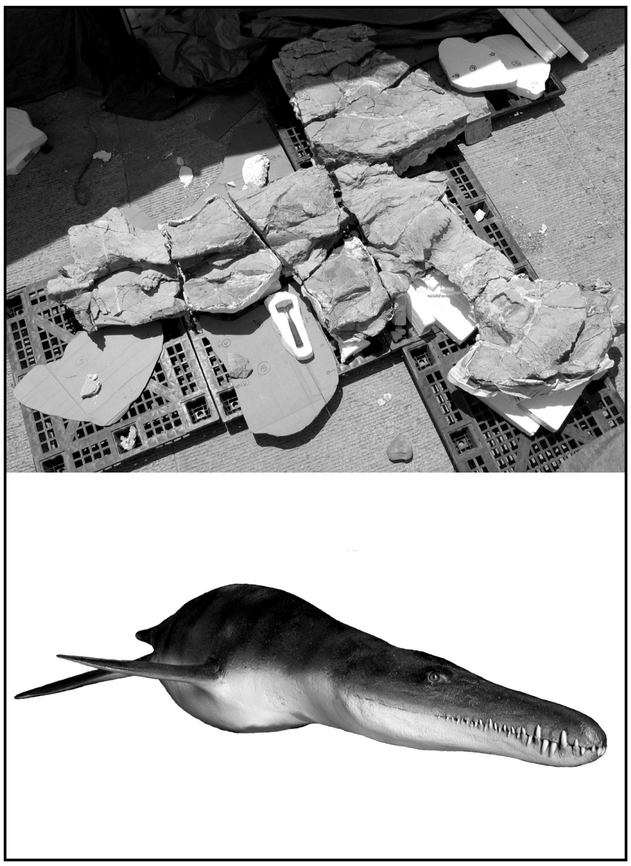


Figure 8: The right complete femur of 'The Monster of Aramberri' (UANL-FCT-R2, top), adjacent portions of girdle and articulated tibia and fibula, mounted prior to an exhibition; note the cardboard and Styrofoam pieces figuring the plaster jackets still awaiting preparation. Hammer for scale is 280 mm. Bottom, the 'Monster piñata', the largest of the series, with 1.5 m in length.

sents the only Mexican fossil referrable to the group at present (Buchy in prep.; Figure 7). Elasmosaurs and cryptoclidids are the groups that have probably recently undergone the most important changes in terms of how we view them as living animals, even if complete skeletons have been known since the dawn of palaeontology (Taylor 1997). Our poor understanding of their life-appearance is certainly due to their otherwise unknown 'Bauplan', that has no recorded equivalent, past or present (Williston 1914). For both groups, albeit more clearly for elasmosaurs, the analogy between the elongate neck and a snake has dominated popular reconstructions for most of the last two centuries (e.g. Everhart 2002, 2009), although the limited flexibility of the neck was argued for earlier in the scientific literature (Williston 1914). Several authors more or less independently came to recently re-examine the question, and slowly there emerged a picture of sediment-sieving elasmosaurs, and a diet partially reliant on sea floor invertebrates (and occasional vertebrates) in the shallow, soft substrate areas available following transgressive phases (Buchy 2005, 2006; McHenry *et al.* 2005; Noè 2006). For our 'piñatas', we followed the conviction of the senior author, still to be tested (see preliminary comments in Buchy 2005, 2006), that Williston (1914) was right about a rather stiff neck, that was more useful from the horizontal plane downwards, and likely little for lateral movements, when in addition to the volume and shape of the centra themselves (e.g. Zammit *et al.* 2008), the neural arches, shape, orientation and overlapping of the zygapophyses, and necessary soft parts are also considered. As for cryptoclidids, their life-style, in the shadow of their elasmosaurid cousins, has elicited little attention; it was considered that the flexibility of their neck was restricted as well (Figure 7), whether or not its function was similar.

Pliosaurs

Last but clearly not least, 'The Monster of Aramberri' is the largest 'piñata' of the series (1.5 m in length, Figure 8). This giant pliosaur (estimated at 15 m in length, Buchy *et al.* 2003) has a recent history of lost opportunities during the past two decades (Buchy 2007) which is likely to have resulted in the loss of most cranial material; although excavation of the rest of the specimen was completed in 2005, it is still partly awaiting preparation in plaster jackets at Mude, due to budget restrictions. Indeed, when 'The Monster' was first reassessed as a pliosaur and as

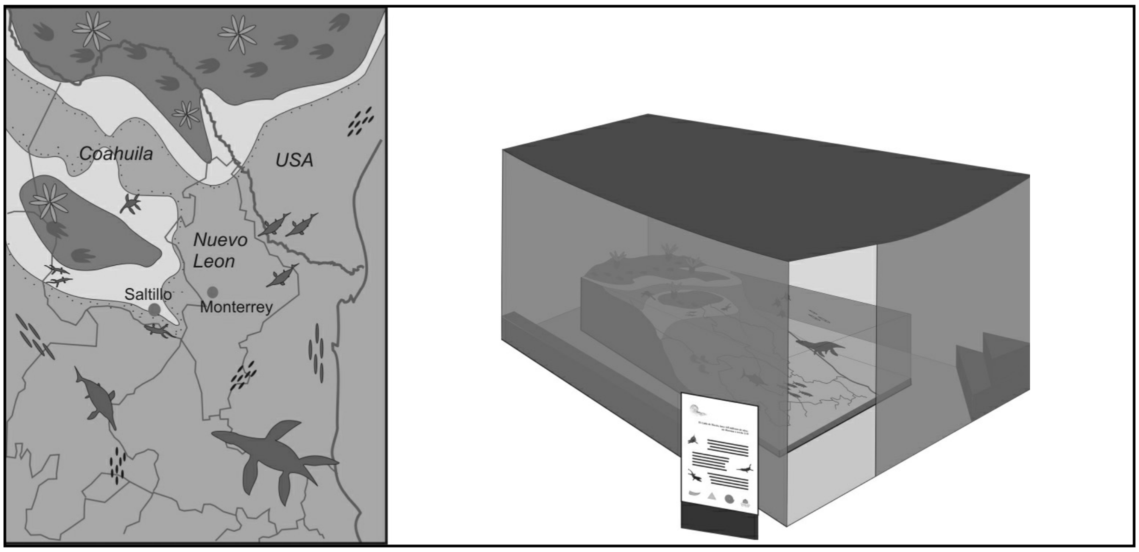


Figure 9: Sketches of a diorama of the Late Jurassic Mexican Gulf thought to house our 'piñatas' (note that fossil turtles are yet to be reported). The diorama is about 5*7 m; figured elements are at a 1/10 scale, whereas the palaeogeographical background is scaled to the dimension of the diorama from the palaeobiogeographical reconstruction of Goldhammer (1999). Right: the diorama from above; left: the diorama in a context where a dark tent allows a blue undulating light and audio to give a marine ambience, and steps allow the visitors (especially children) to view the diorama under different angles. All known fossiliferous sites are located to the south-east of the island north of Saltillo (also due to Cretaceous sediments cover); there, the most abundant reptile groups represented in the fossil record are ophthalmosaurs (of the 'small', cf. **Ophthtalmosaurus** ***type) and thalattosuchians (Buchy 2007). The diorama therefore considers several individuals of these taxa, and few of the elasmosaurs and cryptoclidids that likely were living in shallower facies further north (which would explain why their known remains are rare and fragmentary). Few also of the large beasts (cf.*** **Brachypterygius**, ***'The Monster') are considered, because they must have been rare in the fauna. Swarms of fishes (e.g. possible aspidorhynchids are known and await study) and invertebrates would fill the aesthetic gaps. Plant remains are numerous from some sites but are yet to be studied, whereas continental elements of the fauna are exceedingly rare, and merely symbolised by dinosaur footprints.***

such, the largest genuine specimen of its kind, however still awaiting excavation, preparation and study, the Mude released an exhibition featuring a 25-m long Mexican *Liopleurodon*. This exhibition is still travelling as it was, in the logic of commercial enterprises that cannot step back from the exaggerations they create to sell their products, but that, applied to the conservation of the palaeontological heritage of a country, appears counterproductive. As such, even if the body of the pliosaur is completely preserved, as are large parts of its limbs, the making of the 'piñata' hardly relied on it, except for the humerus and femur. We drew our inspiration from various publications about pliosaurs worldwide (e.g. Andrews 1913, White 1935, Romer & Lewis 1959, Noè 2001), personal observations and of course the plethora of pictures released on the Internet. Ironically, if 'The Monster' is the most famous fossil from the region (if we are to rely upon the comments of the visitors of the Mude), and the very one that triggered a decade of investigation of the previously unknown assemblages of north-east Mexican Late Jurassic marine reptiles (and also Late Cretaceous ones, see Buchy *et al.* 2005, Buchy 2007, Ifrim *et al.* 2008, Smith & Buchy 2008), its 'piñata' is the most fanciful of all. Recently, a couple of other very large pliosaurs of the same age were unearthed (Knutsen pers. com. 2008); therefore it is hoped that even if 'The Monster's' story stalls here, at least in other contexts, preparation and study will continue and yield crucial anatomical and physiological information about these giants (Buchy 2007).

Conclusions

The series of piñatas makes better sense when they are exhibited together, showing the size range and variety of marine reptiles from the Late Jurassic Mexican Gulf. The idea to integrate them within a diorama, together with other elements of the known fossil fauna and flora awaiting study, was a natural step (Figure 9). We also thought that they ultimately could be animated after further studies of the locomotive abilities of the fossil animals had been concluded. However, the 10th anniversary of the Mude was not celebrated by an exhibition of fossil treasures and their reconstructions; indeed, the anniversary was hardly celebrated at all. Still, the 'piñatas' were informally exhibited in the window linking the preparation laboratory of the palaeontology department and the public area of the Mude, where visitors see the fossils in preparation, and can ask questions that are answered on-the-spot by members of the crew. The comments and questions from the public were unexpectedly rewarding. One was for example about why, if this ophthalmosaur looks so much like a fish, do we say that it is a reptile in fact? Such a question clearly indicates the interest of the visitors for what is shown, the 'piñata' giving a much clearer idea of past life than the raw fossil next to it. On the other hand, the raw fossil next to the 'piñata' allows the crew member to show the very anatomical features that prove its reptilian nature. Such a question also demonstrates a lack of didactic material in the relevant area of the Mude, where not all visitors would dare to ask if they were in doubt: sometimes we need to trigger comments and questions. Similarly, for museums where such a direct contact between the public and scientists or technicians does not exist, it is strongly recommended to provide detailed explanations, not presuming the background of the public - otherwise the aim of exhibiting life reconstructions would be clearly missed.

Many comments were actually compliments and acknowledgements of our work (in general, from rescuing the palaeontological heritage of Coahuila to its preparation and bringing it to the knowledge of the general public, as well as devoting time to answer live questions). As we can hear what the visitors say when they sometimes do not realise it, we heard that 'The Monster of Aramberri' is 'the big reptile that ate the fossils' (from a 4 or so year old boy), and that the dakosaur looks like a lady's husband when he is angry. It is expected that the profession of 'palaeosculptor' has a whole future open and awaiting vocations, while palaeontologists will be asked more and more to advise on such reconstructions, including on features that can only be guessed at - and most likely with some friendly pressure to make them look as fierce as possible.

Acknowledgements

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THE SMITHSONIAN INSTITUTION'S EXHIBIT FOSSIL PREPARATION LAB VOLUNTEER TRAINING PROGRAMME PART I: DESIGN AND RECRUITMENT

by Steven J. Jabo, Abby Telfer, Matthew A. Brown, Peter Reser, Matthew E. Smith and Michael Holland

Jabo, S.J., Telfer, A., Brown, M.A., Reser, P., Smith, M.E., Holland, M. 2010. The Smithsonian Institution's exhibit fossil preparation lab Volunteer Training Programme. Part I: Design and recruitment. *The Geological Curator* 9 (3): 169 - 178.

The Smithsonian Institution, through a grant from the Smithsonian Women's Committee, implemented a programme during the fall and winter of 2008 to teach the basics of mechanical fossil preparation, moulding and casting to individuals seeking to work as volunteer preparators in the National Museum of Natural History's exhibit preparation lab, called FossiLab. Four outside preparators were contracted to conduct the instruction; two instructors taught two five-day sessions on molding and casting and two other instructors taught two six-day sessions on preparation. The Department of Paleobiology's (Paleobiology) curatorial staff instructed the groups in paleobotanical preparation and microfossil processing and picking. All instruction took place in FossiLab during public hours.

Registration for the programme was conducted via the department's web page where a detailed description of the work and the lab familiarized prospective students with the type of work they would be performing. They were also asked a series of self-evaluative questions in an attempt to filter out those who might not have the innate motor skills or temperament needed for the job. Those who were confident in their decision to volunteer were interviewed in FossiLab, and the majority of those then registered for the programme.

Twenty nine people, some new and some experienced, were trained. FossiLab is now staffed each day by as many as six volunteer preparators who perform a variety of tasks for Paleobiology. The number of weekly person-hours has tripled since the training. Continued, focused training on individual projects is carried on by the Vertebrate Paleontology Preparation Laboratory staff. Eighteen hours of videotape was recorded during the training and will be edited and made available via DVD and the internet.

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Introduction and background

FossiLab is a fossil preparation laboratory prominently located in the ancient life halls of the Smithsonian Institution's National Museum of Natural History. This glass-enclosed work space, originally nameless and built in 1987, was designed as a site where visitors could observe researchers and collections specialists making scientific discoveries and preparing fossils for research and display. Over its first five years of operation, the exhibit laboratory was in use seven days a week while the lab staff painstakingly excavated numerous skeletons of the Late Triassic dinosaur *Coelophysis bauri* from a ten-ton block of rock brought to the Museum from Ghost Ranch, New Mexico. Over twenty million tourists visited the Museum during that time span.

Unfortunately, due to a change of focus in the Department of Public Affairs, which was responsible for the lab, funding for this uniquely visible resource was cut in 1992. A major interior renovation, along with new external exhibit cases and a new name, culminated in the re-opening of FossiLab in 1995. The exhibitry around and inside FossiLab was designed for the explicit purpose to teach people something about fossils even if the lab was unoccupied. Basic information, such as, "What is a fossil? What kinds of fossils are there? Why are they important? What tools do we use?" is explained and illustrated in the external cases, and photographs of some of the Department of Paleobiology's (Paleobiology) field localities adorn the interior walls.

However, volunteer preparators and staff from Paleobiology only worked sporadically on large projects in FossiLab during the following twelve years. The lab was underutilized, rarely being open more than 20% of the time and almost never on weekends. Fossil preparation and conservation projects remained largely behind the scenes. As the Museum increasingly stressed public outreach in its mission and education goals over those same twelve years, this underutilization of FossiLab prompted the Director's Office to request that occupancy improve. Because there were not enough technicians within the department to fulfill this requirement, more trained volunteer preparators were needed.

We determined that approximately thirty-two new, part-time volunteer preparators, combined with the two or three existing ones, would be sufficient to staff FossiLab seven days a week and allow a variety of jobs to be performed. These new volunteers would be trained in the basic techniques of moulding and casting fossil specimens for research and display, mechanical fossil preparation for vertebrate and paleobotanical specimens and whatever other specialized techniques Paleobiology's research staff required. Training would take place in FossiLab during public hours. Because of the relatively small size of FossiLab and the limited number of available tools and preparation materials, the trainees would be split into two groups. Each group would be trained through a five-day course on moulding and casting, and a six-day course on preparation. External preparators were hired to conduct the training because the Vertebrate Paleontology Preparation Laboratory's (VP Lab) two preparators could not simultaneously train the volunteers and continue their other preparation and collections responsibilities.

Because of the dearth of published literature on the subject of volunteer preparation labs and the training that is necessary to make them successful, much of the planning was based on the VP Lab's long-time experience in training and supervising volunteers, as well as input from the outside preparators. We also solicited advice from preparators who run similar volunteer programmes at the Denver Museum of Nature and Science, the Academy of Natural Sciences in Philadelphia, The Field Museum in Chicago, the Carnegie Museum of Natural History in Pittsburgh, and the Royal Tyrrell Museum.

Setting up the FossiLab Training Programme

Grant support for $40,835 was sought and obtained from the Smithsonian Women's Committee - a granting entity within the Institution. This amount of money was calculated to cover the costs of travel, per diem and time compensation for the four external preparators, as well as the cost of all of the additional air scribes, compressed air and preparation supplies needed for the course. To find preparators to teach the courses, the proposed programme was advertised on "PREPLIST", the Society of Vertebrate Paleontology's fossil preparator's email distribution list. To help diversify the activities taking place in the lab, Paleobiology's research staff were asked if they had any volunteer tasks that required specialized training and if they would assist in teaching the techniques. This would also take some of the pressure off of the Vertebrate Paleontology staff to provide all of the projects. Advertising for potential volunteers was put on the web pages of the Department of Paleobiology, the Museum, and the Smithsonian Institution Visitor Information and Associates' Reception Center. Flyers were posted in the FossiLab windows and at the headquarters of the American Association for the Advancement of Science and the National Science Foundation. Notices were also sent to local fossil and geology clubs and science writers' associations. Supplies and equipment were ordered, and FossiLab was readied for the courses.

Recruiting the preparators

Through the PREPLIST advertisement, P. Reser and M. Holland were recruited to teach the moulding and casting course, and M. Brown and M. Smith to teach the preparation course. All four are experienced in mechanical preparation, moulding and casting. General outlines of the basic techniques to be taught and a list of the materials the VP Lab generally uses were provided and the instructors developed their own syllabi - playing to their strengths and comfort zones. Safety aspects were to be stressed in every procedure they were teaching. The instructors were responsible for developing a practical exam for the students and for providing a full evaluation of each student at the end of the course (Brown *et al.* 2010).

Finding the students

There are a few recurring obstacles that volunteer programmes encounter. One problem is a high turnover rate. A lot of time and effort goes into training volunteers, and then after a short while they leave for a variety of reasons; many move, lose interest, or get a full-time job. Another difficulty is high enthusiasm but a low skill level. A volunteer may be prompt and dedicated and a nice person, but might not have the skills required to be a good preparator, leading to a difficult management decision. Another is sporadic attendance; someone might be a great preparator, but they just cannot consistently come in and can never complete a project.

We used several methods in the application process to reduce the likelihood of these problems occurring:

▪ A course fee was charged. It has been found that students are more invested in a training course if they pay a fee. The fee was enough to let them know that they were going to get significant training, but not so much that it created a hardship - and it was negotiable for those of lesser means. The fee was set at $200 per student for the whole course. This additional money went into a discretionary fund for future supplies.

▪ The courses were offered to existing volunteers seeking to hone their skills.

▪ The applicants were pre-screened through a detailed online application process (Appendix 1), which also let them know that this was a serious endeavor. The pre-screening included giving them a thorough, realistic description of the work and lab environment. This included the tools they would be using, the need to wear a dust mask and other protective equipment, that everything they do will be closely watched and that there will be constant activity outside the glass.

▪ The applicants filled out a self evaluation form to reflect on whether or not they had the aptitude to become a preparator. Some characteristics of a successful preparator were listed:

- patient, careful, observant, and coordinated
- willing to take direction and work independently
- able to see well with or without glasses and have good depth perception
- able to sit or stand for long periods of time.

▪ Each applicant was asked to commit to working at least five hours per week, to occasionally work weekends, and to volunteer for at least one year.

▪ Finally, each applicant was interviewed in FossiLab during visiting hours. This let them see and get a sense of the lab setup and a feel for being watched by the public. It was also a chance for a face-to-face, eye-to-eye talk with them. (Appendix 2)

The application and interview sessions allowed us to identify 30% of the applicants as unsuitable candidates. These applicants probably would not have been detected using the previous method of enrollment: first come, first served. Some prospective students did not initially understand the level of commitment that was required, or the necessity of actually being in Washington, DC for the programme, or what tools and chemicals they would actually be using.

Equipping FossiLab

Prior to the start of the course, FossiLab went through a major cleanup and a wide variety of specimens and matrices on which to train the volunteers was gathered (Figure 1).

Extra departmental dissecting microscopes were gathered and portable partitions were constructed from PVC pipe and plastic wrap to place between the preparators to confine flying rock chips. The PaleoTools vendor booth display at many of the Society of Vertebrate Paleontology annual meetings influenced the idea to get CO_2 tanks and make splitters to run two air scribes from each tank so a total of eight scribes could work at the same time (Figure 2). At the time of the training, FossiLab did not have a vacuum pump or chamber, so P. Reser provided a portable, fast-cycling vacuum pump and chamber for silicone rubber moulding and a pressure pot for resin casting to enable students to rapidly process their projects reducing a bottle-neck in work flow (Figure 3).

Training

The classes ran from approximately 9 AM to 4:30 PM, with an hour lunch break. The first morning of each course consisted of an introductory talk by the consultants and a tour of the labs and collections. After that, all of the training was done in FossiLab during public hours so the thousands of tourists passing through each day could watch (Figure 4).

Two of the key items used in the training were the FossiLab's video camera and monitor. These were

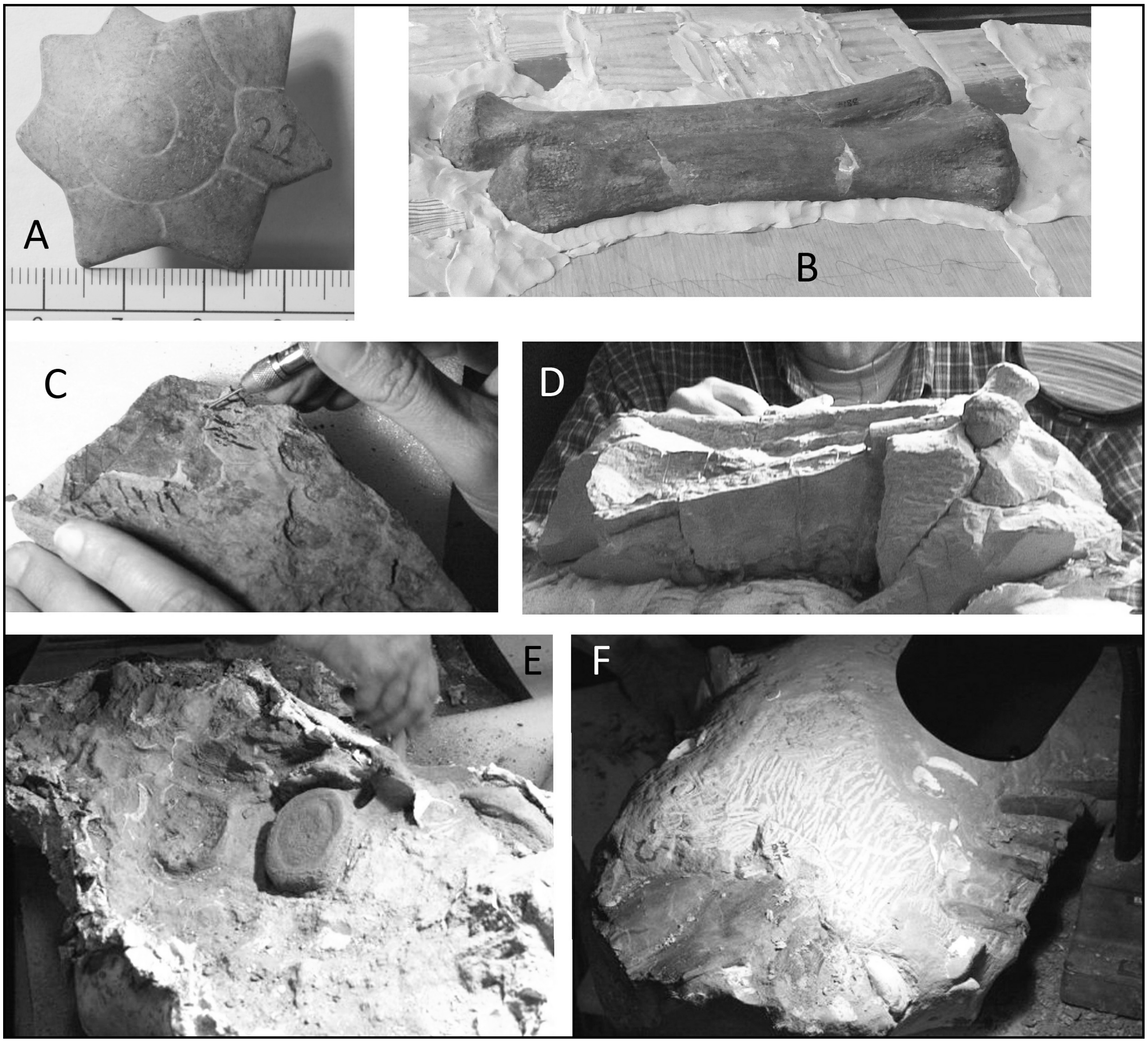

Figure 1. Some of the specimens used during the training: A. large-scale foram models from the 1800's for simple, two-part block molds (centimeter scale); B. hadrosaur carpal bones for large-scale layup moulds; C. one of the paleobotanical specimens used for air scribe training; D. a White River Formation (Late Eocene/Early Oligocene) entelodont for relatively easy air scribe work; E. a Miocene whale for opening jackets and soft sediment prep with hand tools; and F. a Miocene nodule containing a partial seal skeleton in extremely hard matrix for hammer and chisel and air scribe work.

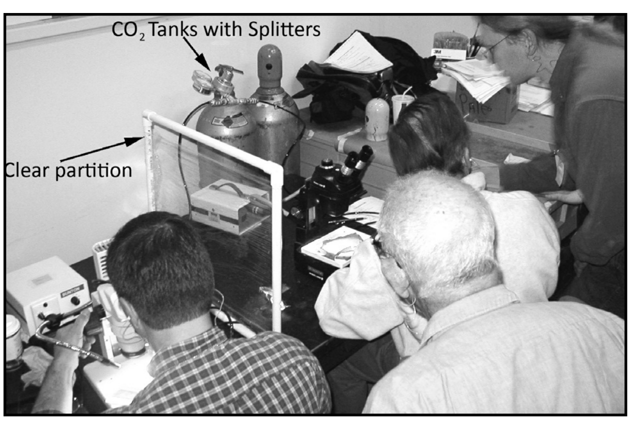

Figure 2. Training workstations with binocular dissecting microscopes and directional fiber-optic lights, air scribes, portable partitions made of PVC and plastic wrap, and CO_2 tanks with splitters to run two tools off of each tank.

used to display intricate work on the hi-definition monitor so that all of the students could see it clearly (Figure 5). All of the different processes covered in the training were also video-taped in anticipation of creating a training video. Brown *et al.* (this volume) further discuss the preparation training techniques and preparation practical exam development and implementation.

Discussion

The self evaluations and interviews during the registration process allowed us to exclude some of the personalities that would not be suitable for this type of work and those on whom the training would have been wasted. Determining *a priori* which candidates will make good preparators is an impossible task. At

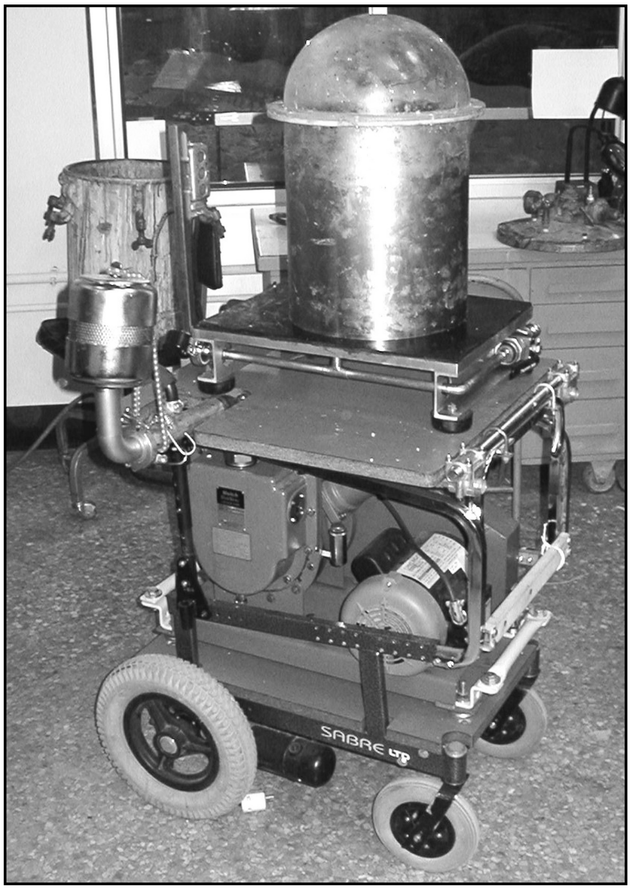

Figure 3. Because FossiLab did not contain them, P. Reser's fast-cycling portable vacuum chamber and pump, which is more efficient than those found in most labs, was brought in for the training. A pressure pot, also used in the resin casting, is visible in the left background.

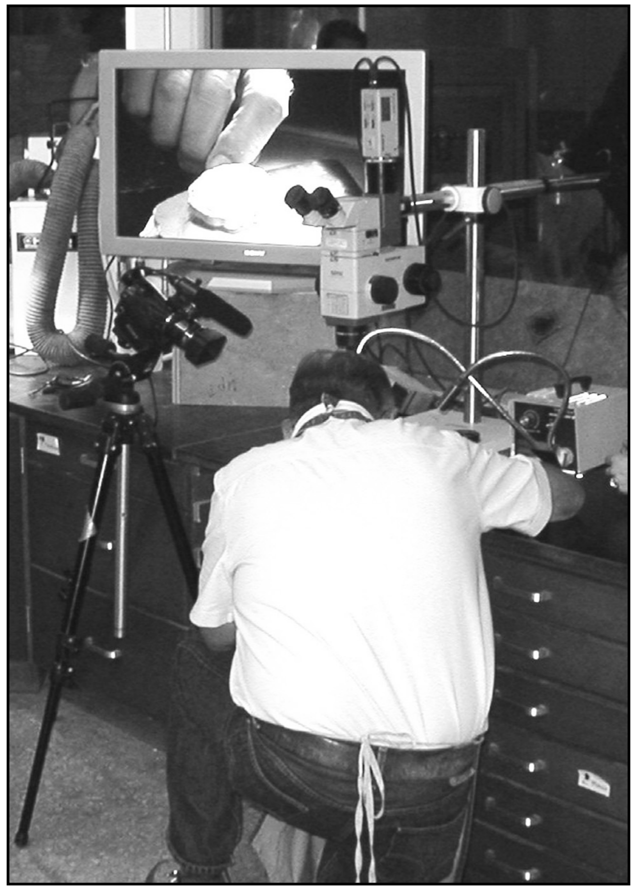

Figure 5. Using the digital camera and monitor for teaching purposes. As P. Reser sets up a small, intricate mould, the camera to his left is trained on his hands, and is simultaneously recording his actions and displaying them on the high-definition monitor so that all students can clearly see his work.

Figure 4. Moulding and casting training while the public watches (behind the glass window in the background).

the least, an attempt was made by the organizers to gauge people's realistic commitment to the job, whether or not they had reasonable personalities, and whether or not they were going to be physically capable of doing the work. There was general success in doing this. Students who participated in the programme demonstrated the ability to take instruction, respect the learning process, and not to "know" more than the instructor. This is important for a successful learning experience.

The programme syllabi are a good starting point for creating a curriculum for future preparator training, and can be modified based on the types of work required and available materials. As extra bonuses, one course participant is producing an illustrated handbook detailing the moulding and casting techniques. It will be used as an in-house training guide and will eventually be available on the internet. Another participant is editing eighteen hours of raw training footage down to individual instructional videos to be used in the training of future volunteers, available both in-house and on the internet.

There was also a chance to practice the emergency procedures when a volunteer collapsed and would not regain consciousness. Emergency Medical Technicians took her to the hospital, where she fully recovered and came back to volunteer. This demonstrated the importance of having an emergency plan in place before the courses began.

Subsequent discussions between the co-authors revealed and highlighted several important topics regarding exhibit preparation labs. As noted by Gavigan (2009), these types of labs are becoming increasingly popular because of the guaranteed visitor interest and positive comments they generate. As more and more public labs are started up, there may be a correspondingly larger number of volunteers needed to staff them if there are not enough in-house professional staff. Exhibit preparation labs also fulfill a more common requirement of public institutions to develop more public outreach programmes and materials. The benefits of these programmes are plentiful. The volunteers act as a liaison between museums and the general public. They foster a larger public understanding of lab procedures and the necessity for them. They create larger public support for the museum, more informed audiences for all sorts of museum events, and the expectation that people should know more about this area of expertise. And, hopefully, more quality research preparation will get accomplished to help further the field of paleontology.

FossiLab furthers the public outreach goals of the Department of Paleobiology at the National Museum of Natural History by making visitors aware of the Museum's active research programmes and providing visitors with opportunities to interact with scientists, both in person and through their volunteer stand-ins. Signs inside the lab inform the public about the projects being worked on. Communicating with the observing public is too complex and nuanced an issue for this discussion and we leave it for a future effort. Tours for the public and after-hours functions often take place in and around FossiLab.

To reap the full benefits of public preparation labs staffed with volunteers, museums should consider a few factors that are crucial to their continuance. Institutional backing is the most fundamental element in establishing a long-term and successful lab programme. The management must completely support the idea of having a lab like this and then make a continued effort to keep it viable. This includes providing the lab's infrastructure in terms of space and security, hiring managerial staff, and providing ongoing funding for supplies and equipment. It is not sufficient to just find an empty corner of exhibit space and create a makeshift lab and throw a few people in there to work. The space should, to some point, mirror any behind-the-scenes lab in terms of equipment - including safety equipment - and supplies. Conversely, it may be possible to have only one lab that serves both exhibition and research functions, to erase the conceptual division between display and function if the building architecture will safely allow it. Gavigan (2009) recommends a full-time lab manager for any lab because it is a full-time job keeping track of the projects, schedules, supplies and general needs of the volunteers. Experience has shown that assigning to an existing staff member the task of managing a volunteer lab as a "side" project prohibits them from being able to dedicate the proper amount of time to both labs and whatever other departmental responsibilities they may have. Invariably, exhibit lab time is sacrificed in favour of departmental priorities.

The funding to operate a lab may come from several overlapping areas of an institution: 1. the research department for whom the work is being provided; 2. any sort of Office of Public Programmes or Education that would supply educational materials, docents, carts, etc; and 3. the Exhibits Department that might fabricate signs or cabinets and supply audio/visual equipment and external exhibitry associated with the lab. Funding for the ongoing mission of an exhibit lab theoretically should come from each of these entities within the Institution, but a fourth stream of funding - and often the most flexible - comes from the goodwill of such groups as "museum friends" or, as in this case, the Smithsonian Women's Committee. Wherever the money comes from, a significant portion must go back into constant training courses and exercises for both new and veteran personnel.

Another essential requirement of any successful prep lab is that the purpose and goals of the lab must be well defined. This is important in guiding the expectations of museum staff members. Should the exhibit lab provide quality research preparation on collection specimens and the public gets to watch, or is its purpose mainly to demonstrate to the public different lab techniques with less important specimens? If an institution maintains two types of labs, there has to be constant communication and positive interaction between the two, not competition. Their missions are not quite the same - research preparation versus preparation demonstration and edification - but they use the same processes, and require the same resources and mostly the same expertise. Should the exhibit lab be populated with formally trained staff, or with personnel from another part of the institution who have been temporarily assigned there? Are docents and explainers necessary, or are they just icing on the cake? In the Smithsonian's case, they are more than icing on the cake. The docents talk to the public and help them understand what is going on behind the glass at FossiLab, providing additional educational content for the public and making their visit much more satisfying.

An important point to consider is that, over time, volunteers who work together create their own social community and political entity; their requirements and issues must be recognized by the permanent staff, starting with the lab manager and ending with the head office of the organization. Productive volunteers must feel that they are doing "real" work, that they are part of the larger mission of the institution, and that the institution cares about them. Face-to-face time with the permanent staff is the best way to convey this, through extra mentoring. It works both ways: the relationship between the professional staff and the volunteers is symbiotic. As professionals train the volunteers in the various preparation techniques, there is pressure on the professional staff to keep their own skills honed and constantly refined because of volunteers asking questions and requiring detailed explanations. It is not unknown for a member of the staff to have started their career as a volunteer in an exhibit lab.

Conclusions

Everyone involved in the training - from the Department of Paleobiology staff, to the instructors, and all of the volunteers - regard this programme as a great success. A total of twenty-nine participants registered and all of them completed the training. This number was very near the thirty-two that were estimated to be needed for staffing, and they have in fact, along with our previous FossiLab volunteers, successfully formed the corps of personnel staffing the lab. The time span between the last day of the training session and the first day of volunteering in FossiLab was around three months due to the Christmas and New Year's holidays, more FossiLab renovations and equipment procurement necessary to accommodate all of the new volunteers, the time to devise a complex scheduling arrangement, and the time to obtain security clearances and ID badges. When the volunteers returned to start each of their projects they were walked through the entire process again, and all seemed able to recall most of the information they had learned and only needed minor instruction here and there. Volunteers were hand-picked for all of the projects based on the practical exams, the instructors' evaluations (Brown *et al.* 2010, Appendix 2), the students' post-training self-evaluations (Appendix 3), as well as personal observation. The occupancy of FossiLab during visiting hours has greatly expanded from around thirty person-hours per week to over one hundred person-hours. There are at least two, and sometimes up to six, volunteers working at a time, seven days a week. The projects they are working on cover vertebrate and paleobotanical fossil preparation, moulding and casting, microfossil washing and sorting, explaining the FossiLab work to the visitors, making padded plaster storage jackets (Jabo *et al.* 2006), and photo-documenting the collections specimens. The evaluations are still used to match people and projects. If it is difficult to match a volunteer with a preparation project, he or she can still talk to the public outside the glass about what the others are doing inside FossiLab. Instruction and evaluation continue with each volunteer to increase their skill levels and productivity, as well as to increase the chances that the long-term success of FossiLab is realized.

Though the training programme was regarded a success in the short term, the real level of success will not be defined for five or ten years after the training. However, some early calculations can be made about the rate of retention of trained volunteers. Of the twenty-nine volunteers, only three were unable to fulfill their commitment to work for one year following the training, and their reasons for leaving were moving away from the region and health. Though they were never asked outright to provide their ages, except to meet the minimum age requirement of eighteen years, the students ranged from their mid-twenties to the mid-eighties with an estimated median age of fifty-three. Approximately 65% were retired or did not have full-time jobs. Twenty months after the training, 62% of the trained volunteers are still working in FossiLab, with 54% working regular weekly shifts of about six hours. This is actually quite good for the Washington, DC area, which consists of a fairly transient population base. Though hard numbers have never been historically documented, anecdotally, this is a better retention rate than has been previously encountered by the VP Lab. Younger students and those with full-time jobs were preferentially lost, which follows an observed trend in preparation lab volunteerism. Common sense points to those who are retired or not fully employed to have less demands on their free time, resulting in more opportunities to volunteer.

The lab is well defined as a place where genuine research preparation will get done, so the research staff has an interest in keeping it running. It is difficult to determine at a relatively early stage if, in addition to being accomplished quicker, additional research is actually being driven by the extra volunteers. A lab coordinator has been hired, at least temporarily, for project and scheduling oversight, and it is hoped that more training programmes can be accomplished down the line and the experienced volunteers can start taking new personnel under their wings.

Acknowledgements

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APPENDIX 1 - Online Application and Pre-screening Process

FossiLab Volunteer and Training Program Application

Last Name:
First Name:
Age:
Email Address:
Daytime Phone Number (include area code):
Evening Phone Number (include area code):
Mailing Address:
P.O. Box, or Street Address and Apartment No.
City , State and Zip Code

Permanent address, if different from above:
P.O. Box, or Street Address and Apartment No.

City , State and Zip Code

Why do you want to volunteer to work on fossils in FossiLab?

If you have previous experience collecting, handling, or preparing fossils, please describe.

References (list two people who know you well):

FossiLab Volunteer Requirements
FossiLab volunteers work during museum hours. The Museum is open daily 10AM - 5:30PM or 10AM - 7:30PM, depending on the time of year. FossiLab scheduling is very flexible, but please note:

- Volunteers are required to work an average of at least 5 hours per week. Because of the necessary setup and cleanup time, it is not practical to schedule work sessions shorter than 2 hours. There is no upper limit to the length of a work session, nor to the number of sessions scheduled per week or month.

- Volunteers will be asked to schedule occasional weekend hours, perhaps as often as once per month

Please indicate the days and times when you would be willing to volunteer in FossiLab. This is not a scheduling commitment, but rather a question about your preferences and availability.

Preferred days: "weekends", "weekdays, with occasional weekends", "no preference"

Preferred hours: "mornings and/or early afternoons", "afternoons", "late afternoons and/or early evenings", "no preference"

Please indicate how many hours per week, on average, you would like to work: "5-9", "10-14", "15 or more"

Do you commit to volunteering for 1 year? "Yes", "No"
Do you anticipate volunteering for 2 years?
"Yes", "No", "Likely", "Unlikely"
Do you anticipate volunteering 3 years or longer? "Yes", "No", "Likely", "Unlikely"

To work successfully with fossils you must be:

- patient and slow to frustrate - work proceeds SLOWLY and large projects can take a VERY long time
- careful, observant, steady handed, and coordinated- a 100 million year old dinosaur bone collected in Madagascar cannot be replaced, and even "common" fossils have scientific value that requires care to preserve
- willing to take direction from staff and then work independently
- comfortable stopping what you are doing to ask advice about your work when something "seems different" or when something unexpected happens
- able to see well (glasses are ok) and have good depth perception
- able to sit or stand for long periods of time

If you are not certain that you have all of the characteristics listed above, please honestly describe your doubts below. We may be able to accommodate some types of physical limitations.

Working in front of the public in FossiLab is a unique experience. Your picture will be taken many times a day, almost everything you do will be observed, and there will be constant activity outside the glass. While many volunteers adjust to this environment quickly, tuning out their surroundings so that they can focus on their work, some are more comfortable volunteering elsewhere in the museum, or "behind the scenes".

Do you think you would be:

1. comfortable working under close observation, and
2. able to focus on your work despite the distractions?

"yes", "no"

Some FossiLab projects generate a lot of dust. Since long term exposure to rock dust can be hazardous, dust masks are supplied and their use is required whenever anyone is generating dust in the lab. Other common sense rules must be followed to limit everyone's exposure to dust; dust collectors and vacuums should be used, and work areas should be kept clean.

Are you willing to wear a dust mask and work to limit others' exposure to rock and plaster dust? "yes", "no"

Education, Employment and Volunteer History
List any colleges or universities attended, degrees obtained, and major and minor fields of study.

School: Degree: Fields of Study:

If you are still working toward a degree, when will you graduate (mm/yy) ?

Please describe briefly how you learn about science and nature, and what topics interest you most.

If you have you taken the Paleobiology Training Program offered by the National Museum of Natural History's Paleobiology Department, please enter the year(s) in which you took the course.
If you have had docent or volunteer training at NMNH or at another natural history museum, please describe.

Work Experience
If you have held jobs that required the use of your hands, please describe the jobs, how you used your hands, what tools you used, if any, how long you held the jobs, and how long ago you did this work.
Which of the full and part time jobs that you have held since you were a teenager have you enjoyed the most? Why?

Volunteer Experience
Please describe your major volunteer experiences including the organization, your duties (be sure to note if you work(ed) with your hands at all), how many hours worked per week, how many months or years worked, and whether you are still working for this organization.

How do you spend your free time?
Do you enjoy creating art, working with your hands to make or build things, or taking apart/repairing things?

Describe, in detail, any activities you have spent a lot of time doing, either as an adult or as a teenager, that require(d) handwork or the use of any type of hand tools, needles, knives, etc.

Use this box to describe the things you have made (or fixed), small or large, that you are most proud of.

Volunteers who enjoy preparing fossils tend, also, to engage in leisure activities

- requiring patience and planning, such as bridge or chess, or
- requiring close attention to visual cues, such as solving jigsaw puzzles or mazes, playing video games or reading music, or
- involving intense and sustained appreciation of nature, such as hiking, bird watching, or collecting natural history specimens

Please describe activities you enjoy regularly (or did at another time in your life) which might indicate that you have similar qualities.

APPENDIX 2
FossiLab Interview Questions

Will you be comfortable working in this environment?
In front of public
conditions inside

Do you prefer to work alone or as part of a team? Describe yourself as a coworker.

Describe the supervision you've had as a volunteer. Did that work well for you? What do you need from a supervisor?
· willing to take direction from staff and then work independently
· comfortable stopping what you are doing to ask advice about your work when
something "seems different" or when something unexpected happens

Describe your temperament.
patient and slow to frustrate, careful, observant

What would you like to be doing 5 years from now? Is a long term commitment realistic?

Do you really have the time to take the course and to volunteer regularly?

Do you have the support of your employer/family to volunteer (and commit long term)?

Between showing candidates around FossiLab, describing the course, and trying to get answers to these questions, each interview took about 45 minutes.

APPENDIX 3
FossiLab Training Program Self-Assessment

FossiLab Training Program Self-Assessment of Skills and Interest

For each task below, please tell us how confident you feel (recognizing that you are a beginner) about your ability to do the job.
Use "1" if you feel like you "really get it", and "5" if you feel like you "need a lot more instruction and practice."

Making Molds	1	2	3	4	5
Making Casts	1	2	3	4	5
Preparing Leaves	1	2	3	4	5
Preparing Bones	1	2	3	4	5
Washing Sediment	1	2	3	4	5
Picking Microfossils	1	2	3	4	5

For each task below, tell us how much you enjoy it. Use "1" if you say, "Let me at it! I gotta do it!"
Use "5" if, when the job needs doing, you'll suddenly need to go home to walk your dog.

Making Molds	1	2	3	4	5
Making Casts	1	2	3	4	5
Preparing Leaves	1	2	3	4	5
Preparing Bones	1	2	3	4	5
Washing Sediment	1	2	3	4	5
Picking Microfossils	1	2	3	4	5
Making Storage Jackets	1	2	3	4	5
Interacting with Visitors	1	2	3	4	5

Please describe what you don't like about any that rate 3-5.

THE SMITHSONIAN INSTITUTION'S EXHIBIT FOSSIL PREPARATION LAB VOLUNTEER TRAINING PROGRAMME, PART II: TRAINING AND EVALUATING STUDENT PREPARATORS

by Matthew Brown, Matthew Smith, Steve Jabo and Abby Telfer

Brown, M., Smith, M., Jabo, S. and Telfer, A. 2010. The Smithsonian Institution's exhibit fossil preparation lab Volunteer Training Programme, part II: Training and evaluating student preparators. *The Geological Curator* 9 (3): 179 - 186.

In November and December of 2008, the National Museum of Natural History hosted a training course for instruction of paleontological preparation methods in order to build a large pool of volunteers for the FossiLab public exhibition. Through a grant from the Smithsonian Women's Committee, the Department of Paleobiology funded four weeks of intensive, hands-on training for a group of 29 volunteers in moulding, casting and fossil preparation methods. Contracted instructors worked with institutional staff to create a curriculum for training specific tasks, as well as to create general knowledge of preparation methods. Classes consisted of lecture, demonstration, and hands-on components. Instructors monitored the students throughout the instruction period, and concluded the programme with written and practical examinations. The instructors provided written evaluations for each student and presented recommendations for placement with specific tasks within the department. After the conclusion of the programme students retained much of their instruction and have gone on to successfully keep the preparation laboratory staffed while preparing fossils for the visiting public.

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Introduction

FossiLab is a public exhibition preparation facility in the National Museum of Natural History, designed to demonstrate the process of fossil preparation to museum visitors (Figure 1). It was created because Smithsonian Institution administration and Department of Paleobiology (Paleobiology) staff desired to increase worker presence in the lab, yet permanent staff duties were already obligated in other parts of the institution. A grant from the Smithsonian Women's Committee thus enabled the creation of a volunteer training programme to greatly increase numbers of productive and visible workers (Jabo *et al.* this volume).

Students were recruited from multiple venues, screened based on self-evaluations and in-lab interviews, and a total of 29 were accepted and trained during the fall of 2008 (Jabo *et al.* this volume). Training sessions were divided into two sections, a five-day course in moulding and casting, and a six-day course in preparation methods. Michael Holland and Pete Reser were contracted to lead the moulding and casting section, and M. Brown and M. Smith led the preparation course. Instructors developed a curriculum based on input from Paleobiology staff members. The department indicated specific tasks they would like students to accomplish within FossiLab and the students were given basic instruction in a wide array of methods to achieve those goals. Both courses created methods for evaluation and critique of student abilities; the process for creating the preparation course is the topic of this paper.

Background

There are currently no widely accepted training programmes for fossil preparation in North America (Brown and Kane 2008; Brown 2009), though some institutions have semi-formal or formal programmes of instruction (Johnson 2001; Anné 2006; Carpenter

Figure 1. The Smithsonian Institution FossiLab, filled with trainee fossil preparators.

2006; Moore- Moauro *et al.* 2006; Brown *et al.* 2008, SDSMT 2010). The Smithsonian programme had a similar goal to the mandatory Denver Museum of Nature and Science preparation class that "weeds out volunteers who discover the romance of preparation is not reality, and gets volunteers up to a certain level of competency for integration with more seasoned lab volunteers" (Carpenter 2006:47A). Creating Master Preparators was well beyond the scope of this programme, rather, providing a consistent knowledge base among the volunteer pool and teaching them when and how to ask questions was the goal. Both preparation instructors have had experience training volunteers, students, and new employees in a variety of lab environments, including one formal, academically accredited, joint programme run between California State University, San Bernardino and Petrified Forest National Park (Brown *et al.* 2008).

Methods

Development

We developed a curriculum for training students based partially on the research needs of Paleobiology, and partially modified from the teaching plan used for the San Bernardino/Petrified Forest programme. Students were instructed in lab safety, record keeping, tool maintenance, and methods for preparing fossils used commonly in departmental projects (Table 1). Paleobiology staff selected a range of specimens from the collections that could be prepared at a beginner level. Selected specimens were representative of departmental preparation priorities: Eocene paleobotanical specimens for air scribe training; a Morrison Formation (Late Jurassic) sandstone block containing a sauropod vertebra to demonstrate opening a field jacket and for air scribe work; a White River Formation (Late Eocene/Early Oligocene) entelodont for light air scribe work; a Miocene (Chesapeake Group) whale for jacket opening and soft sediment prep with hand tools; and a White River camel for more difficult needle (pin vice) and air scribe work (Jabo *et al.* 2010, Figure 1C-E). The specimens were selected in order to provide a broad range of experience representative of typical volunteer projects.

Training

Training took place over the course of six days, with topics broken into lecture and demonstration sessions, followed by hands-on work with observation and assistance given by the circulating instructors. Due to the size of the class a pair, or trio, of students

Day 1	Lecture-Who are we? What is paleontology? What is preparation?
	Lecture- Lab safety and lab orientation, lab ethics/manners.
	Lecture-Specimen handling.
	Lecture- Documentation
	Lecture- Problem solving in the lab.
	Demonstration/Hands-on - Opening field jackets.
Day 2	Tour - Collections and basement with emphasis on preparation/conservation.
	Demonstration- Intro to preparation with airscribe.
Day 3	Lecture- Adhesive and consolidant basics, how to mix, how to apply.
	Demonstration/Hands-on - Practice with airscribes, use of pin-vice and picks.
Day 4	Hands-on- More practice with airscribes.
	Hands-on- Use of pin-vice and picks.
	Demonstration- Temporary jackets and stabilizers.
	Demonstration/hands-on- Sediment washing and microfossil sorting.
	Hands-on- Practice with pin-vice and picks.
Day 5	Demonstration- Creating padded plaster jackets.
	Hands-on- Specimen prep.
Day 6	Tour/Lecture- Basic vertebrate anatomy, why do you need to know it?
	Conclusion- Practicum/Evaluation

Table 1: Smithsonian FossiLab Course Curriculum.

often shared a workstation and alternated working on a specimen while observing their classmates' techniques. This gave the students a means of contrasting and comparing their styles and skills and also allowed them to coach and encourage one another as peers.

The programme began with a classroom lecture providing an overview of the nature of preparation and types of projects the instructors had experience with. Students were then moved into FossiLab for an extensive overview of laboratory safety protocol. Types of Personal Protective Equipment (PPE) were discussed, as well as the appropriate times to use them, where they are located in the lab, and how to use them correctly. Methods of handling specimens were demonstrated, and circumstances for how and when to handle specimens were outlined. Students were shown how to document work through preparation records, photographs, sketches and notes.

Preparation instruction began with a brief demonstration of the methods for opening a field jacket, directly followed by individual hands-on application. Volunteers took turns making cuts, while methods (including documentation) and safety were reinforced with each round. They were shown what to expect at the interface between jacket and contents, how much jacket to retain in order to keep the specimen stable, how to distinguish between bone and matrix, and how much to consolidate freshly exposed bone on a case by case basis.

Students were then introduced to both pneumatic and hand tools, including pin-vice, dental pick, awl, brush, and air scribe. Air scribes used in FossiLab include Paleotools Microjacks, ARO scribes, and Chicago Pneumatic scribes. Students were taught how to select tools based on the matrix and bone conditions, how to maintain them, and how to use them safely. Instructors drew instructions on the matrix with a marker directing students to work within a certain area, with arrows indicating in which direction preparation will be most effective, and estimates of approximately how much time they should spend in a given area based on their skill level.

Paleobiology research staff members gave specialized instruction in departmental methods through lecture and demonstration. Research staff explained the significance of the research area, why preparation is critical to that process, and the impact that the volunteers would have on the research programme. Specifically, students were taught basic collections and housing techniques and paleobotanical and microfossil preparation methods. Departmental staff demonstrated a method for housing specimens in custom padded plaster jackets (Jabo *et al.* 2006), Eocene leaf specimens were prepared under microscope with airscribes and pin-vice, and forams and ostracods were washed in an ultrasonic bath, screened, sorted under a microscope, and adhered to slides using gum tragacanth.

FossiLab uses Butvar B-76 almost exclusively as an adhesive and consolidant, greatly simplifying the instruction required regarding materials choices. However, basic principles of conservation were instilled through discussion of materials choice and deconstruction of hypothetical situations. Procedures for effectively consolidating and adhering fossil specimens were covered. Students were taught how to decant stock B-76 into containers for daily use, how to thin it for use as a consolidant, and how to safely handle resins and solvents.

Instructors kept notes on the progress of the individual students, their ability to handle themselves in the lab, and levels of cooperation or patience. Instructors noted and corrected red flags like safety concerns and the difficulty for some students to follow directions, these comments were saved for final evaluations.

Part of one day was spent with the students in the exhibit Osteology: Hall of Bones. In addition to pointing out the basics of vertebrate skeletons and showing similarities and differences between bones across taxa, instructors displayed the textures associated with muscle scars, vascularization, pathologies, and the differences in texture along a bone shaft and near the articular ends. This demonstration was used to show how a basic understanding of anatomy contributes to skilled preparation. Students were asked to identify analogous and homologous structures, and to speculate about how an intimate understanding of the anatomy of a group being prepared and the ability to recognize critical characters could impact the process of preparation and research.

Testing

Written exam - The written exam (Appendix I) drew questions from topics discussed during the training session. Questions were designed to reinforce primary themes introduced in the course. The test consisted of True/False, Short Answer, and Essay questions, and was conducted with open book conditions.

Practical exam - The lab practical was based on the Prep Test developed by Bill Simpson at the Field

Figure 2. An Eocene fossil leaf being used as a skills test. The black hash marks represent areas to be prepared.

Museum required of all applicants for preparation positions in the Geology Department (Bergwall 2009). This version used the Eocene leaves that the students were by now familiar with. Each student was given explicit directions about where and how to prep a given specimen. These specimens were very effective because they were robust, plentiful, and had enough ease of separation for beginners. The specimens showed damage easily when poked with a pin-vice or air scribe. Additionally, these specimens were part of a large collection transferred to the institution with only vague locality data; therefore they could be more easily sacrificed without loss to science. Areas to be prepared were selected carefully by the instructor to demonstrate how much the student had learned during the instruction period. These areas were highlighted with a marker so that students knew exactly where to work (Figure 2).

The students were allowed an hour for each test, and the group was split into two sections so that one half was taking the written exam and one was taking the practical. Instructors again circulated through the room, taking notes on each student, and keeping track of many criteria such as: is the person using the microscope for micropreparation?, are they using the tool as directed?, if not, is their innovation paying off?, are they wearing hearing protection or safety glasses where appropriate?, does their posture steady and comfortably support their body while leading to good preparation results?

Evaluation

Student knowledge and skills were evaluated using the results of the written examination, practical examination, and notes taken during the course of instruction.

Written exam - Corrected exams were returned to the class and instructors went over expected answers, and addressed apparent misunderstandings. Some of the incorrect answers provided excellent opportunities to reinforce what not to do, and some of the more creative answers allowed discussion of the fluid, problem solving nature of fossil preparation. The need to continually self evaluate and adjust techniques to safely prepare a given specimen was discussed during this section of the course as well as the need to recognize when to stop and ask for assistance.

Practical exam - Results of the practical were examined and critiqued in front of the group using a camera and television monitor connected to a microscope (Jabo *et al.* 2010 Figure 5). Instructor familiarity with the desired methods and physical properties of the specimens, coupled with five days of experience with individual students, allowed an honest and accurate assessment of why mistakes were made, and an opportunity to point out ideal results.

Final Report - Instructors wrote an assessment of each individual, and in order to make the evaluations more useful for the Smithsonian lab managers, initially assigned a letter grade to each student. Finding that one designation did not accurately reflect the complexity of abilities and skills required for every aspect of preparation, four grading-categories were established: preparation skills, knowledge of theory (which is not the same as knowing how to apply it), enthusiasm, and instinct (Appendix II). Another longer way to name these categories could be: can they do it?; do they know why we do it this way?; are they excited and patient enough to be involved?; and can they intuit their way from knowledge, through action, to result while recognizing when to stop?

Preparation skill was graded based on observation of the act of preparation, keeping in mind that technically perfect preparation can sometimes be achieved (though rarely) without knowledge of conservation principles. Grading for knowledge of theory was influenced by written test results and discussion with the students.

Since positions being evaluated for were voluntary in nature, the category for enthusiasm was created to aid in placement. To help lab managers justify the time expenditure required for extensive training, instructors noted whether or not students seemed bored with certain tasks, were able to remain focused over the long term on a project, and whether they paid attention during lecture. Also, some students who lacked certain manual capabilities were determined to be enthusiastic and personable enough to still be useful as assistants for jobs such as washing matrix and speaking with the public.

Initially, trying to score an intangible quality like instinct seemed daunting. However many subtle clues such as how the student first picks up a tool, approaches a microscope or workbench, steadies themselves once seated, their rhythm with a scribe and how they handle the specimen proved to be immensely informative. Also, the questions the students asked during the course illuminated what their concerns were and what was going on inside their learning process. The instructors feel that in most cases a future preparator's potential can be judged within moments of a candidate's first attempt to prepare a specimen. Both instructors just kept coming back to a question of "Do they get it?" and this seemed to justify the creation of the Instinct category.

To conclude the evaluation report, some students were recommended for specific tasks, indicating whether or not varying levels of supervision may be required. Lab managers were also cautioned against some students for certain duties. This system is not only immediately useful for the lab managers, but also establishes a baseline for measuring the abilities of the students as they mature as preparators.

Results

Twenty-nine students were trained in the Smithsonian FossiLab preparation course. Some students clearly understood the importance of using PPE, good posture, proper specimen support, and could effectively use the tools as instructed, and some had trouble grasping or executing some of these concepts (Figure 3). As noted by several professional preparators in Wylie (2010:9), not every candidate can be trained beyond their skill level, innate skills can only be developed.

Twenty-five of them received a C or above in letter grade in preparation skills, and were recommended for at least some level of supervised specimen preparation. Eleven students received an A for preparation skills, and were recommended without reservation for most tasks. One student was recommended for dismissal due to refusal to take instruction, and one was unable to complete the course for health reasons.

Discussion and Conclusion

Benefits of an institutional programme-An institutional training programme establishes a consistent knowledge base among the volunteer pool and reduces the amount of conflicting information that volunteers may receive from members of the staff. This makes it less likely that volunteers will perpetuate misinformation in the absence of staff members. Rather than accumulating relevant information piecemeal over several months, students are systematically exposed to methods and techniques and literature, so that the reasoning behind protocol (i.e., the benefits of using reversible adhesives) is understandable from the outset of training.

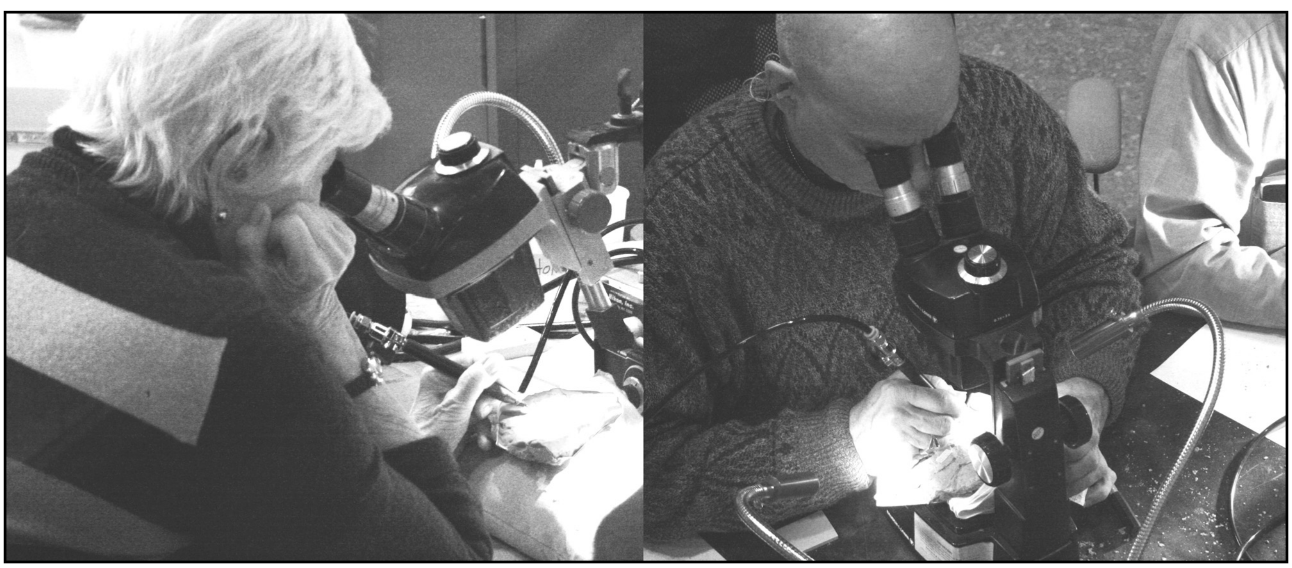

Figure 3. In addition to evaluating final results, students were graded based on technique and adherence to standards. A: The specimen is not well stabilized, the student's chair and microscope should be adjusted to allow for comfort and proper ergonomics without leaning on the table, the student should be wearing earplugs. B: The student is properly supporting the specimen with the off-hand, is wearing hearing protection, and is practicing proper posture.

Group training significantly reduces the amount of staff time required for teaching mundane information (i.e., location of supplies, decanting adhesives, recordkeeping), and allows for more individualized instruction on technique.

Benefits of contracting outside instructors-There are several advantages to using outside consultants to conduct this training (Belacourt 2006). Principally, contracted instructors free staff time for the projects taking institutional priority and relieve pressure on the preparation programme as a whole.

Outsiders can also bring legitimacy to the decision making process. Students see that the lab is using Butvar B-76 as an adhesive not because there is a 50-year supply in the basement, but because it fits within a universal standard in the field. Additionally, outsiders can reduce pressure on the staff in case of conflict. For example, one existing volunteer was not taking direction well, or at all, from lab managers. After evaluating the individual's work, course instructors pointed out deficiencies in the results, and gave very specific direction to correct mistakes. The volunteer ignored these instructions, and the instructors recommended removal from the lab. In this way, contractors can become the "bad guys", making it easier for lab managers to maintain day-to-day working relationships with the volunteers. Further, this step helps to protect institutional staff in the case of a dismissed volunteer who becomes disgruntled.

The entire process of training was greatly facilitated by programme organizers during their very thorough screening of candidates, and transformation of the lab into a functional classroom setting. The questionnaire provided to students also served to improve student performance by identifying with a high commitment to quality and detail oriented hobbies or behavior (Jabo *et al.* this volume).

Finally, maintaining a high level of professionalism throughout the programme reinforces several core messages to the students. Namely, these core messages are: preparators take their work seriously; the techniques, materials, and methods used have a basis in scientific methodology, preparators respect the specimens and the conservation ethic. It is hoped that this extra effort serves to directly transfer this ethos to the student. Their presence also demonstrates the institution's commitment to high quality fossil preparation, which of course must be the underlying philosophy behind any such preparation programme.

This process has proven to be a short-term success within the institution, the goal of staffing the lab on a regular basis with capable volunteers was met, and a universal knowledge pool was established. An evaluation is necessary in the future to show whether the training goals are met over long term. Based on initial experience, this type of programme is recommended to other institutions as a method for training large numbers of volunteers quickly and uniformly. Further studies should investigate training programmes for both professional and volunteer preparators in other countries, as well as consider modifying and adopting formal training programmes for professionals in North American educational institutions.

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APPENDIX 1

Written Examination

True/False
If false, explain why

1. You should use consolidant to stabilize leaf fossils
2. Preparation is a slow process
3. Forams are macrofossils
4. Sandals should be worn in the prep lab.
5. Butvar is chemically stable over long periods
6. You should always use the strongest adhesive possible.
7. Diligent documentation is overkill.
8. You do not always need to follow the product instructions to get the most stable results
9. Fossils are generally stable and you do not have to worry about the chemicals and conditions they are subject to.
10. You do not need earplugs if you only have to raise your voice to be heard.

Short Answer

1. Describe the procedure for thinning Butvar B-76 with acetone and why the Fossil Lab uses Butvar as adhesive on fossils.
2. What are two materials used in plaster storage cradles (other than plaster)?
3. What are three options or alternatives for gluing poorly fitting joints together?
4. Using the SPNHC wall chart, identify two adhesives or consolidants that were used in the prep lab, list their reversibility and solvents, as well as their use in the field.
5. Explain what it means for an adhesive to be reversible.

Short Essays

1. Define conservation as relevant to paleontology collections.
2. Even though you haven't made any temporary lab jackets, explain the process and cite an example when it would be appropriate. If a specimen required a temporary jacket, how would you learn about the methods and equipment necessary to complete the job?
3. Explain in your own words why knowledge of comparative anatomy is critical to competent preparation.

APPENDIX 2

Sample evaluations
***** *******- High level of dexterity, wasn't obvious that he was paying attention at all times, but his results were good. Written test answers were not quite accurate, seemed safety conscious. Recommend for microvertebrate prep, sorting. Microscope skills very good, did not seem interested in larger specimens.
Prep: A Theory: B Enthusiasm: B Instinct: A

***** *******- Good listening skills, quick to adapt skills, self-directed. Good manual skills, safety aware, well suited for preparation. Good at asking appropriate questions, good instinct for problem solving. Recommended for all tasks.
Prep: A Theory: B Enthusiasm: A Instinct: A

*** ******- Enthusiastic and conscientious, identified personally with the specimens. Manual skills subpar, but recognized her limitations. Recommended for screen washing and interpretation, large scale soft sediment preparation under very close supervision.
Prep: D Theory: B Enthusiasm: A Instinct: C
****** *********- She recognizes her limitations but struggles against them. Still willing to learn. Was frustrated by her lack of depth perception under the scope, but seemed to do fairly well on softer-matrix macro material. Friendly and outgoing good qualities for an interpreter.
Prep: C Theory: C Enthusiasm: A Instinct: D

****** ******* - Not punctual, slept through a number of lectures. Pushed microscope away during test, no hearing protection during test. Might be good for macro prep, room for improvement.
Prep: C Theory: B Enthusiasm: incomplete Instinct: D

**** ******* - Unwilling to recognize or admit to considerable damage done to specimen. Reluctant or unwilling to take direction. Recommended for removal from lab.
Prep: F Theory: B Enthusiasm: C Instinct: F

DESIGNING A MICROPREPARATION WORKSTATION

by Lisa Herzog

Herzog, L. 2010. Designing a Micropreparation Workstation. *The Geological Curator* 9 (3): 187 - 192.

When working on small and delicate specimens at a micropreparation workstation it is always important to keep a clear and uncluttered working surface. With an increasing array of tools and equipment being introduced to the field of fossil preparation the setup, organisation, and maintenance of a clean workstation requires detailed planning. This is an illustration of work station design and implementation. A list of commonly used tools and equipment along with solutions for storing and positioning are discussed along with illustrations. Tools and equipment included are pneumatic air scribes, pin vice and carbide rods, rotary grinder, microscope, and air supply hardware. Compounds and chemicals used at a workstation include solvents, adhesives, consolidants, and lubricants.

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Introduction

The design of a micropreparation workstation must take into consideration all the tools and uses that the station should provide. It is important for the station to be versatile and accommodate changing priorities and uses. For example, each specimen will vary slightly in size and quality of preservation and the task to be completed at the workbench will vary as well. Primary use of the workstation is assumed to be micropreparation but in some cases moulding, casting, note taking, or specimen labelling may take place on the same workbench. With the proper equipment, maintenance, and design characteristics one station can fulfill many needs with maximum efficiency.

Micropreparation of vertebrate fossils requires the ability to efficiently and accurately work on small and delicate specimens under a microscope. Historically, microscopes have been used in the field of fossil preparation, especially on smaller specimens (but not exclusively) as it enhances the ability to discern bone surface from the surrounding matrix. Additionally, once research on a specimen commences, the specimen will often be analyzed with the aid of a microscope. Researcher conclusions regarding the morphology and pathology are often made based on microscopic analysis. The use of a microscope for preparation is necessitated by this process as it makes good sense for the technician to be able to see what the researcher will ultimately see (Amaral 1994), with the same quality of scope.

While the microscope is the centerpiece of an effective micropreparation workstation, peripheral items such as pneumatic, rotary and mechanical tools have become integral tools of fossil preparation. Effective use of these tools can increase the overall efficiency and accuracy of preparation (Palmer 1989, Chaney 1989) while causing problems with clutter as well. Preparation can periodically be done with only a sharpened needle held by a pin vice and a little glue on hand (Cavigelli, 2009). However, the variety of commonly used tools that require tubing or electrical cords must be properly organized to avoid tangles and clutter on the workbench surface and allow for easy access during preparation. A clean, clear, and organised workstation can have a dramatic positive affect on productivity and quality of work. Additionally, specimen fragments are much easier to find with a clear, uncluttered working surface (Amaral 1994). Specimens are better cared for and safer when attention is given to organisation and maintenance of work areas.

Details to consider when setting up a workstation include four main points in addition to the assumed microscope and airstream supply. First, an inventory of tools that are used on a regular basis is determined. During preparation these tools should be seamlessly interchanged without becoming tangled with each other. This may change from specimen to specimen and the workstation will be versatile enough to undergo periodic revisions. Second, the consolidants, solvents and lubricants accepted for use in the laboratory is listed and ranked according to items that will be in use on a regular basis.

Safety should also be considered in selecting containers that will hold hazardous chemicals. Third, the method used to sharpen tools is also an issue and may require special fixtures to mount a grinding tool such as a dremel or foredoom with flexible shaft. And finally, the method in which your microscope is mounted should be either on a long boom arm with base placed on a platform above and behind the working surface or a boom arm that mounts directly to the wall or base of workbench. It is critical that the microscope arm has easy fluid motion to move right, left and forward, backward. This is not only for positioning over the specimen but also to allow the microscope to be fully swivelled aside, leaving the space above workbench clear and capable of being used as a regular desktop surface.

The equipment, tools and compounds mentioned here are fairly universal to all preparation laboratories. The set up and design is unique. Suggestions here are meant to enforce the idea of keeping an organised and clear workstation for the purpose of enhancing preparation efficiency and accuracy.

Materials

Manual tools used in preparation that benefit from specialized organisational equipment include pin vice (holding carbide rod or needle), pneumatic impact and rotary tools as well as electric tools. Because all these tools are connected via electrical cord or compressed air tubing, their use can create a workstation mess. Tools easily become entangled with each other and clutter up working surfaces. Despite such complications, it is advantageous to have multiple tools on hand while working on a specimen that requires rapid removal with a high powered impact tool in some areas, and a finer more precise impact tool for more delicate areas. In addition, there are also myriad compounds/adhesives that can be applied to specimens for stabilization, repair, etc. It is important to keep a variety of these compounds on hand to accommodate the individual reactive properties of each specimen.

The challenge in setting up an effective micropreparation workstation revolves around managing all these tools and compounds while still maintaining a clear working surface. An additional concern for many institutions comes with budgetary constraints involved in properly outfitting a laboratory. With innovative and creative ideas, many accessories used to organise a workstation can be built in the laboratory or picked up at a local hardware store at minimal cost. Scrap lumber, aquarium equipment and simple hardware store spring clips were all used in this example.

When it comes to setup and design, equipment such as microscopes and their accessories as well as additional items that help position specimens and keep tools organised are used. These include (Figure 1):

Microscope platform: Constructed of wood, the platform raises the microscope above the working surface, holds it in place for stability and prevents it from tipping forward via plywood screwed in place over the base of the microscope stand.

Spring clips: Purchased at a local hardware store, the clips hold impact and rotary tools in place within arms reach above the workstation.

Light box: Fiber optic ring light attached to lens illuminates specimen under microscope. The ring light provides even illumination over the entire surface of the specimen. Some fiber optic lights are outfitted with two adjustable arms that are positioned to focus light in a given area (Amaral 1994).

Hydraulic lift table: Holds large specimens and adjusts vertically for preparation under microscope.

Compressed air regulators: Allows for use with multiple tools requiring separate psi settings.

Air supply gang valve: This piece of aquarium equipment splits the air supply from one source to multiple outlets and allows more than one tool to be connected to foot pedal controlled air.

Locline ™ modular tubing: Tubing is created using segments that snap together and provide movement for directional adjustments. Air controlled by a foot pedal is pushed through the modular tubing and precisely aimed through a 1/16" inch nozzle at desired work areas.

Foot pedal: A dental foot pedal activator supplies air to connected tools when depressed.

Methods

Microscope platform: A microscope platform is designed to hold a microscope that is mounted to a traditional swing arm stand. The microscope is secured on the swing arm and can swivel left and right as well as slide forward and back. The arm can be raised and lowered along a vertical beam that is secured to a weighted base. The weighted base is designed to counter balance the weight of the microscope when drawn to maximum extension. This setup is self-contained, can be placed on any work surface and is easily moved when needed. Other mounting options include wall mounted and C-clamp models. Wall mounted boom arms are very stable and can allow for easy motion but are not easily moved as it is designed to be permanently mounted to the wall. Workbench location must be suitable for a wall mounted boom arm to be installed. Not all laboratories can accommodate this type of set-up. C-clamp microscope arms are capable of being moved

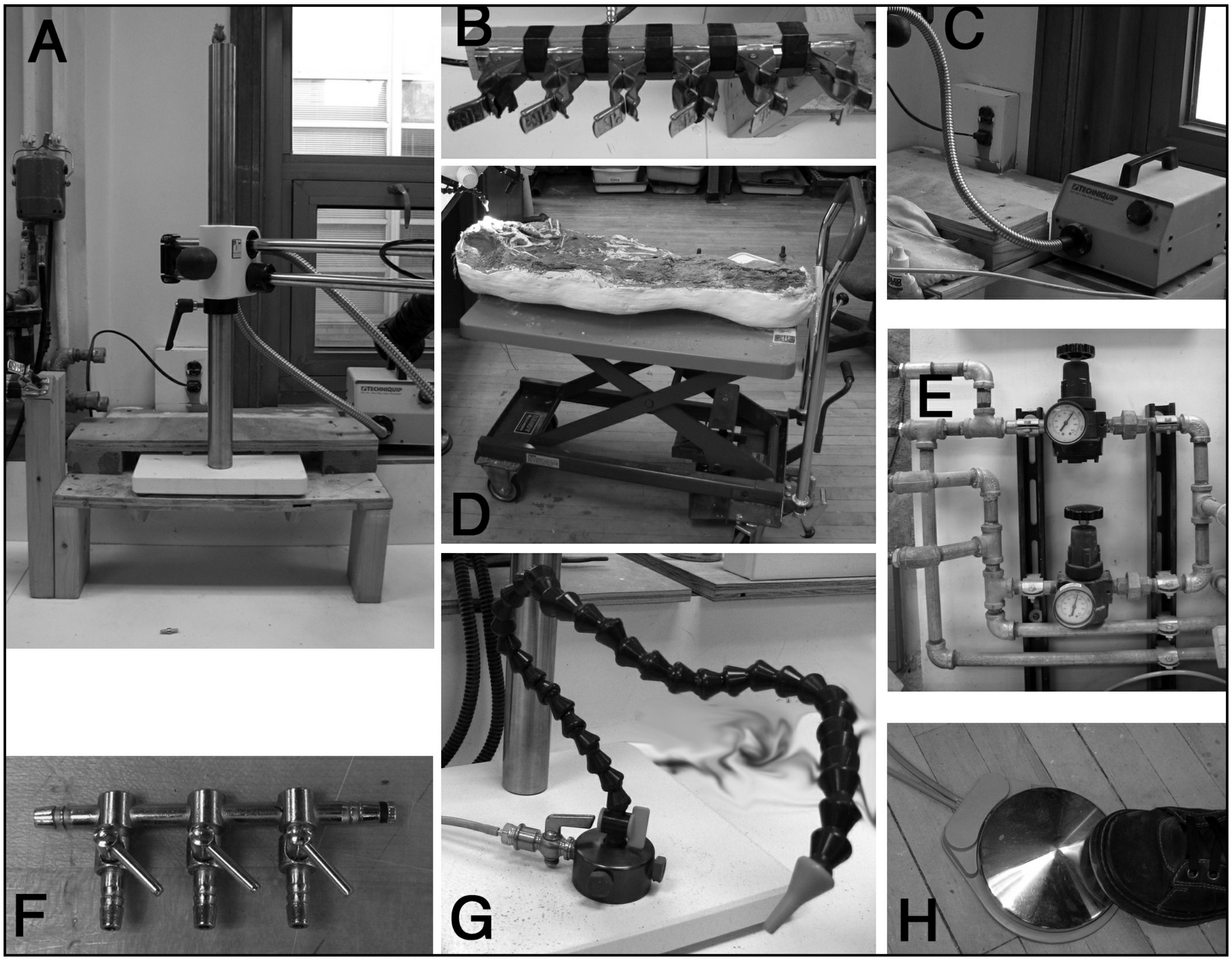

Figure 1. (a) Microscope platform, (b) spring clips, (c) light box, (d) hydraulic lift table, (e) compressed air gauges, (f) air supply gang valve, (g) modular tubing, (h) foot pedal.

fairly easily, but must always be clamped to the edge of a surface that can accommodate the clamp and the weight of the arm and microscope. Without a proper surface to attach the clamp, the microscope will not stand on its own.

The microscope platform provides a perfect surface for mounting a small custom made box that can hold solvents or adhesive compounds such as B-72, B-98, acetone or ethanol in 30mL eyedropper bottles. Other appropriate containers holding useful compounds such as cyannoacrylates and lubricating oils can also be accommodated. Additionally, a small cube of ethafoam cut to fit is used as a receptacle for pin vice, tweezers, extra carbide, grinder tips and exacto-blade. The box is slot mounted to protruding flat-headed wood screws and can be removed easily. Each dropper bottle or other container in the box is clearly labelled and easy to read. The platform and box were both constructed with scrap wood in the laboratory at no additional cost. Auxiliary surface area is created by the microscope platform that holds the lightbox and additional materials such as larger containers of consolidants, sandbags, etc. By elevating the microscope stand above the main working surface any additional items placed on the platform are kept away from specimens and any possible fragments that come loose during preparation. The spring clips used to hold pneumatic tools are mounted to an arm attached to the wooden microscope platform as well. The clips are evenly spaced along the arm. The plane of the arm is positioned at roughly 40-45 degrees back from vertical. This is done so that when pneumatic scribes are mounted in the spring clips (point up), their sharpened carbide needles point back away from the preparator. This will decrease the likelihood of accidentally impaling oneself when reaching for a tool. Tools are held above the workstation and tubing tangles are kept to a minimum while keeping all varieties of impact and rotary tools on hand and ready to use.

Hydraulic lift table: Some specimens are too large to fit at the workstation without requiring excessive microscope height. The height of the microscope is determined by the focal length of the scope, the height of the preparator, height of the workbench and size of the specimen. A hydraulic lift table can be

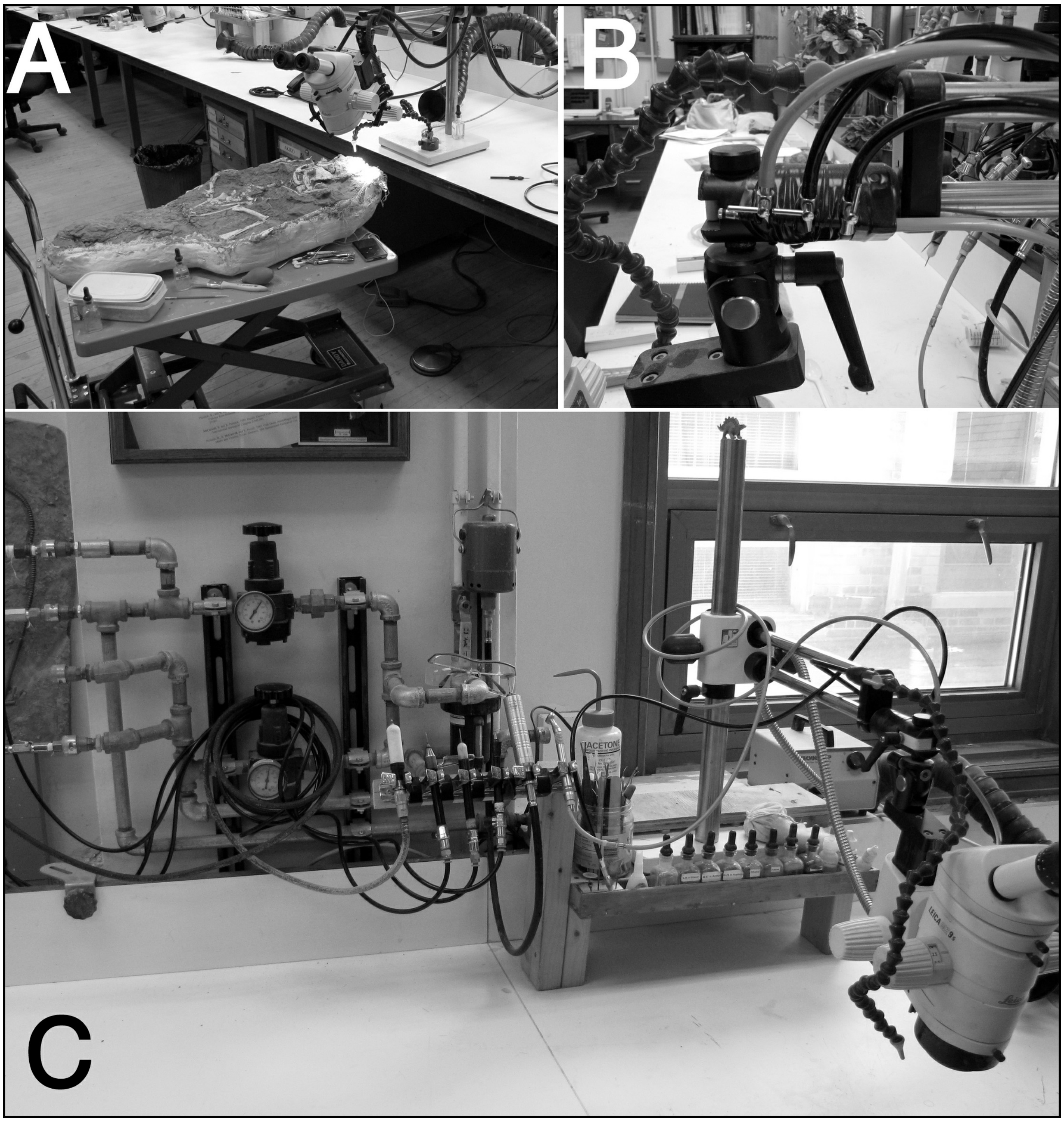

Figure 2: (a) Hydraulic lift table with microscope, (b) Gang valve mounted on microscope arm, (c) Workstation setup.

positioned adjacent to the permanent workstation with the microscope stand positioned on its margin. The hydraulic table is set on rubber tread casters for easy positioning with a floor lock that keeps the table stationary during work. A foot operated hydraulic pump allows the table surface to be easily raised and lowered according to need. This allows the specimen to sit lower than the height of a standard worktable while the microscope is positioned over the lift table (see Figure 2a). The microscope stand supports the fully adjustable arm with fluid ball bearing motion and allows the microscope to be positioned above the specimen. Light box fibre optic arms are attached to the scope, allowing the lighting to move with the scope. As the specimen is prepared, the lift table height can be adjusted to meet the focal length of the scope and provide for a comfortable seat height position for the preparator.

Foot pedal air supply: The foot pedal controlled air supply (normally used to control the turbine speed of a dental drill) is adapted to provide a stream of air for use in the preparation of fossils (Davidson 1998). For preparation, the foot pedal air supply can be used to operate a dental drill, but can also be connected to modular tubing that directs airflow to remove matrix debris during manual/pin vice preparation. For the sake of maximum utility, the foot pedal air supply can be split using a traditional metal fish tank gang valve (plastic varieties are inferior). Rather than keeping multiple foot pedals or changing out fittings depending on use, an air supply splitter allows the use of one foot pedal to power three or more tools without disconnecting and reconnecting tubing. Airflow from the foot pedal is diverted by opening or closing the air supply valve. With a gang valve mounted on the microscope arm (Figure 2b) a dental drill, modular tubing and air supplied pin vice (Davidson 1998) can all be connected at the same time. When not in use, the dental drill is placed in one of the spring clips located on the arm of the microscope base, the pin vice is placed safely point-down in the ethafoam located in the box at the front of the microscope base. The Locline ™ modular tubing is permanently mounted on the microscope arm. This keeps all the tools used in conjunction with the foot pedal air supply perpetually connected and above the work surface at all times.

Compressed air regulator: The use of multiple air supply tools often requires different air pressures to be available simultaneously. This can be achieved by fitting the air pressure system with two (or more) pressure regulators. One can be set to a higher pressure (i.e. for use with air scribers that require 100+ psi) and one with lower pressure for tools such as the foot pedal control that powers the dental drill, pin vice, and modular hose.

Results

Effective workstation organisation results in a workspace where multiple tools and compounds are stored neatly within arms reach and positioned above the working surface (see Figure 2c). Commonly used impact tools are held in place and are easily interchanged for use without requiring extra time to disconnect and reconnect. They are held in place by a series of spring clips mounted to a bracket that extends from the microscope platform. Uniform containers are in a stable mounted box, within reach, and clearly labelled. Additional tools and compounds are organised on the microscope stand, and foot pedal air supply is easily split among multiple tools with a metal gang valve that is neatly mounted on the microscope arm. The microscope platform provides additional space for sandbags or other containers that may be used on a specific project. Workstation modifications can be made to suit the needs of any given specimen. Large specimens can be placed on a hydraulic lift table adjacent to the workstation and can be adjusted vertically to fit within the microscope's focal range. A foot controlled rotary tool with diamond wheel for sharpening carbide is available and neatly mounted. Workstations are also equipped with air extractor units composed of modular tubing. Safety glasses are also on hand for frequent use. The station is set up for use by any individual who needs to do preparation work without additional set-up time to arrange tools and compounds for a specific project.

One important variation to setup that should be noted here is the orientation of the tools with regard to the right-or-left handed nature of the preparator. The station illustrated here (Figure 2c) is setup for a left-handed person. The tools are positioned for accessibility and use on the left side of the microscope. The tools can be used on the right by running tubing over or under the scope behind the ocular viewing area, so it is still adequate for variable users, but is ideal for left handed use.

Discussion

Regardless of how a workspace is setup, the most crucial consideration is organisation and control of clutter on the work surface. The workstation design presented here represents one method of keeping an organised workspace that is flexible enough to work on a wide variety of specimens. Adjustments can be made for difficult projects that require individualized attention or more specialized tools and compounds. Having the proper tools and compounds on hand helps the flow of work and ability to control any damage that may occur. The variety of tools available for fossil preparation creates a specialization that enhances the precision with which work is done. This is why it is so important to be able to work on a specimen with several tools on hand at all times while still keeping a clear working surface.

The ability to use the workstation for multiple tasks is enabled by the easily adjustable boom stand for the microscope. While remaining at the station, the microscope arm can be easily pivoted 90° so it is no longer above the work surface. Since the base of the scope is physically secured to the microscope stand there is no concern about the microscope tipping. The work area can now be used to look at the specimen with the naked eye, fill out paperwork, take notes or prepare moulds. This is especially important in laboratories where space is an issue and workbench surfaces are limited.

The ideas, design and setup in this presentation are compiled from multiple sources. Use of specific tools and equipment have been developed over the many years of fossil preparation history.

Acknowledgements

Thanks to all who have participated in this process by being part of the active Preparation Community. Special thanks to preparators at The Field Museum who help by sharing and developing new ideas: A. Shinya, C. Van Beek, D. Wagner, J. Holstein and W. Simpson, and to A. Davison for information regarding the use of the hydraulic lift table.

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VIRTUAL REPAIR OF FOSSIL CT SCAN DATA

by Mark R. Johnson, Phillip L. Manning, Lee Margetts, Philip J. Withers and Paul M. Mummery

Johnson, M.R., Manning, P.L., Margetss, L., Withers, P.J. and Mummery, P.M.. 2010. Virtual repair of fossil CT scan data. *The Geological Curator* 9 (3): 193 - 198.

X-ray micro-tomography (XMT) and 3D image-based modelling software has unlocked the ability to digitally repair distorted or broken fossil specimens, thus permitting interpretation of previously unusable finds in finite element analyses (FEA). A fossilized terminal ungual phalanx from the manus of the dromaeosaur *Velociraptor mongoliensis* (Manchester Museum, University of Manchester, specimen LL.12392) was scanned at the Henry Moseley X-ray Imaging Facility. Inspection of radiographs revealed the *Velociraptor* manual ungual was broken in several places, previously going unnoticed due to cement repair of the fossil. After conducting a high resolution scan of the ungual the increased sensitivity of the apparatus enabled separation of areas of differing density, in this case the fossilized bone and cement. Image-based modelling software produced by Simpleware (Simpleware Ltd, Rennes Drive, Exeter, EX4 4RN, UK.) allowed slice-by-slice repair in three planes, resulting in a complete, fully stitched 3D digital model of the ungual, whilst maintaining internal cavities and the micron resolution reconstruction of trabecular bone architecture. This software also has the capability to digitally re-inflate specimens that have been compressed during fossilization, restoring skeletons to their original shape and dimension. 3D dissections on geometrically precise reconstructions allow the interpretation of previously unusable specimens and reinterpretation of already described fossils. Further, use of Simpleware software to convert repaired fossils into microstructurally-faithful finite element meshes enable the biomechanical testing of these repaired structures. Testing of fossil structure and function is already underway at the University of Manchester and is adding to our knowledge of the mechanical behaviour of extinct animal biomaterials.

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Introduction

X-ray micro-tomography (XMT), image-based modelling and finite element analysis (FEA) is utilised by evolutionary biologists interested in the relationship between form and function (Moreno *et al.* 2008; Kupczik *et al.* 2009). XMT and image-based modelling coupled with rapid prototyping techniques can also be used by museum curators to generate museum displays and teaching aids of rare specimens.

Previous work (Manning *et al.* 2006) proposed a further study of the function of a Dromaeosauridae (Matthew and Brown 1922) terminal ungual phalanx, utilising the technique of finite element analysis (FEA) to consider the mechanical capability of these biological structures.

A manual terminal ungual phalanx of *Velociraptor mongoliensis* (Manchester Museum, University of Manchester, specimen LL.12392) was computed tomography (CT) scanned to provide a 3D dataset for the finite element (FE) mesh. Initial examination of the radiographs (Figure 1) showed that this specimen was fractured in two places and had been skilfully repaired with cement. Radiographs were inspected first as a quick step of checking the quality of the sample before more detailed scrutiny of the reconstructed dataset.

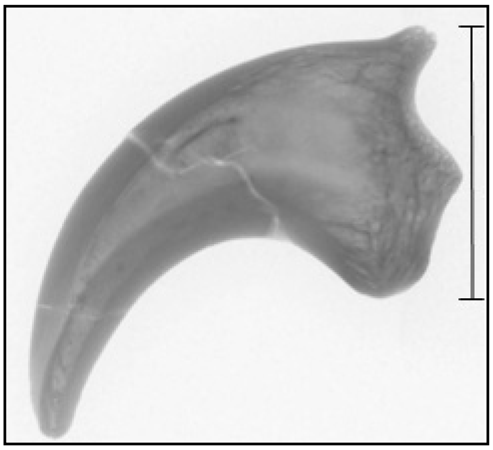


Figure 1. Radiograph of **Velociraptor** ***manus claw (LL.12392) (Scale bar= 10mm)***

Closer inspection of the reconstructed volume revealed that the repair of the larger crack had left the two halves misaligned. The alignment posed a problem as specimens of dromaeosaur claws are rare in collections, and FEA of this specimen would not be representative of the true structure, thus rendering the fossil unusable. The novel solution was to digitally repair the fossil by using image based modelling software from SimplewareTM to align the claw and "heal" the fractures.

Material

Fossil Material

A manual ungual of *Velociraptor mongoliensis* (Manchester Museum, The University of Manchester, specimen LL.12392) (Figure 2Figure 2). *V. mongoliensis* is known primarily from the Djadokhta Formation (Campanian) of Mongolia (Osborn, 1924) and was a small (˜15 kg) bipedal predatory dinosaur (Paul, 1988).

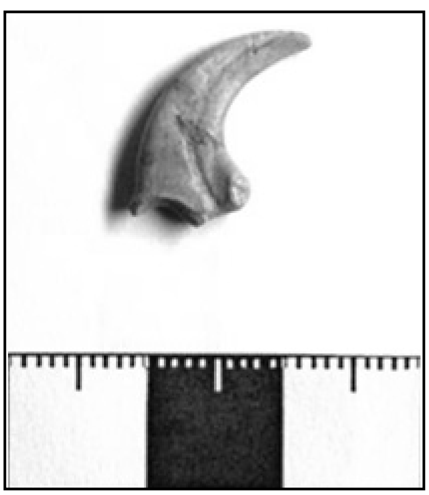


Figure 2. Manual terminal ungual phalanx of **Velociraptor mongoliensis** ***(LL.12392) (scale bar in cm and mm)***

Methods

X-ray Micro-tomography

X-ray micro-tomography (XMT) is a non-destructive evaluation technique that allows the internal structure of an object to be imaged by reconstructing the spatial distribution of the local linear X-ray absorption coefficients of the phases contained within (Elliott and Dover, 1982). This provides a virtual 3D representation of the internal architecture of an object from which two-dimensional (2D) cross-sectional slices can be extracted along the three orthogonal planes of the object (Mummery *et al.*, 1994; Babout *et al.*, 2005).

Data was acquired using a HMX-ST CT 225 X-ray micro tomography (XMT) scanner from Metris X-Tek Systems Ltd., capable of tube potentials up to 225 kV. The scanner used a fast CT collection method recording 2735 projections at 1 frame per second, resulting in a voxel size of 19.1µm3. The radiographs were collected using a tube potential of 136kV, current of 146µA, and with a silver anode. All of the x-ray projections were saved as images in .tif file format. The data were reconstructed using proprietary software utilising the filtered back-projection reconstruction algorithm.

Digital repair

Following reconstruction, data was imported in RAW format to ScanIPTM. The fossilised bone was segmented as a mask from the background by thresholding grey values corresponding to the specimen only and not the surrounding air. The proximal and distal parts of the fossil separated by the fracture were identified and assigned as two distinct masks. Manipulation of the distal portion of the claw by rotating and translating the image based mask allowed the two parts to be realigned by visual inspection in 3D and in the three orthogonal planes.

An alternative approach would have been to align the two masks by first exporting them as point clouds, importing them to a commercially available package such as PolyWorks, and using the point cloud registration and alignment capability of the software. PolyWorks is able to align point clouds in two ways: if there is overlap between the two point clouds it can automatically detect this and correlate the two point clouds; Alternatively the user can manually pick a minimum of three points that correspond on both fracture surfaces and PolyWorks will align the two point clouds using this reference points. Using PolyWorks was not possible with our sample as there was no overlap between the two masks and the two fracture surfaces were not from a clean break, the result being material had been lost so suitable registration marks could not be assigned. The best option available was to align the data within ScanIPTM manually and determine the quality of the alignment by eye.

Within ScanIPTM dilation and erosion algorithms were used to heal the fractures on a data set down-sampled to 10% of the original resolution and at this resolution the technique worked effectively. On a low resolution data set the use of global filters has a minimal effect on features as the data has already been smoothed. However on the 100% high resolution data the fidelity of the entire data set was compromised by the use of global filters as the kernal required to "heal" the fractures also removed many of the internal voids and trabeculae. To keep the data faithful to the original specimen it was necessary to manually paint large areas of the data set to completely fill in both cracks. Painting was carried out utilising all three orthogonal view and review of the 3D preview function. Following this all masks were merged and a recursive gaussian filter with a kernal of 0.0192 (the length of one pixel) was applied to smooth the surface features. This approach maintained the fidelity of the entire data set.

Depending on the requirements of the investigator both methods are suitable, for example if all that is required is a model for measuring claw curvature then the 10% model would be adequate. However as the intended use of this model by the authors is to perform FEA then the latter approach is required.

Re-inflation and morphing

During the fossilisation process it is common for biological structures to be flattened and distorted due to post-depositional controls. A crude two-stage method to digitally re-inflate/morph this specimen was investigated. First, the medial line of the claw was aligned with one of the orthogonal axis in ScanIPTM. Then, by increasing the pixel spacing in the direction perpendicular to this axis, thereby changing the aspect ratio of the voxels, the claw was dilated.

Results

Figure 3 illustrates the original and realigned position of the claw tip. Digital realignment of the specimen ensures that any further work on this dataset will yield results based on the true geometry of *Velociraptor*'s claw.

Following realignment the two fractures were "healed" by manually painting in the missing material. Figure 4 outlines this process. Figure 5 illustrates that the internal microstructure of the claw is retained throughout the fixing process.

A Finite Element mesh was generated to test the effect of loading this biological structure (Manning *et al.* 2009).

The results of digitally re-inflating the claw are presented in Figure 7. This was a purely a demonstration of how to re-inflate a specimen, no criteria as to how compressed the specimen was known.

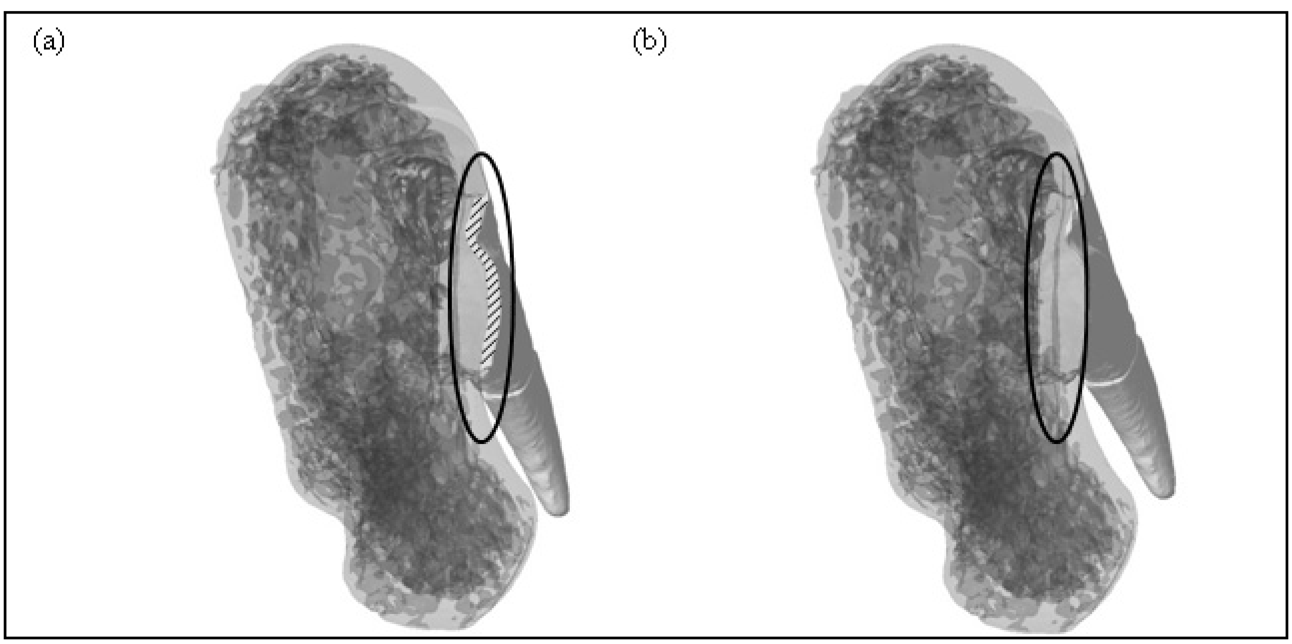


Figure 3. (a) 3D rendering of claw showing the original position of the claw tip and the proximal portion of the claw. The shaded area indicates the offset between the two pieces. (b) 3D rendering of claw showing the two pieces of the claw realigned.

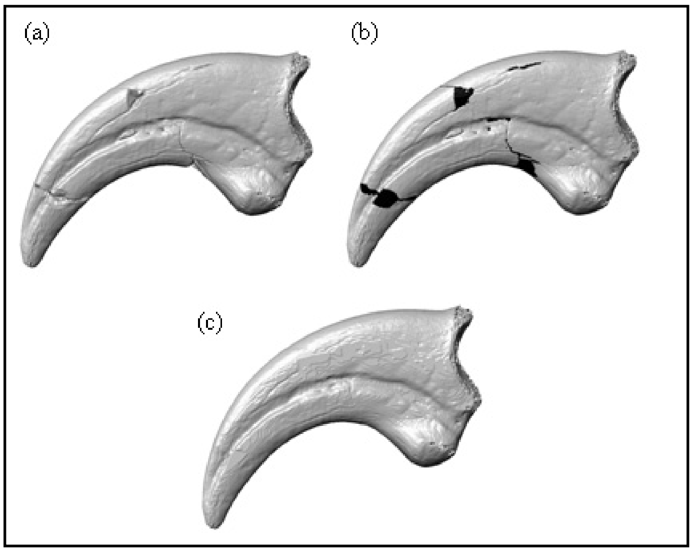
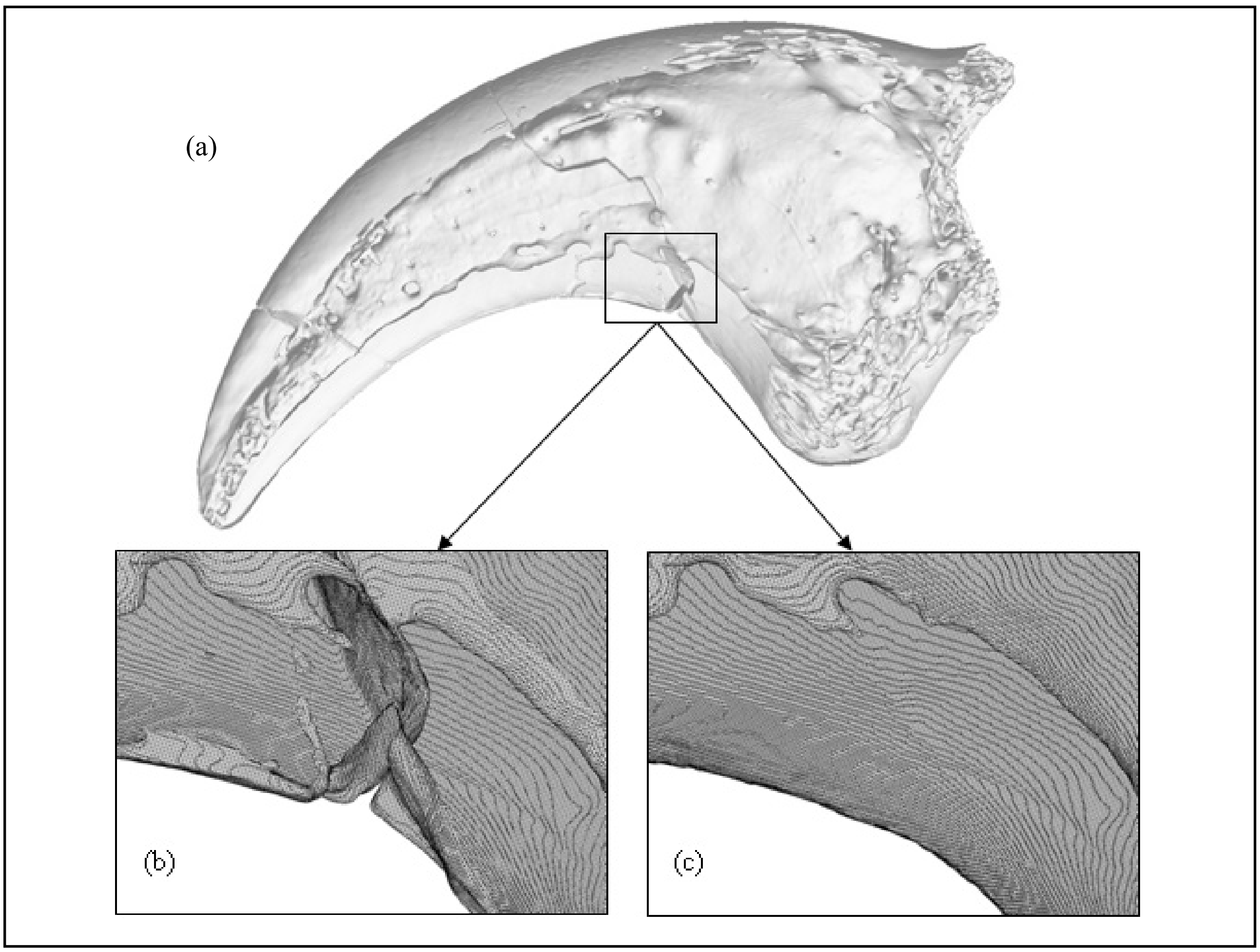


Figure 4. (a) realigned claw, (b) repaired regions shown in black, and (c) final rendering of aligned and "healed" claw.

Figure 5. (a) Slice through image based model of claw, (b) close-up of FE mesh detail along crack, (c) close-up of FE mesh detail after repair



Discussion

Significant repair was needed for the *Velociraptor* claw specimen and was conducted using image-based modelling software from Simpleware. This required manual segmentation, manual alignment, and manually painting in material to "heal" the fractures and restore missing material.

Reconstruction and repair of damaged fossil specimens with image-based modelling has much value in palaeontology as it increases the usable fossil record. This is especially significant when studying rare, incomplete specimens. XMT and image-based modelling are particularly useful techniques when studying ill-prepared specimens, still bound in matrix. Matrix material can be digitally removed without risk of damaging the fossil, allowing the quality of the fossil to be assessed without the need for traditional, and somewhat lengthy manual preparation techniques. Once digitised, fossils can be studied by several scientists working in different locations, accelerating collaborative projects.

Once a fossil has been digitised it can be used as a

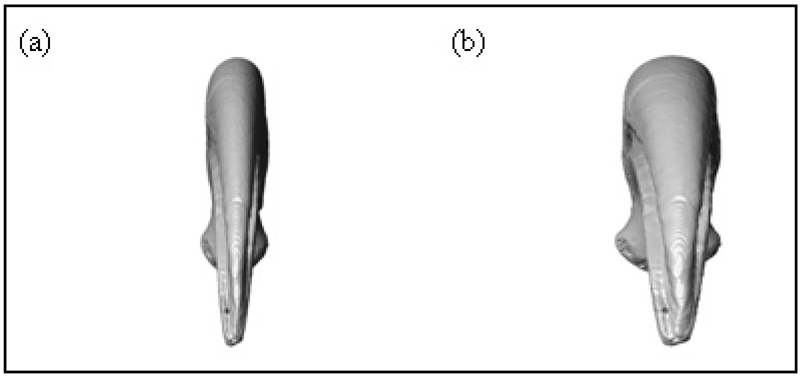


Figure 6. (a) reconstructed claw (b) re-inflated claw.

template structure and morphed to extremes to see what affect that would have on different structures, potentially revealing key evolutionary trends. Pierce *et al.* (2008) explored the patterns of variation in crocodilian skull morphology and the functional implications of those patterns. Morphing those skulls to extremes beyond the observed morphospace would have conclusively shown there is no mechanical advantage to be gained by increasing snout width.

Demonstrated within this paper is a method for morphing specimens captured by XMT. Further development of this technique could be of interest to evolutionary biologists who wish to test hypothetical forms. A possible FEA study for the *Velociraptor* would be to create variations upon the original claw and determine the effect of changing a range of parameters on the claws ability to perform various functions.

This paper covers only FE model preparation, and not any subsequent analyses. However, FEA within palaeontology can be used to test biomechanical hypotheses non-destructively and repeatedly with differing boundary conditions and material properties. Being able to analyse the biomechanical capability of a fossilised biological structure allows greater understanding of extinct form and function.

Conclusions

A finite element mesh of the digitally repaired *Velociraptor* claw was successfully created utilising image processing techniques within Simpleware software. The 3D digital model captured internal cavities and trabecular bone architecture on the micron scale.

This work indicates the potential of XMT and image-based modelling to other discounted specimens, opening the possibility of studying previously unusable material. This will lead to new research possibilities and further FEA studies of poorly preserved fossils, with the prospect of revealing the mechanical behaviour of extinct animal structures and their viable functions.

Demonstrated within this paper is a method for morphing specimens captured by XMT. Further development of this technique would provide the capability to digitally re-inflate specimens compressed during fossilisation, and could also be of interest to evolutionary biologists who wish to test hypothetical forms.

Acknowledgements

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USING DIGITIZATION AND RAPID PROTOTYPING TECHNOLOGIES TO REPLICATE AN URUS CRANIUM

by José Luis Barco, Gloria Cuenca-Bescós, Victor Sauque, José Ignacio Canudo, Alfredo Moros, Rosana Perruca y Javier Lorente

Barco, J.L., Cuenca-Bescós, G., Sauque, V., Canudo, J.I., Moros, A., Perruca, R. and Lorente, J. 2010. Using digitization and rapid prototyping technologies to replicate an urus cranium. *The Geological Curator* 9 (3): 199 - 206.

After its excavation and preparation, the cranium of *Bos primigenius* Bojanus 1827, found in Upper Pleistocene sediments of the Río Martín Park (Ariño, Teruel), displayed a series of features that made it unadvisable to subject it to excessive handling, let alone to transport or exhibit it. Preparations for an exhibition of palaeontology in the facilities of the Cultural Park prompted us to find the solution in the production of a replica, but this had to be carried out in such a way as to involve minimal handling and no risk to the fossil remnant. Bearing this in mind, we decided to tackle the project using the technologies of digitization and rapid prototyping, allowing us to find out for ourselves the many advantages and relatively few drawbacks associated with this methodology.

The digitization was carried out using the technique known as structured white light triangulation, which generated a CAD-based 3D model that allowed us to approach the replication and other aspects of the research and paleontological operation as set forth and analysed in the present paper. Subsequently, the 3-dimensional CAD solid model was used for replication by means of polyamide sintering technology, which resulted in a replica that was faithful to the original, light and easy to handle. The final step was the artistic decoration of the replica, thus achieving a high level of realism in the finish and readying the replica for the exposition and future studies, or didactical uses.

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Introduction

The fossil remains of macrovertebrates have certain characteristics that make it difficult to handle them throughout the processes of excavation, preparation and even study. The main factors hindering such manipulation are the size and weight of the remains, as well as the structure of the fossil, which may sometimes combine parts that are very heavy and compact with very delicate and fragile laminae; and the host material, which may have weakened the fossil during its deposition (in the case of gravel and breccia) or allowed roots and other bioerosive elements to penetrate it in the case of soft materials.

Obviously, extraction and preparation work has to be carried out on the fossil that is itself the object of study. Nevertheless, it is possible to search for alternatives that facilitate the study and even the exhibition or diffusion of knowledge about the fossils once they have been studied: namely, replicas. The problem in the production of replicas occurs when, as in the cranium of the urus found in Fogañán, the fossil is large, heavy and above all fragile, all of which makes it difficult to manipulate in preparing the mould and means in particular that it is subjected to an additional risk that may result in the destruction of some of its parts. This made excessive handling of the fossil unadvisable, let alone its transport and exposition (Moros *et al.* 2009).

The cranium of the urus from Fogañán: background and requirements

The cranium of the urus was found on the terraces of the River Escuriza, more specifically on the left bank of the river in the district of Fogañán (Figure 1), in the municipality of Ariño (Teruel, Spain) (Cuenca-Bescós and Canudo 2005). This area is part of the Río Martín Cultural Park, a group of legally associated municipalities overseen by the regional Government of Aragon with a view to preserving, spotlighting, raising awareness and promoting the cultural heritage of the region.

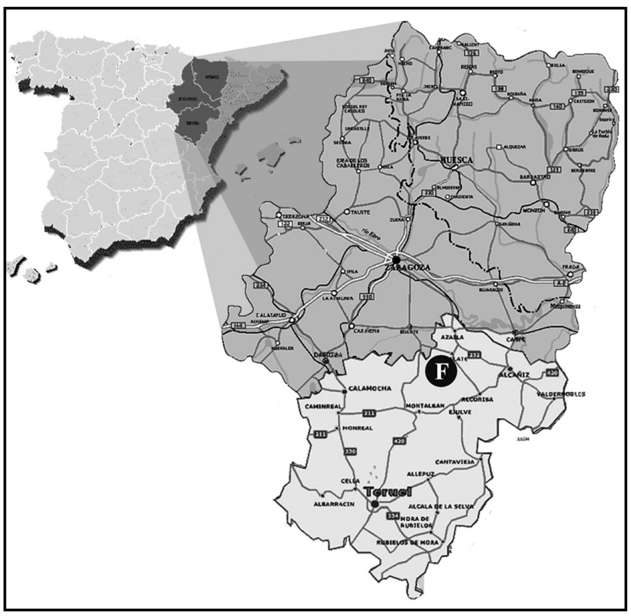

Figure 1. Geographical location of the Fogañán site, where the cranium of the urus was found in 2005.

The fossil was found at the base of a stretch of alternating lutites and sandstones, and its relation with the rest of the deposits may indicate that its deposition was a consequence of lateral sheet-flows from a ravine of the Escuriza River (Sauque *et al.* 2010). The fossil remnant has been carbon-14-dated to some 45,000 years ago, which implies that its burial occurred in the Upper Pleistocene (Cuenca-Bescós and Canudo 2007), The morphology, orientation and location of the bony nuclei of the horns permit us to affirm that it corresponds to the cranium of a *Bos primigenius* Bojanus 1827 (Cuenca-Bescós and Canudo 2005).

The discovery of a fragment of horn, the only outcropping part of the cranium, was the work of José Manuel Blesa, one of the Cultural Park's guides. The park immediately contacted the Grupo Aragosaurus of the University of Zaragoza, with a view to undertaking the excavation of the fossil, which took place with the assistance of members of staff of the Cultural Park. The surprise came when, after removing the sediment surrounding the visible horn fragment, the cranium was found to be virtually complete and well preserved (Figure 2A, B, C). The only exception was the other horn, which had a root running through it, making it impossible to preserve its distal fragment and thus ascertain the length of either of the animal's horns (Cuenca-Bescós and Canudo 2005).

The preparation was the work of the Grupo Aragosaurus and took place in the University of Zaragoza (Figure 2D). It consisted primarily of removing the matrix and above all consolidating the most fragile bony laminae. Nevertheless, the fossil still presented certain problems of stability, which were particularly serious when it came to manipulating it. The inside of the neurocranium had not been emptied for two reasons: the difficulty of reaching the sediment and above all the structural stability that it gave to this whole area. This meant, however, that a great quantity of weight was concentrated in this part of the cranium whereas other parts were not only lighter, but also more fragile due to the thinness of their bony laminae.

For these reasons, when at the end of 2008 the Río Martín Cultural Park was preparing an exhibition to celebrate 10 years of discoveries, investigation and preservation of palaeontological remains in the area, it was decided that if the cranium from Fogañán was to be one of the star exhibits on display, an alternative solution had to be found. After assessing the state of the cranium, it was considered ill-advised to move it elsewhere or even to handle it in any way with a view to making a mould or a sculpture and reproduction. It was thus necessary to find a solution that would allow us to reproduce the fossil remnant with the greatest possible detail, but ruling out or reducing all handling of it to a minimum.

It was at this point that the decision was taken to produce a replica using the methods of 3D digitization by means of structured white light, with the subsequent reproduction using rapid prototyping technologies.

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Figure 2. Cleaning (A), digging (B), removing after covering with a plaster jacket (C) and preparing (D) the cranium of the urus from Fogañán.

Figure 3. Solid model of the cranium generated after the assemblage of all the scans.

Digitization using structured white light triangulation

Three-dimensional digitization is the representation of the surfaces of which an object is composed. This is recorded in a file that integrates the x, y and z coordinates of the points that define these surfaces and any other information on the object in 3 dimensions (Zeballos *et al.* 2008).

Although there are various methods of 3D digitization, in this case structured white light triangulation was chosen, a method of projecting patterns without contact (Faico 2010). It involves projecting black and white lines onto the object and capturing images by means of a camera integrated in the measuring instruments (Nub3D 2010). This makes it possible to analyse the deformation undergone by the lines on being reflected onto the surface of the object and the location, by means of coordinates, of the points that define it. In this way, a cloud of points and mesh of triangles that represent the surface of the object is generated, allowing us to transform a physical reality into a computer file that can be manipulated digitally (Nub3D 2010).

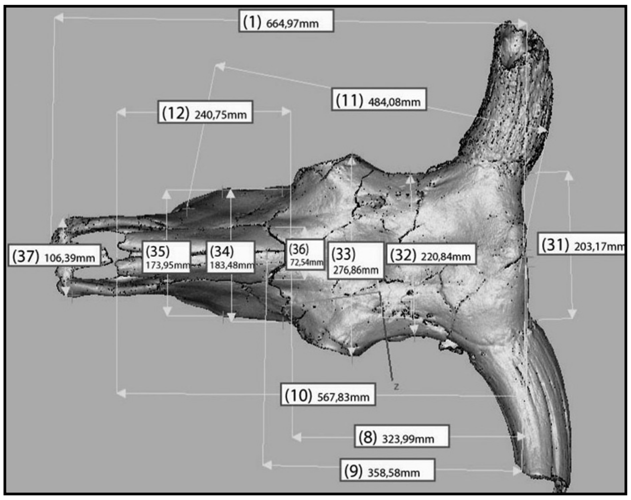

Figure 4. Some measurements of the urus cranium in dorsal view taken digitally from the computer model.

The beams of white light (from which the technique takes its name) are projected onto the object in complete darkness, so the black and white strips are in fact areas of light and darkness. This implies that the method guarantees optimum results on white objects, so to optimize digitization it was necessary to whiten the fossil cranium. To this end, talcum powders were used, these being easy to remove by means of the compressed air that supplies the hammers used in mechanical preparation. The talcum powders are usual to protect fossil of vertebrates in the preparations of moulds and casts, being totally innocuous for them. The other options to whiten the cranium required the use of water to remove the remains and thus run the risk of damaging the fossil. The use of ammonium chloride sublimation was ruled out because its application is complex and requires an important handling of the fossil remain within an extractor hood. Furthermore, this being a modern fossil and since the fossil diagenesis is not so complete as in older ones, it is quite porous and the sublimation can penetrate inside the pores and be very difficult to remove.

The complete process of digitizing the urus from Fogañán took place in just over a day, including the preparation (darkening) of the room, the application and subsequent removal of the talcum powder, and the digitization itself. Having assembled all the scans, the STL file and the solid model (Figure 3) were ready in just two days.

Data management. Measurements and parameters

In addition to the production of the replica of the fossil remnant using prototyping technologies, one of the main values of the digitized model obtained is that it makes it possible to carry out measurements and make observations on the item without having to handle it. Not only does this preclude damaging the fossil, but it also provides considerable flexibility and convenience in that it is no longer necessary to manipulate the original fossil, which is fragile and heavy and often requires the presence of two or more people to be able to study it.

The existence of a digitized model also makes it easier to send it quickly through the Internet, in this way saving on time and financial costs when it comes to providing colleagues and collaborators with information and even making journeys unnecessary in pursuing joint projects.

Managing these files makes it possible to use the computer for activities such as:

- Observing and describing details of the fossil remnant.
- Generating images of the model that are very useful for presentations, websites, multimedia, illustrations, or any other representation of the fossil remnant (Figure 3).
- Taking measurements of the fossil remnant and even incorporating them in illustrations (Figure 4).
- Drawing comparisons with theoretical models, holotypes and other specimens from the same or another taxon that are already digitized.

In the case of the urus cranium from Fogañán the application Mini Magics v12.0.5.9 (Materialise 2010) was used, a free software program that allowed us to take measurements and generate images of the model in different orientations.

Other uses of the digitization of the palaeontological record are the documentation and recording of sites with indirect remains (such as ichnites) or direct remains (such as still-unexcavated bones where one needs to know how they are arranged in order to undertake a taphonomic interpretation); the possibility of producing reproductions to scale with various aims (sale, reproduction, filming, etc.); the reconstruction of the item in real or virtual contexts for exhibition or even documentary projects; help with the preparation of the fossil, because once the item has been scanned it can be reconstructed in the computer to show the preparator where matrix has to be removed or absent elements reconstructed; and the designing of packing to facilitate transport by joining sheets of polystyrene with perforations defined by the template produced by processing the STL file (Zeballos *et al.* 2008).

Producing the replica using rapid prototyping technologies

The reproduction of the urus cranium was carried out using rapid prototyping technologies. These technologies make it possible to create models and prototypes on the basis of the solid 3D-model generated by means of CAD systems (Computer Aided Design) (Alonso Rodriguez 2010). Rapid and simple, they are very common in the production of three-dimensional models in industrial design processes, although recently work has also started on the reproduction of items of historical significance.

These technologies generally involve the addition of fine layers of liquids or components on the basis of cross-sections (in the manner of contour lines) taken from the CAD model in STL file format generated during the process of digitization (Alonso Rodriguez 2010). There are numerous techniques, and many components can be used (plastics, metals, ceramics and even wood), but for the reproduction of the urus cranium the technique of selective sintering by laser was chosen.

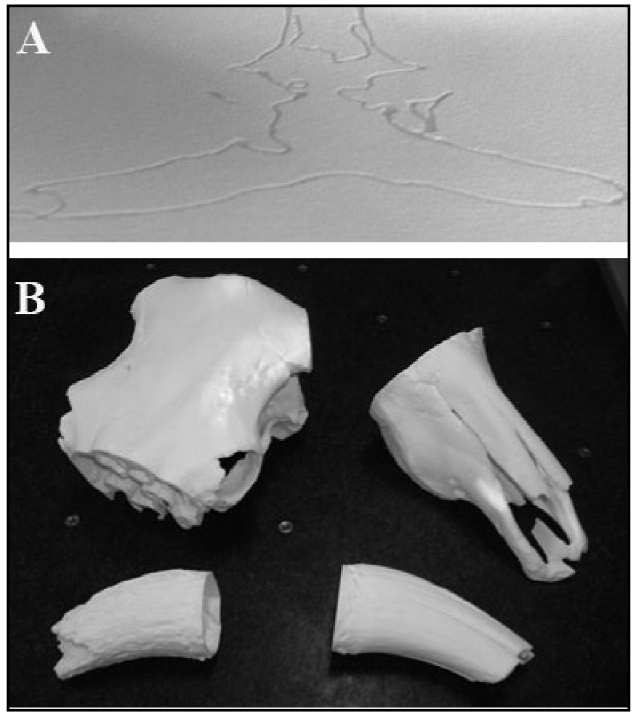

Figure 5. One of the layers after sintering with the CO_2 laser (A) and the four pieces of the urus cranium replica (B).

Figure 6. The original urus cranium (left) and the replica, still white (right) in the laboratory of the Área of Paleontology of the University of Zaragoza.

Selective sintering by laser

Sintering is a thermal process for converting components from powder or microspheres into solid form. The treatment involves subjecting the compound to very high temperatures in such a way that, without reaching melting point, a union is produced between components with similar properties.

In the case of the urus cranium polyamide microspheres were used, deposited in layers 1 mm in thickness. On each of these layers a CO_2 laser was applied to provide the heat necessary to cause the sintering of the successive sections that made up the digitized model (Figure 5A) Layer by layer we thus gradually constructed the solid that would form the final volume.

As a result of the cranium's considerable size and the rapid prototyping machine's limitations, the model had to be produced in four parts (Figure 5B) that were subsequently joined together (Figure 6). With the polyamide powder that was surplus from the process, two replicas of the urus cranium were made to scale.

Among the qualities and advantages of the replica produced using polyamide are its lightness and strength. The items produced in industrial design tend to be subjected to functional tests, and are almost as strong as the components made of injected plastic for which they serve as a model, enduring high levels of humidity and temperatures greater than 180º. This guarantees that the replica of a fossil, which is very seldom subjected to stress or exceptional thermal conditions, will display more than sufficient strength to undergo manipulation, study, exhibit and even transport.

Other applications and methods of rapid prototyping

In addition to producing replicas, rapid prototyping technologies can make other contributions to palaeontological research and dissemination of knowledge:

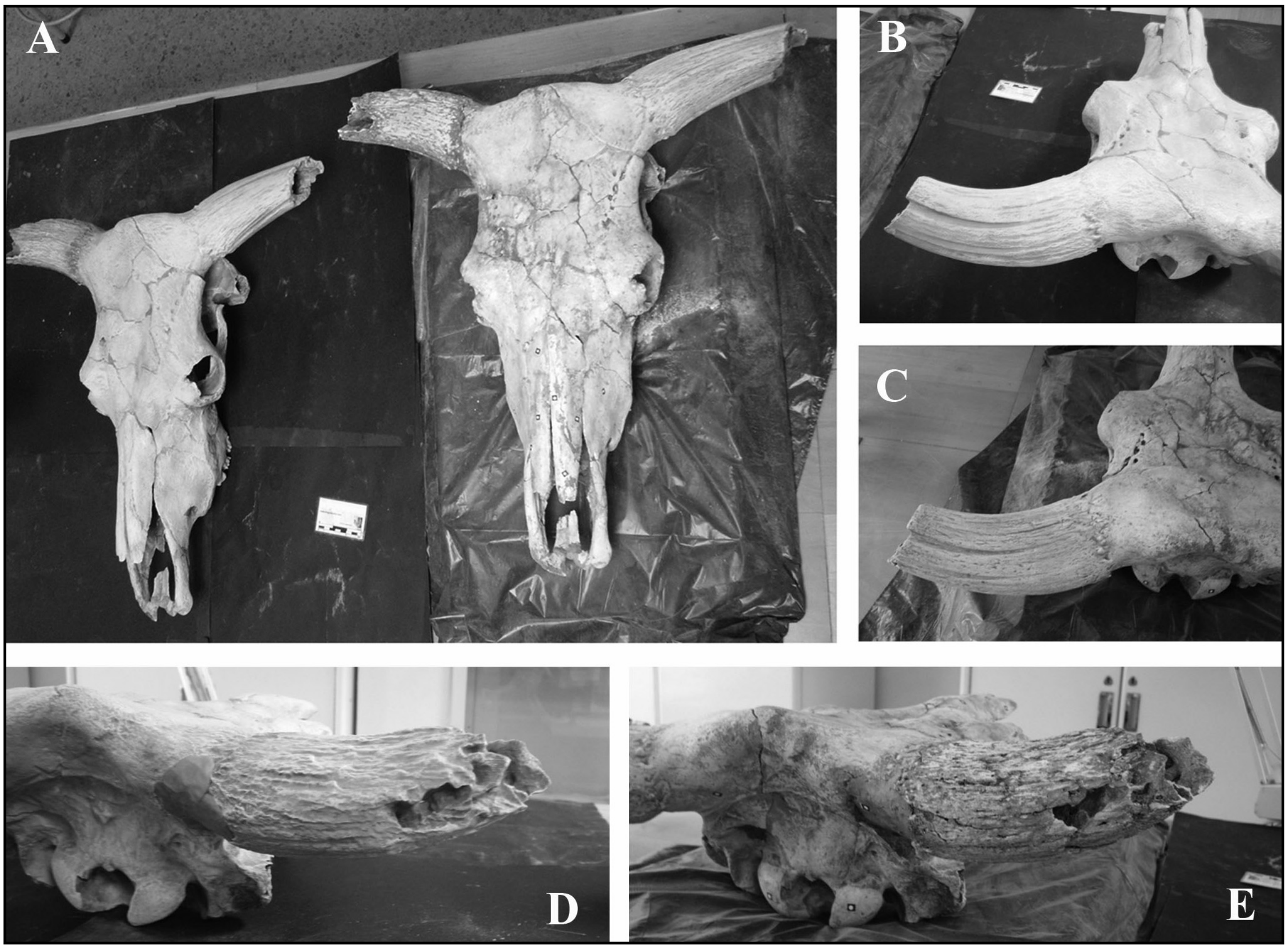

Figure 7. The replica of the urus cranium after painting and decoration (left) and the original fossil (right) (A); detail of a posterodorsal view of the replica (B) and the original fossil (C); and detail of the posterior view of the cranium and right horn of the replica (D) and original fossil (E).

- Production of pieces on a smaller scale, making it possible to reduce pieces in size (or sets of pieces, such as a whole skeleton) so they can be lent, studied or exhibited or used for any other activity that requires the handling of pieces that are faithful to yet smaller than the original.
- Production of pieces on a larger scale. This makes it possible to amplify details and produce pieces that can be subjected to studies in strength, force, aerodynamics or hydrodynamics. It may also be of use in producing enlarged items for exhibition.
- Recreation of volumes of elements that were not fossilized and not visible. If the STL file is generated using computerized tomography, it is possible to recreate cavities which during the life of the organism were occupied by soft structures such as the brain or air sacs, or which were simply empty.

There are methods that allow for replicas to be produced in greater detail. Prototyping with cured photosensitive resin and solidified with ultraviolet light allows the layers that form the final solid to be as little as 0.16 mm in thickness. Use of this method, which is considerably more expensive, facilitates the production of smaller pieces, whether the original was small or to scale.

Decoration and finish

After sintering and assembling the pieces, a perfect replica of the urus cranium was obtained, though it was pure white in colour (Figure 6). As its final use was to be as an exhibit, the item's aesthetic value was of great importance, making it necessary to give it a finish that was as realistic as possible. To this end, the collaboration of an artist was called upon.

The painting was done by impregnating the replica with a base of ivory-coloured paint applied with an airbrush, upon which earth was applied that was similar to that of the sediment where the original fossil was found. The same resins and components were used as during the preparation and reintegration of the volumes, enabling us to give the replica a degree of realism that made it difficult to distinguish it from the original (Figure 7).

Conclusions: advantages and disadvantages

From a purely palaeontological point of view, and without going into too many technical considerations regarding the methods of prototyping and their application to industrial engineering, there are various determining factors to be borne in mind in assessing the usefulness and viability of this method for use by a museum, university, public administration or research group. These are its financial cost, the staff involved, the functional characteristics of the replica (above all its weight and strength), the degree of faithfulness to the original, and the finish and final quality. These are the factors we shall touch upon in assessing its advantages and disadvantages.

Advantages:

The advantages include first and foremost the reasons behind the decision to consider this method of replication.

- The risks of harming the fossil are minimized by reducing the handling of the original as much as possible. This is substantially less than in the production of moulds using the fossil itself, and less even than methods of manually sculpting the replica in clay or wax from the original.
- Likewise, the faithfulness of the reproduction in terms of its dimensions and morphology is absolute, and thus substantially greater than for manual methods of sculpture.
- The replica is very easy to handle, being light and above all very resistant to being dropped, etc. This also makes it possible to reduce the number of people necessary for handling it during study by a single person.
- If undertaken with sufficient artistic skill, the finish too is of an absolute faithfulness and fulfils to perfection the objectives of exhibition and diffusion of knowledge.
- The whole process is a great deal quicker than the option of producing moulds and casts, whether these are made on the original fossil or a sculpture of the original.
- Both the minimal time required for producing the replica and the minimal number of staff required for the subsequent handling of it (whether for study, transport, setting up exhibitions, etc.) represent a considerable reduction in labour costs.

Of further note are the advantages that stem from the process of digitization itself:

- Handling of the fossil remnant is minimal, which is very useful when it comes to damaged or fragile remains.
- Files are created that make it possible to manage the information regarding the physical features of the fossil without having it present. This means that merely with a computer and the appropriate software (which for many of these operations is free), it is possible visualize, describe, measure, figure and present the fossil under study. Moreover, these files are easy to exchange through the Internet, facilitating collaborations and reducing transport and costs.
- The digitization is very rapid.
- The digitized files also make it possible to draw comparisons, make reconstructions, idealizations, etc.

Disadvantages:

The greatest drawback of replication by means of sintering is the cost. However, in comparison with other, more traditional methods such as the casting of moulds, constructed on top of the original or on a sculpture of the original, the costs are similar.
If other technologies such as photosensitive resin are applied, the cost is approximately twice as much as with polyamide sintering.

As regards the digitization of fossils, only two small drawbacks are worthy of note:

- It is recommendable, though not essential, to colour the fossil white. And though this is easy to remove, it is a further process that has to be undertaken with care depending on the fossil's state of preservation.
- The digitization equipment has to be transported to wherever the fossil is located, and this represents an additional cost. It is compensated, however, by the many advantages and applications that result from having the object defined in STL format.

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A MECHANICAL PREPARATION OF RHYNIE CHERT FOSSILS

by Sarah M. Finney and Lyall I. Anderson

Finney, S. M. and Anderson, L. I. 2010. A mechanical preparation of Rhynie Chert fossils. *The Geological Curator* 9 (3): 207 - 211.

The Early Devonian Rhynie cherts represent the surface deposits of a subaerial hot spring system. Historically palaeobotanists have studied the exceptionally preserved early land plants contained within the cherts by mounting thin sections of the rock on glass microscope slides. Investigation of plant morphology and life habitat has relied on reconstruction from consecutive serial sections with the inherent loss of information at the blade width scale. Here we detail the previously unrealised potential for some of the Rhynie chert beds to respond well to mechanical preparation. Recognition that some chert beds may be prepared in this way provides an additional technique for the continued investigation of the flora and fauna of this important fossil locality. The technique might find wider application in the investigation of other more recently discovered fossil-bearing sinters worldwide.

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Introduction

The Early Devonian Rhynie Chert is a fossilised siliceous hot spring deposit situated in north-east Scotland approximately 50 km from the city of Aberdeen (Rice *et al.* 2002). Mackie (1913) correctly identified the original source of the preserving silica as localised hot springs related to contemporaneous volcanism. At first, the fossiliferous chert was thought to represent a single bed of silicified peat (Kidston and Lang 1920, 1921). However subsequent investigation through trench digging and recovery of drilled borehole core in 1997 dramatically increased the number of known beds of this fossil sinter to well over 37 at the type locality (Rice *et al.* 2002; Trewin and Wilson 2004). Furthermore, prospecting for other cherts in the Rhynie Inlier successfully localised former epithermal hot spring activity at Windyfield (Powell *et al.* 2000; Anderson and Trewin 2003) and Castlehill (Fayers and Trewin 2004). To that end, no 'typical' bed of Rhynie Chert exists. However, the greater part of the early palaeobotanical work was originally carried out on one particular textural subtype. This consisted of well preserved relatively uncompressed plant axes in a dark blue-black homogenous chert matrix with a sandy carbonaceous base (Figure 1). This textural subtype is extremely tough and resilient presenting a challenge to most saw blades. Sampling bias in terms of what material was collected from the site specifically for palaeobotanical research has resulted in this subtype becoming the accepted face of what is commonly perceived as constituting 'Rhynie chert'. The colour, floral content and textural variant subtypes now known require a broader definition of this deposit. Within that definition, it must be acknowledged that although the cherts all share a common origin in drainage from hot spring outflows, their physical properties form a broad spectrum. Some are very well cemented, some have marked porosity, whilst others have porosity filled by secondary minerals such as calcite and zeolites. These differences in physical properties can be exploited by mechanical means to yield further palaeobotanical knowledge of the 'whole plants'.

Historically, Rhynie chert fossils were studied solely through the examination of glass mounted thin sections of standard thickness or acetate peels prepared using hydrofluoric acid (Hass and Rowe 1999; Trewin 2004). Subsequent workers have prepared thicker sections than normal or studied saw cut faces either bedding parallel or bedding perpendicular to examine the palaeoecological relationships of *in situ* plant stands or rare arthropod remains (Anderson and Trewin 2003). Here we report on a technique for the mechanical preparation of three-dimensional plant axes which exploits the physical properties of one particular textural subtype, the 'white chert'. This technique relies on the natural tendency of plant axes

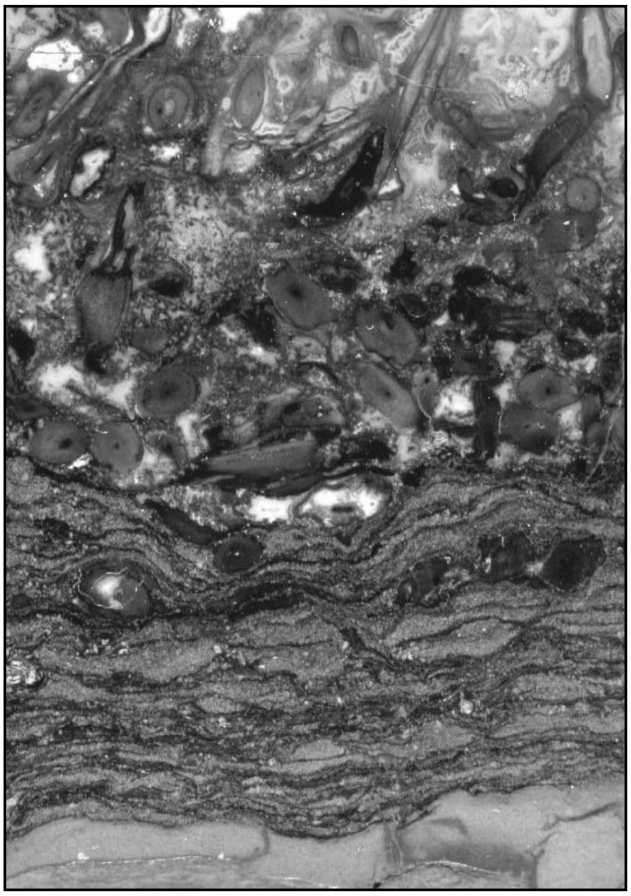

Figure 1. Cut and polished block of 'blue-black' Rhynie chert demonstrating the characteristic textural subtype from which most palaeobotanical descriptions of the Rhynie plants were originally made (NMS.G.2004.68.1).

to split cleanly from the enclosing chert matrix leaving the outer surface of the plant exposed to view. Edwards (1986) previously reported mixed success in isolating Rhynie plant fossil axes by using a combination of hot steel needles on pre-cooled blocks, but did not elaborate any further on this crude technique. Powell *et al.* (2000) figured photomicrographs of the cuticle surface of the vascular plant *Ventarura lyoni* which were taken using a scanning electron microscope (SEM). This relied on natural fractured surfaces present on some 'float blocks' (large fragments of chert bed in the overlying soil above the subcrop) collected from the Windyfield site. In theory, SEM examination of cuticle surfaces would be possible for any plant or animal remains preserved in the 'white chert' matrix and thus able to be mechanically prepared.

Materials and Method

One of us (SF) mechanically prepared SM X50151, a small block of Rhynie 'white chert' from the collections of The Sedgwick Museum of Earth Sciences (University of Cambridge)(Figures 2A, B, C). Preparation of this type of material presents a challenge due to the almost intractable nature of fossils from this locality. Although easier to prepare than the blue-black chert subtype, a considerable amount of 'will power' must still be employed for the material to yield results! The preparation technique itself is straightforward and requires very little equipment; a reciprocating dental drill with a modified tip which can hold a 1mm tungsten carbide rod, ground to a fine point, and a needle point pneumatic pen. Fine tipped pneumatic pens are useful for removing the toughest areas of matrix but are not suitable for use in proximity to the delicate surface of the plant fossils. The preparation work was all carried out under the field of view of a binocular microscope.

The white chert subtype is most frequently encountered during field walking after agricultural ploughing in the field across the A941 road opposite the Rhynie SSSI (Site of Special Scientific Interest). This field occupies the low ground between the road and the Easaiche Burn. Historically this was the bed from which the first finds of the charophyte *Palaeonitella cranii* and the arthropod *Heterocrania rhyniensis* were made (*Heterocrania* was subsequently identified as a euthycarcinoid by Anderson and Trewin 2003). The white chert also commonly yields cuticles of the crustacean *Lepidocaris rhyniensis*. This area was excavated by Mr David Tait of the Geological Survey in 1916 with his 'Trench 11' collecting many samples of the 'white chert'. The excavation was financially supported by the British Association for the Advancement of Science (Trewin 2004).

Description of SM X50151

The chert block has one saw-cut face which was polished to allow microscope examination of the surface without the need for immersion oils or cover slip glass. On this polished face, at least three very obvious sporangia can be seen in various cross-sectional attitudes (Figure 2C). Additional sporangia are obvious in longitudinal cross section on the rough unprepared side of the block (Figure 2B). All of these display a palisade structure to the outer walls of the sporangia and still contain *in situ* spores. The sporangia are elongate, fusiform and terminally borne. These features coupled with their dimensions (11mm x 4.5mm) suggest they belong to *Aglaophyton major* (Kidston and Lang 1921) (see also Wellman *et al.* 2006). The spores are tightly packed in one half of each respective sporangium, but the spore mass has a diffuse 'upper boundary'. Overlying this boundary and occupying the remaining space between the spores and the sporangial wall is a geopetal infill of cloudy, white chert clear of any other organic remains. Judging from the correlation between these

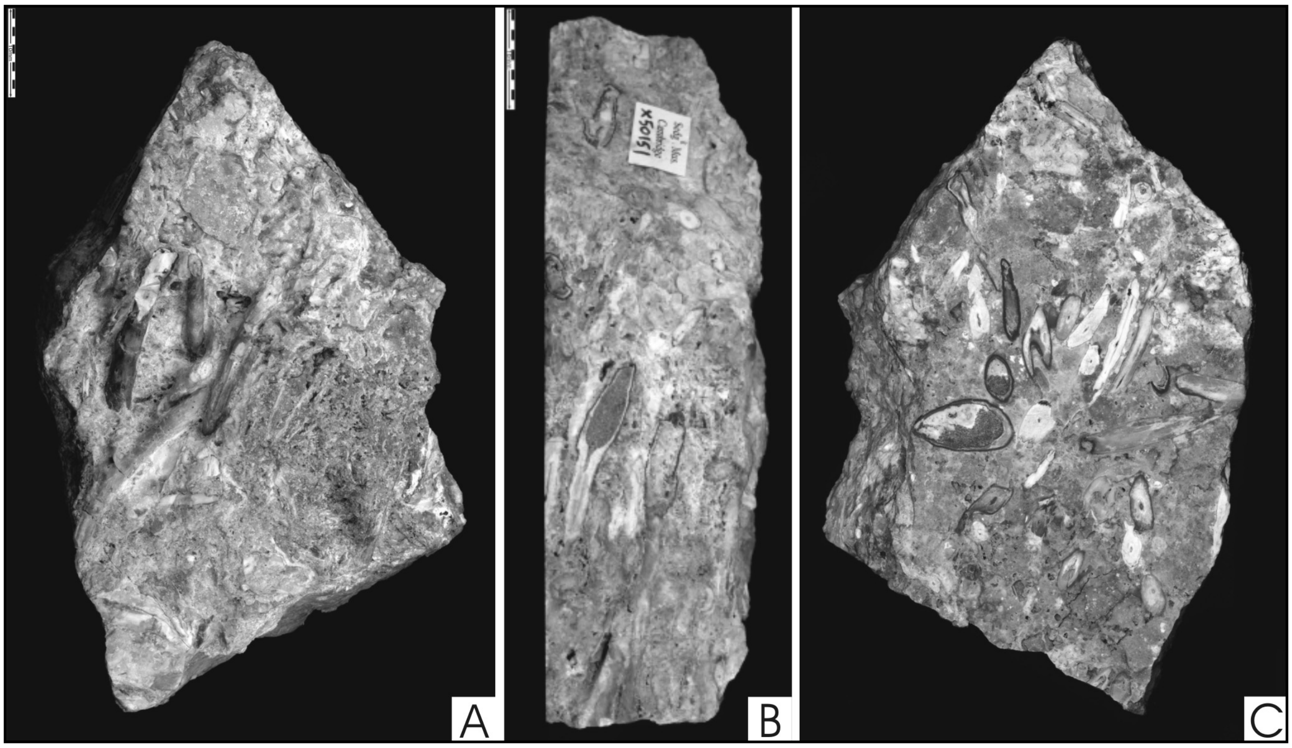

Figure 2.** 'Right way up' orientated block of 'white chert' from the Early Devonian of Rhynie, Aberdeenshire, Scotland (SM X50151). (Scale bars = 10mm). A. Mechanically prepared surface demonstrating visible surface features of the epidermis of* **Aglaophyton major** *and* **Rhynia gwynnevaughanii. B. Saw-cut edge of block revealing axes with attached sporangia still containing spores. C. Cut and polished surface exhibiting sporangia with geopetal infills (white) and* **in situ** *spores (grey-black).*

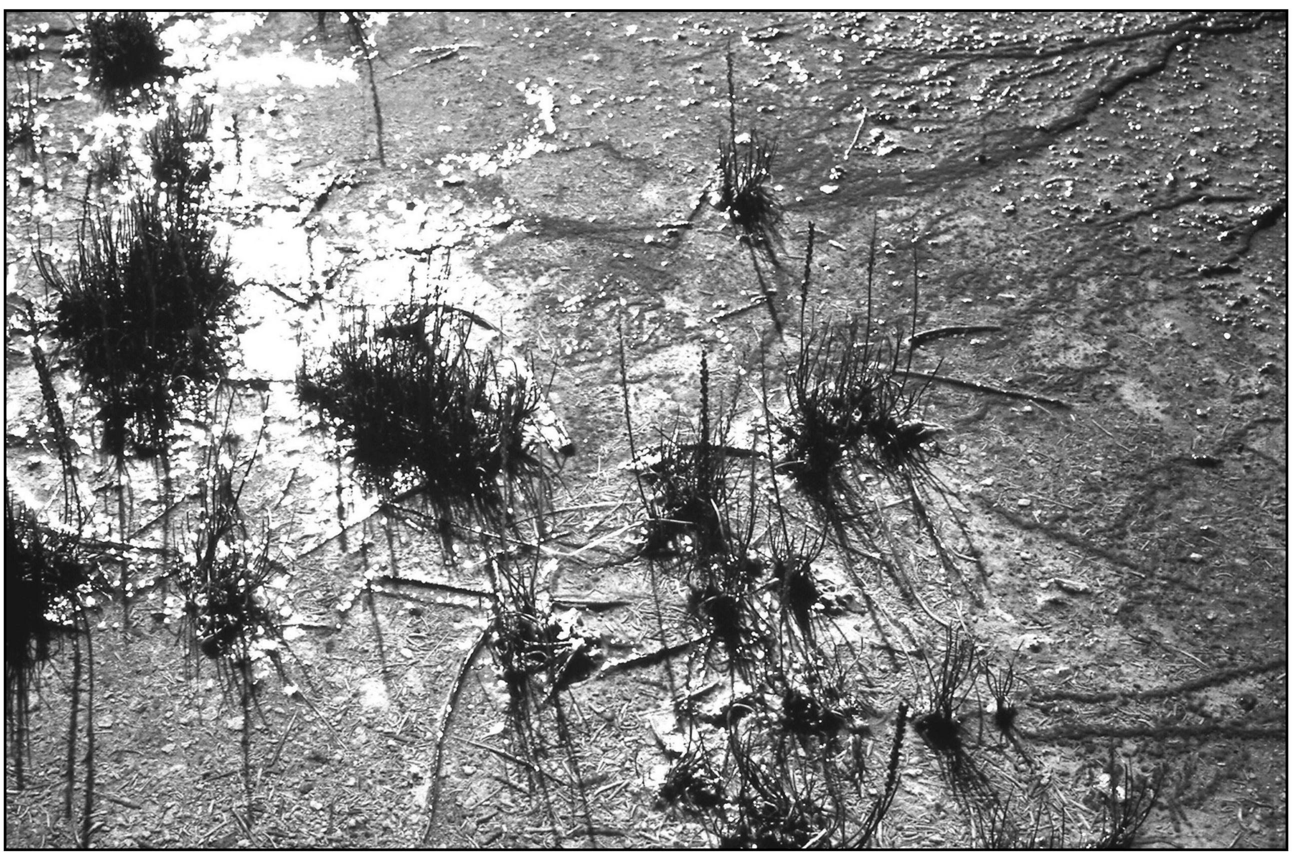

Figure 3. **In situ** ***living plants on the sinter apron of Grand Geyser, Upper Geyser Basin, Yellowstone National Park, Wyoming observed during August 1999. The bases of the plants and plant debris lying on the sinter surface become coated in silica precipitated by hot spring run-off waters as they cool and evaporate.***

geopetal or 'way up' indicators, the sporangia are in life position with a vertical or slightly sub-vertical attitude. This chert block exhibits a poorly defined bedding lamination within what would have been a vertical bed of over 74 mm. The matrix holding the three-dimensional plant stems has a diffuse 'mulm' texture (as defined by Anderson and Trewin (2003)) consisting of light brown amorphous clots of organic material, micro-coprolites, scattered fragments of *Lepidocaris rhyniensis* crustacean cuticle and algal strands. Vuggy porosity is often developed within this diffuse matrix, the vugs either lined with euhedral quartz crystals, or criss-crossed with silica encrusted algal strands. The resultant porosity of this chert texture subtype is probably the key to its successful preparation using mechanical means.

Fruiting bodies of the fungus *Palaeoblastocladia milleri* are present on the surface of a number of the *Aglaophyton major* axes emerging out into the white chert matrix. This particular chert texture is recognised as having formed by the silicification of shallow pools on the sinter surface choked with blue-green algal growth (Anderson and Trewin 2003). It differs markedly from the texture of the blue-black cherts with their distinctive meshes of plant axes, inclusion of clastic detritus and well defined lamination picked out by thin stringers of black, carbonaceous plant material (Figure 1). Terrestrial arthropod remains are more common in these blue-black cherts suggesting that they formed as a result of hot spring fluids washing over a land surface and depositing the resultant debris in shallow depressions (see Figure 3 for a modern analogue). This subtle difference in the initial depositional environment of the chert is sufficient to influence the final physical characteristics of the resultant bed.

On the reverse and roughly parallel side to the cut face of the block lie the mechanically prepared plant axes (Figure 2A). These are also in vertical to sub-vertical orientated life position in respect to bedding and are a mixed grouping of the aerial axes of *Aglaophyton major* and *Rhynia gwynnevaughanii* The white chert matrix is marginally softer than the infill to the axes and consequently, their three-dimensional nature can be revealed. This may be due to silicification of the plant axes in an event prior to that which formed the later enclosing matrix. Such preservation scenarios have been demonstrated in modern hot spring environments by Channing and Edwards (2004) (see also Figure 3).

The plant axes prepared out of the chert matrix (Figure 2A) demonstrate a number of surface features the spatial distribution of which would not be obvious in the limited plane of view of a thin section alone. Two adjacent axes demonstrate markedly different external morphologies. In particular, one axis reveals regularly spaced elliptical features (with long dimensions of approximately 1 mm) recognised as the 'hemispherical projections' (see Edwards 1980) sometimes found on the axis of *Rhynia gwynnevaughanii*. These have been shown to bear rhizoidal hairs when in contact with the ground but also in some cases in aerial axes. The other axes displays smaller circular black pits distributed across the external surface (circa 0.1mm in diameter). These circular features are surrounded by the polygonal cell structure of the plant epidermis (see Edwards 1986, figs. 8 - 9 for comparison). The regular spacing of these pits and their radial distribution in distinct bands strongly suggests that they are an original feature of the cuticle of the plant rather than some random subsequent damage. Closer inspection reveals sausage-shaped guard cells surrounding stomatal openings. The benefit of having axes in both prepared three-dimensional relief as well as cross-sectional aspect in a single block is that the nature of external surface features preserved under the same taphonomic conditions can be examined and related to the internal structure of the plant demonstrated through sectioning of the axes. Under these conditions, the black pits seen in the polished cross-section are identified as the point of entry into the plant axes of fungi which began the process of cell decomposition. The white chert formed under predominantly aquatic conditions where pre-existing stands of *Aglaophyton* were flooded and so it seems likely that these were water borne fungi, but different species to those known to parasitize the charophyte *Palaeonitella cranii*.

To date, mechanical preparation has not been applied to arthropod remains within the chert. It may not be suitable as the arthropods from the deposit tend to be uncommon, relatively small and have very thin cuticles. Consequently there may be insufficient contrast in hardness between the chert within and outwith the arthropod remains to allow successful preparation. Other optical and digitally enhanced techniques have recently been successfully applied to some of the trigonotarbid arachnids from Rhynie (Kamenz *et al.* 2008).

Recognition that some Rhynie chert can be mechanically prepared may pave the way for future studies of both plant and arthropod cuticles using SEM techniques on chert prepared in this manner. Recent work by Channing *et al.* (2007) reveals that fossil plant-bearing hot spring sinters have a much wider spatial and stratigraphic distribution than was previously thought. The recognition of broadly similar micro textures within the Argentinian Jurassic cherts described by Channing *et al.* (2007) suggests that similar mechanical preparation may be possible with this material giving the best of both worlds (anatomical cellular preservation coupled with three-dimensional external morphology).

Acknowledgements

Mrs Suzy Stevenson (NMS) photographed the blue-black chert block illustrated in Figure 1. Mr Dudley Simons (University of Cambridge) photographed SM X50151 (Figures 2A- C). LIA gratefully acknowledges funding from the Isaac Newton Trust (Trinity College, University of Cambridge).

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ACID PREPARATION OF LARGE VERTEBRATE SPECIMENS

by Carlos B. Padilla, María E. Páramo, Leslie Noè, Marcela Gómez Pérez and Mary Luz Parra

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Acid preparation of large vertebrate fossils poses special problems for the preparator. The Fundación Colombiana de Geobiología has prepared a number of large vertebrates (marine reptiles from the Cretaceous of Colombia, South America) using acid to remove calcareous matrix. A combination of factors, including: specimen size: choice of acid; number and length of acid baths; ventilation needs; area of matrix and fossil exposed; matrix homogeneity; number of acid resistant protective coats applied; management of voids; and acid consumption are shown to be important. By varying these parameters, exceptional preparation of specimens ready for detailed research and study can result.

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Introduction

Most literature describes acid preparation of vertebrate fossils without focus on specimen size. In general the material described or illustrated is just a few kilos of combined fossil and matrix (Toombs and Rixon 1959; Rutzky *et al.* 1994; but see Lindsay 1987: Figs 1, 2). An exception is Toombs and Rixon (1959, p.307), who point out that "larger specimens, such as ichthyosaur skulls and associated skeletons of all sizes, present other problems", and go on to describe how the weight of a specimen can damage newly exposed, delicate structures. The Fundación Colombiana de Geobiología (FCG) has undertaken acid preparation of large vertebrate fossils, and here we would like to outline our experience of preparing specimens that can exceed several hundred kilos of initial matrix and fossil bone, and compare this to preparation of specimens of smaller size.

Our results show that, with larger fossil specimens, the chemical properties of the matrix and the fossil bone are highly heterogeneous. This affects a range of chemical preparation parameters, such as the choice of acid(s), as well as the concentration and periodicity of immersions. The volume of matrix; its chemical characteristics; weight, volume and number of fragments; and number of acid bath cycles all affect the preparation in time, and volume of acid consumed. In this paper we wish to share our experience, by citing specimens ranging in mass from small (just a few kilos) to large (weighing several 100 kg), and hence spanning more than two orders of magnitude in weight.

Preparation

The Fundación Colombiana de Geobiología began acid preparation of large marine vertebrates from the Cretaceous sediments of Colombia. The specific specimens referred to here are: the cranium of a small testudine (FCG-CBP40; Figure 1), whose gross weight was 2.3 kg; a large plesiosaurian (FCG-CBP3; Figure 2), whose gross weight (the sum of all the fragments making up the specimen) was 409 kg; and a very large, near complete pliosaurid skeleton (FCG-CBP4; Figure 3), whose gross weight was 728 kg. Where pertinent, we also figure material from other prepared specimens.

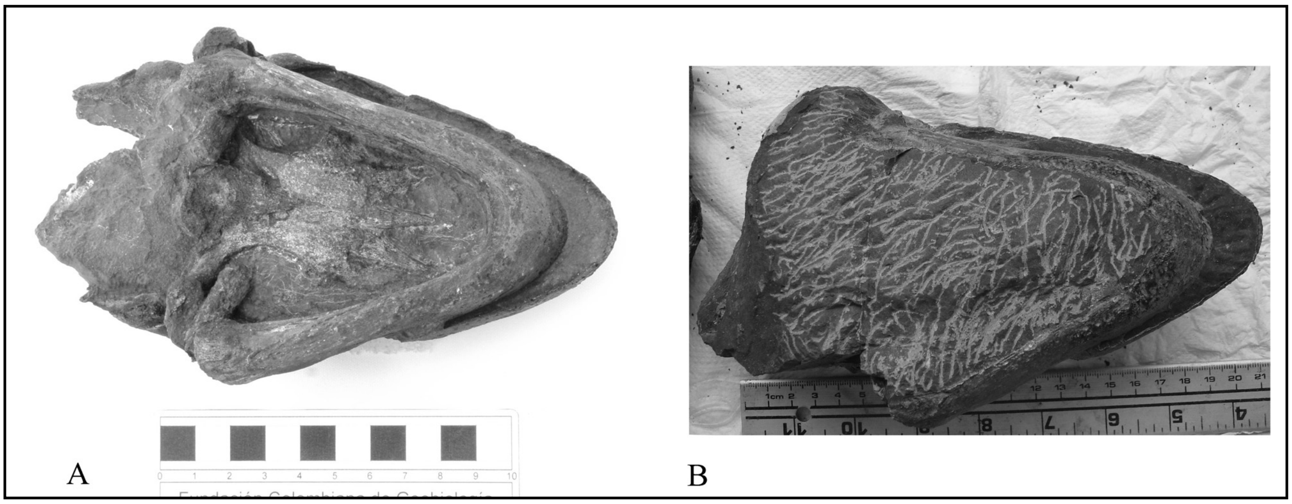

Figure 1. FCG-CBP40, a small testudine (marine turtle) cranium with the lower jaws uppermost and snout to the right. A, the partially prepared cranium; B, prior to acid preparation. Both acid and mechanical preparation were used to assist with matrix removal. Total weight prior to preparation 2.3 kg, scale bars in centimeters.

Figure 2. FCG-CBP3, an almost complete plesiosaur (sauropterygian marine reptile). A as recovered in the field with head in the foreground with snout to the right, and turning away left and towards the rear, B head and neck fully prepared showing exceptional detail of the acid preparation. Weight of specimen prior to preparation was 409 kg, skull 520 mm long, complete specimen 6.22 m.

Figure 3. FCG-CBP4, a pliosaurian (sauropterygian marine reptile) cranium as recovered in the field lying with the lower jaws uppermost and snout to the upper left; see also Figure 8. Weight of unprepared specimen 728 kg, length of the cranium 1940 mm.

All specimens were enclosed within a calcareous matrix containing small but varying amounts of non-reactive iron minerals. Acid preparation, combined with standard mechanical preparation, was used to develop the specimens from the matrix. The relevant parameters for optimizing the process of acid preparation of these large vertebrate fossils, compared to smaller specimens, were found to be:

- Size: weight, volume and number of fragments comprising the specimen;
- Choice of acid(s) used;
- Acid bath cycle time and ventilation needs;
- Area of exposed matrix compared to fossil bone exposed;
- Matrix homogeneity;
- Number of protective acid-resistant lacquer coats;
- Managing crevices within the matrix and/or specimen;
- Rate of acid consumption.

Each of these parameters is dealt with in more detail below.

Specimen size

The importance of surface area is a well known parameter relating to solubility in chemical activity (e.g. Tyagi 2009, p. 4.7.; Albarède 2003). Hence, the activity of an acid, independent of the acid used, varies with the size and number of fragments that make up the specimen. Smaller fragments have a larger surface area to volume ratio, compared to a single larger specimen of the same mass, and the matrix will be removed more quickly from the smaller specimens compared to larger fragments. The largest element of FCG-CBP4 (Figure 3) weighed 50 kg. Such large specimens require more acid bath cycles to prepare than smaller specimens, or skeletons recovered from the field as numerous loose elements (Figure 4).

The variance in time required to prepare larger versus smaller fragments of a specimen poses challenges to the preparator, as the smaller elements will be fully prepared sooner than the larger ones. Where large and small fragments have contact surfaces, these should be verified after each acid bath cycle to ensure continuing contact. The importance of protecting contact surfaces between fragments cannot be overemphasized in order to ensure a good joint surface after preparation is finished. Indeed it is preferable to overprotect these joint surfaces with multiple coats of acid resistant lacquer, than to risk acid attack and damage to these surfaces. Excess protective coats can then be removed after preparation is finished. These well-preserved fracture and contact points are extremely useful for reconstructing original complex morphology, and for exposing internal anatomical structures, when study of the specimen begins.

A second area of importance to chemical activity is the effect of temperature (e.g. Fisher and Arnold 1999). Acid bath temperature can be expected to have an affect on acid preparation activity; however, in our laboratory temperature is relatively stable, between 18-20°C. We therefore did not focus on this area of study. Nonetheless, acid bath temperature may need to be controlled if ambient temperature varies by many degrees during the course of one, or a series of, cycles. Higher temperatures will provide faster removal of matrix, but they will also increase the fumes produced by the acid bath, and potentially cause more rapid damage to the specimen being cleaned.

Figure 4. FCG-CBP1, an almost complete skeleton of a large testudine (marine turtle) with head to lower right. The specimen was recovered in many pieces and this fragmentation simplifies acid preparation, however, the junctions between contiguous elements must be extremely well protected from acid attack during preparation to ensure close fit of adjacent fragments. Scale bar 300 mm.

Choice of acid(s)

Acid preparation is carried out with weak acids, generally organic, which disassociate (ionise) incompletely, rather than strong acids, generally inorganic or mineral acids, which essentially disassociate completely. Weak acids are used in order to limit acid activity and potential damage to fossil material (Lindsay 1987); in addition a phosphate buffer is added to the solution to limit acid damage to the calcium phosphate of the fossil bone. Acetic and formic acids, both weak organic acids, are the most commonly used in calcareous fossil preparation (Lindsay, 1987), with acetic preferred in Europe, largely due to the slightly greater health and safety risks associated with using formic acid, and formic in the US because of the more rapid reaction times. Of the two acids, formic is the stronger weak acid, as it has a greater disassociation constant (pK_a) thereby providing a greater number of H+ ions to the solution; acetic acid has a lower pK_a than formic acid and can therefore be considered a relatively weaker weak organic acid. However, the Fundación Colombiana de Geobiología has also used sulfamic (US English) or sulphamic (UK English) acid (chemical formula H_3NSO_3) which is a somewhat stronger weak organic acid than either formic or acetic acids. Sufamic acid is a colourless crystalline solid with long-term stability during storage.

When the area of exposed fossil is small relative to the volume of matrix, a stronger weak acid is preferable, as it requires fewer, shorter acid immersions (but see Jeppson *et al.* 1985 and Baars 2009 for comments on acids and style of preservation). These more rapid cycles limit the potential for acid to penetrate the specimen and can thus cause unseen damage. If the specimen is already well exposed, or when preparation has advanced exposing more fossil material, a decision can be made as whether to continue with the stronger weak acid or whether to finish the preparation with a weaker weak acid, such as formic or acetic. We have found that a combination of acids produces the best results.

Acid bath cycles and ventilation

When preparing large specimens, results were consistently better using the stronger weak acids to speed up initial matrix removal. The lower dissociation constants of the weak organic acids, compared to mineral acids, allow them to be used at low concentrations (we have standardized sulfamic acid concentration to 2% weight by volume) permitting longer immersion cycles (of up to 8 hours) without causing damage to the fossil material. Historically much greater weak organic acid concentrations have been utilised, starting at up to 33% acetic acid, later reduced to 10-15% where much care is required (Rutzki *et al.* 1994). At the lower concentrations the weaker acetic acid H+ ions are quickly consumed, so that for the most part the acid activity finishes within about 2 hours. Hence the number of acid bath-wash-dry-protect cycles more than doubles compared to stronger acids. However, stronger acids can last many more hours before losing their activity. Due to the longer acid bath cycle times that stronger acids allow at low concentrations, it is important to inspect the cleaning process at least every two hours to assess progress as new fossil is exposed. This will minimise potential damage to the specimen being prepared.

Specimens consisting of many fragments benefit from multiple acid bath tanks being used in parallel for each cycle. This requires more physical space in the preparation laboratory, and a more sophisticated ventilation system. The Fundación Colombiana de Geobiología opted for a significant change in the acid used, incorporating the use of a weak organic acid that does not produce toxic or corrosive fumes; sulfamic acid (whose use is currently being described in another paper to be published elsewhere). The use of sulfamic acid simplifies ventilation to just the CO_2 produced from the activity of the acid on the calcareous matrix. During acid bath cycles, it is important to have a firm spongy material (such as Plastazote foam) to support the fragments being prepared, as direct contact with the bottom or sides of the container may cause damage to the integrity of the fossil or protective films caused by the weight of the specimen (Rutzki *et al.* 1994).

Area of exposed matrix and fossil

The greater the area of matrix exposed on the specimen, the greater the benefit of using a stronger acid to remove the matrix more rapidly with fewer acid immersion cycles. If, on the exposed surfaces, fossil material predominates, starting with a weaker acid is generally a better option to avoid unnecessary stress or damage to the fossil material. However, if matrix dominates then a stronger weak acid will remove more of the matrix more rapidly than a weaker acid. The issue is then one of acid strength and acid speed of action (and hence preparation time) versus potential damage to the specimen, which can be minimised by careful observation whilst the specimen is in the acid and judicious washing with fresh water upon completion.

Matrix homogeneity

Large specimens that may extend over many metres in length, and with varying width and height, are unlikely to be surrounded by homogenous matrix. Hence, matrix heterogeneity is quite usual, and for the Fundación Colombiana de Geobiología material containing ferric (Fe 3+) iron in the matrix is one of the most difficult and intractable problems to deal with. A strategy of mixed acid and mechanical preparation has proven indispensable (Figure 5). Trials on small, 5-10 g, fragments of matrix will quickly indicate where the acid will work best, or where more mechanical preparation is required.

Figure 5. FCG-CBP25 pliosaurid, a sample of calcareous matrix containing ferric (Fe 3+) iron, which is not susceptible to acid attack. This must be removed mechanically for acid preparation to continue. This is a chip of matrix ws used to test the efficiency of the acid on the matrix; field of view approximately 150 mm

Figure 6. FCG-CBP4, the snout of a large pliosaurian with snout to lower left. A, specimen 'overprotected' with several thin layers of B72 polyvinylacrylate to impede acid attack on the bone; B, the same specimen, but inverted, with preparation completed and the excess B-72 removed, to reveal the fully prepared specimen.

Number of coats of acid resistant lacquer

Over the years we have experimented with the polyacrylates Butvar (polyvinyl butyral) and Acryloid (or Paraloid) B-72 as acid resistant lacquers. Eventually we have continued to work only with Acryloid (Paraloid) B-72, as we preferred the integrity of the film after repeated handling and acid cycles. To dissolve the B72 we have minimized the use of acetone as a solvent, largely for health and safety reasons, and are currently using industrial grade ethanol. Acetone continues to be used, but only for the removal of excess B-72 after matrix removal is completed.

The outcome of acid preparation of large specimens, which need to be submitted to many acid cycles, depends on the extent of the protection provided to the gradually exposed bone. Rixon (1976) points out that some failures with both formic and acetic acids have been caused by over coating specimens as they are prepared. We agree that a single thick protective layer does not provide adequate protection, as the acid easily undermines a single layer of acid resistant lacquer. In addition, the physical integrity of a single thick layer can be compromised during manipulation and handling of the specimen. However, several thinner layers of acid resistant lacquer, commencing with a solvent wash to displace remaining water, can effectively protect the fossil material over many acid bath cycles. However, it is better to over protect the specimen and later remove excess layers of polyacrylates once the fossil is completely prepared, than to under protect it.

After initial acid cleaning, consisting of immersion of a fragment for a few minutes without any protective coats (Lindsay 1987), the specimen is washed and allowed to dry. To begin protection of the exposed fossil material, initially immerse or brush on pure solvent (we use ethanol) to displace remaining water in pores or crevices, followed by one or two coats of very dilute polyacrylate (1-5% wbv). This is followed by application of pure solvent (ethanol) brushed on to assist the dilute protective lacquer solution to penetrate the fossil bone. Once dry, applying one or more final coat(s) of a more concentrated polyacrylate solution (5-15% wbv) will provide the final protection; we have used up to four layers on some specimens, gradually increasing the concentration of the applied lacquer. After each acid cycle, the procedure is repeated to protect the newly exposed bone, and if necessary to reinforce the protection of previously exposed bone. With the preparation completed, the excess polyacrylate is removed with acetone (Figure 6).

Management of crevices

Rixon (1976) indicates that sometimes it is not advantageous to fill the cracks and crevices in the bone until acid preparation is almost complete. We agree that on free bone the selective cleaning of the acid can really bring out the details of suture lines, foramina and other features However, we make the case for occluding small cracks and larger crevices not in the fossil material, but rather in the matrix being removed. Not managing these crevices in the matrix will allow the acid to penetrate deep into the material being prepared and potentially damage the fossil long before the matrix encasing the material has been removed. After the cracks and crevices have received polyacrylate protection, provided by pouring or injecting it into the crevice, the specimen is allowed to dry. Further filling of the crevices to restrict entry of the acid solution is attained by physically filling in the remaining spaces. The best material is dental wax (Figure 8); however its cost can be prohibitively expensive in large crevices, so a second best option is Plasticine. Both are substances are reusable in the laboratory following completion of acid preparation, and the initial acid resistant lacquer acts as a separator layer between specimen and filler.

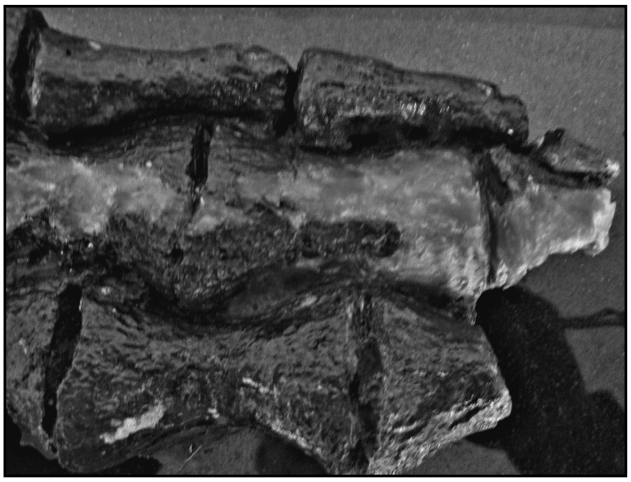

Figure 7. FCG-CBP4, plesiosaur paddle bones, with dental wax being applied to the gaps in matrix and bone; field of view approximately 200 mm.

Acid Consumption

Acid consumption is proportional to the volume of calcareous matrix removed, and during the preparation of three fragments of the snout of FCG-CBP4 (Figures 3 and 7), the volume of acid used varied according to the weight of matrix removed. The unprepared weight of each fragment is shown in Table 1 together with the final weight of each prepared fragment and the mass of matrix removed. From this, it was possible to calculate the percentage mass loss, and to observe that, although all three fragments joined together, the amount of matrix removed from each varied considerably. This difference in the volume of matrix removed indicates a difference in the volume of acid required in their preparation. However, as the volume of matrix to be removed is generally unknown at the outset of acid preparation, the consumption of acid is essentially unpredictable. Hence, it is good practice to have a generous supply of acid available to ensure work does not need to be interrupted, thereby wasting valuable preparation time.

A B

Figure 8. FCG-CBP4, the snout of a large pliosaurian (sauropterygian marine reptile), upper surface of cranium with snout to the right; see also Table 1. A, the unprepared snout showing the anterior three fragments; B, the prepared specimen with the three snout fragments in place at the front of the cranium. Length of cranium 1.94 m.

Fragment number	Initial weight	Final weight	Weight of matrix removed	percentage mass reduction
Cranium 1	11.4	4.1	7.3	64
Cranium 2	8.8	7.6	1.2	14
Cranium 3	14.0	12.6	1.4	10

Table 1. Reduction in mass of three consecutive cranial fragments of FCG-CBP4 (Figures 2, 9) following acid preparation. Specimens were weighed prior to and following acid preparation; all weights in kg.

Conclusions

Acid preparation is an excellent choice for removing large vertebrate fossils embedded in a calcareous matrix, as has already been documented for many smaller specimens (Jeppson *et al.* 1985; Lindsay 1987). The use of sulfamic acid, a stronger weak organic acid, in the initial preparation cycles has distinct advantages; it does not produce toxic fumes which simplifies ventilation and increases the number of acid baths that can be used at once. This stronger weak acid increases initial matrix removal and reduces the number acid bath cycle times, without compromising the quality of preparation.

The use of a mix of acids and mechanical preparation techniques not only optimizes the results of preparation, but is almost essential due to variations in the make-up of the matrix across large specimens. The importance of protecting the often fragile fossil material cannot be overemphasized, especially given the number of acid bath cycles required to prepare large specimens. The parameters followed need to be varied to optimize the process given the nature of dealing with large and complexly shaped specimens. The choice of acid(s) should also be carefully selected in order to avoid undue stress to the fossil material, while achieving the preparation goal in an adequate time frame. This combination of factors has produced excellent results with minimal damage to the specimens being prepared, whilst providing excellent material for subsequent research and display.

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Appendix: Materials

Acetic Acid. 99.5 % USP (United States Pharmacopeia), purchased locally from Quimicos ORBE, can be purchased from a chemical supply house such as SIGMA-ALDRICH Corporation, 3050 Spruce Street, St. Louis, MO 63103, USA.

Formic acid. 85% USP, purchased locally from Quimicos ORBE, can be purchased from a chemical supply house such as SIGMA-ALDRICH Corporation, 3050 Spruce Street, St. Louis, MO 63103, USA.

Sulfamic acid. We used a commercial version of sulfamic acid sold for descaling of boilers, evaporators aboard ships; trade name DESCALEX, Unitor Marine Services (reference 571646) which incorporates a pH indicator to show when the acid is spent. Available in 25 kg cans through Wilhelmsen Ship Service at any port in the world: in New York, Wilhelmsen Ship Service, 210 Edgewater Street, US-10305 Staten Island, N.Y., USA, telephone 718-815-9835. It can also be purchased USP grade from SIGMA-ALDRICH Corporation, 3050 Spruce Street, St. Louis, MO 63103, USA.

Ethanol. Industrial grade 96% (denatured), purchased locally from Quimicos ORBE, can be purchased from a chemical supply house such as SIGMA-ALDRICH Corp., 3050 Spruce Street, St. Louis, MO 63103, USA.

Acryloid (Paraloid) B-72. Purchased from Talas, 568 Broadway, N.Y., N.Y. 10012, telephone (212) 219-0770.

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VOLCANICLASTIC MATRIX: METHODS, PROBLEMS, AND SOLUTIONS OF EXTRACTION

by Ana M. Balcarcel

Balcarcel, A.M. 2010. Volcaniclastic matrix: methods, problems and solutions of extraction. *The Geological Curator* 9 (3): 221 - 225.

Over the last two decades, expeditions to the Chilean Andes have produced diverse mammal faunas and extremely well-preserved specimens. Many of these specimens are preserved in volcaniclastic matrix that is the hardest encountered by preparators at the American Museum of Natural History, and it offers unusual challenges for collection and for preparation. The nature of the matrix requires that specimens sometimes be collected in multiple pieces and with a much higher proportion of matrix than is common in specimens from more typical localities. Many times, the Chilean fossils are exposed in section and, in contrast to the matrix, the included fossils are very soft and fragile. The exposed, eroded surfaces of the specimens often cannot withstand the impact of typical tools such as airscribes and needles. Here, I describe the difficulties offered by this matrix, a protocol for dealing with those issues, and an embedding technique that allows recovery of all salient details of the specimen.

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Introduction

Dr. John Flynn, Curator of Fossil Mammals at the American Museum of Natural History, has been leading expeditions to South America to search for Cenozoic fossils for more than two decades. Among the regions worked by him and his colleagues is an area in the Andes of central Chile that has yielded numerous new fossil mammal localities and species. Because these specimens derive from a virtually unsampled part of the continent, and in some cases also represent under-sampled time intervals, they are of great interest for understanding the evolution of South American mammal faunas, paleoenvironments, and geological history of the Andes. These fossils are mainly preserved in volcaniclastic rocks of the Abanico and Cura-Mallín formations that sometimes appear to be reworked from older volcanic deposits.

Preservation of fossil remains in volcaniclastic matrix is unusual and offers a special set of challenges. This Andean rock is among the hardest encountered by preparators at the American Museum of Natural History. In contrast, the fossils within are friable and much softer. Often there is no visible color difference between the bone and the matrix. Moreover, the high density of this matrix is such that it typically renders CT scans and X-rays useless.

Many preparators will be familiar with the juxtaposition of hard matrix and soft fossils exemplified by the specimens described below. Here, observations are offered regarding the nature of the problems posed by this unusual mode of fossil preservation and a protocol for safe preparation of these specimens and, perhaps, others like them.

Color and Density Challenges: In the Field and In the Laboratory

These fossils come from an area in the Chilean Andes that experienced extensive volcanic activity throughout much of the Cenozoic. The host matrix contains a variety of volcanic rock fragments likely derived from older massive lava flows. This rock has been highly lithified (compacted and cemented), resulting in extremely low porosity (C. Mandeville, *pers. comm.*). Most likely this matrix is an amalgam of many types of older volcanic debris, making it a matrix that challenges traditional preparation techniques.

Difficulties with this volcaniclastic matrix begin in the field. Because the matrix is dense and hard, and the fossil-bearing beds are massive, standard collection tools such as the Marsh pick and awls often are inefficient or ineffective. Instead, tungsten-carbide tipped chisels usually are a necessity. Sledge hammers can be invaluable. Sometimes, even large, gas-powered, diamond-bladed rock saws are carried on expeditions. Specimens are cut out as large blocks from the substrate. These labour/time intensive collecting methods do not allow for the usual field practices wherein extraneous matrix is removed on site. Thus, the matrix-to-specimen ratio tends to be high, yielding heavy blocks of a size and density greater than those collected from typical sandstone and mudstone matrices. Additionally, hammering the rock to form smaller blocks creates fissures, often splitting the block through the fossil. Consequently, many specimens arrive in the preparation lab as shattered pieces.

Dense matrices are a common issue for preparators, as are lengthy preparation times. In the case of this volcaniclastic matrix, preparation using standard pneumatic air scribes can take several months, even for small specimens. Aside from the issue of excessive matrix, very low contrast in both color and texture makes it difficult to distinguish the fossil specimen from the surrounding rock. There is often little to no color difference between the matrix and the fossil included within it. Eroded and weathered bone surfaces are the exception because they may sometimes be lighter against a darker matrix. Differences in texture between bone and matrix can only be discerned under high magnification, and even then the edges of a specimen can be difficult to define. This is a particularly important problem when deciding where to trim excess matrix to reduce preparation time. The tendency is to believe the naked eye, but appearances can be very deceiving with these specimens. Careful analysis under a microscope is critical before trimming (Figure 1).

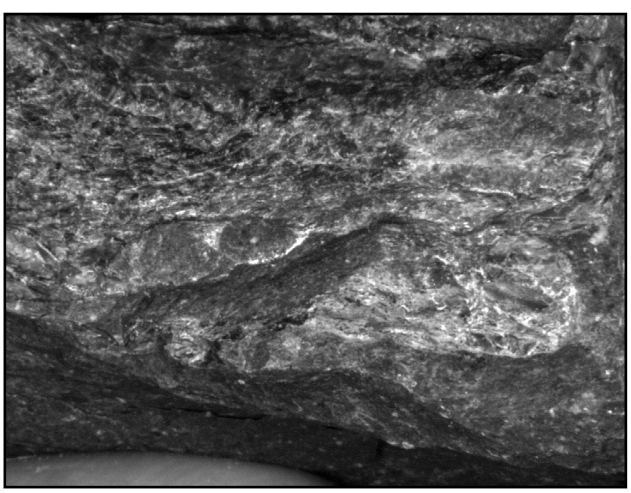

Figure 1. Typical, prepared specimen from Abanico Formation of central Chile in section, under high 12X magnification. Jaw fragment showing cross-section of teeth and dentary. Note that it is difficult to distinguish the bone of the dentary from the surrounding matrix.

Excess matrix can also mask the presence of more than one specimen or multiple elements of a single individual. With little to no preparation done in the field, the extent of the included fossil is unknown. Under more forgiving circumstances, we might alleviate this problem by x-raying or using computed tomography (CT) scans of the specimen. However, the density of this matrix is such that traditional radiographs or newer CT scans frequently provide no helpful insights.

In the Lab: methods and solutions

I offer below a suggested protocol for significantly reducing preparation time, while preserving the integrity of both the specimen and its morphological data. The methods are simple, yet have withstood the challenges of the parameters described above.

Identification and Assembly

First and foremost, delineation of a specimen's margins must be achieved before the required trimming of a block. The naked eye and knowledge of anatomy can enlighten only so much. As described above, the use of a microscope allows for a more accurate distinction between fossil and matrix. If both of these options prove insufficient, ultra-violet (UV), or "black" light can be used. When UV light is shone on these Chilean fossils, the bone fluoresces. Fortunately, the matrix does not, making this a reliable technique that can be applied at any stage of preparation (Figure 2).

Once the exposed areas of the specimen have been identified, trimming can be done in two ways: via diamond-bladed rock saw or by simply scoring and chiseling. Trimming will take approximately one to two hours for a typical Chilean block. The reduction in weight alone is critical for handling the specimen during preparation. Most importantly, however, this quick removal of bulk matrix translates to a reduction of preparation time by several months (Figure 3).

Once this is done, re-assembly and adhesion of all parts ensues, if it is a specimen collected in multipart blocks. Re-assembly of the specimen requires the selection of an adhesive that will support the weight of the specimen and one that later will withstand the vibration of air scribe preparation. In our case, Devcon 2-Ton epoxy is used, mainly for its strength, but also because of its durability and low viscosity. An Adhesive such as Acryloid B-72, even at a high concentration, is too weak to support the weight and density of this matrix. Two-ton epoxy, however, is strong enough, and due to its slow setting

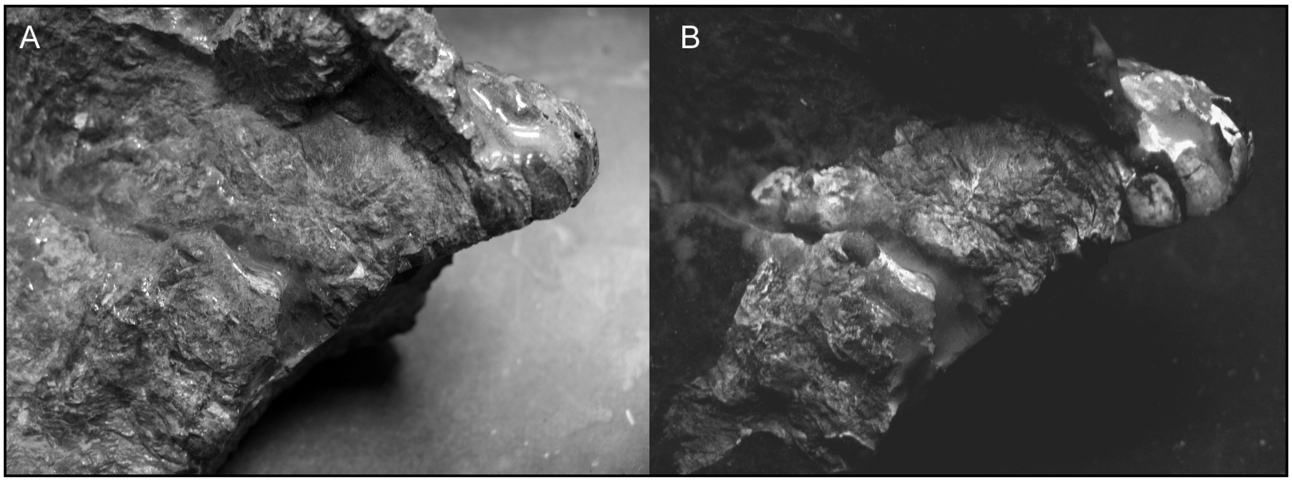

Figure 2. A. Unprepared specimen, after all parts were adhered, in natural light, no magnification. B. Same specimen under black light. The dark area is matrix, the glowing white area is fossil bone. The lighter grey areas are 2-ton epoxy, where the specimen was glued.

Figure 3. The specimen being held on the left shows the actual exposed bone from a specimen. The pile of matrix on the right is the 3-4 kg of matrix that has been removed.

Figure 4. Above. Constructing the silicone cup using rings of household silicone.

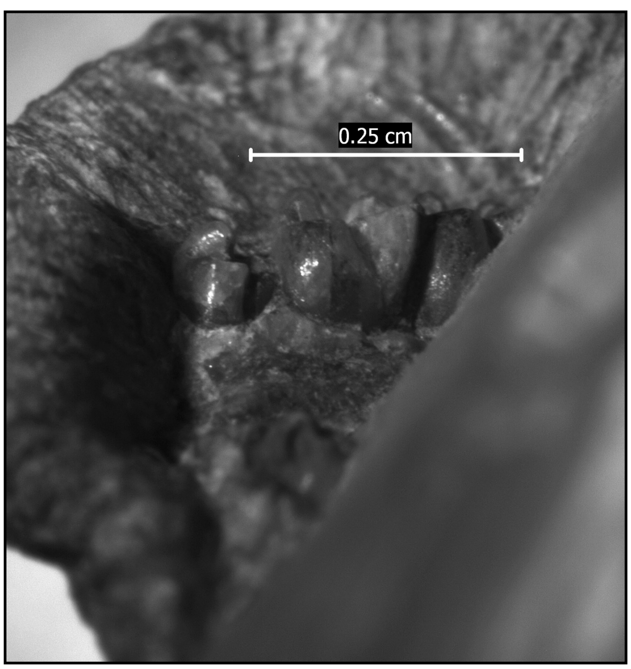

Figure 5. Left. Finished, prepared specimen illustrating the preservation of the important morphological features. Note the very small size of the specimen. The epoxy provides a stable base that may serve as a handle while manipulating and preparing the specimen, and a substrate for engraving the specimen number. This is especially useful because the number will remain visible in the specimen casts.

allows for penetration into small cracks. The brand used here is Devcon 2-Ton Clear Epoxy. The set time is eight hours; mixed viscosity is 8,000 pcs; tensile strength rating is 2250 psi. Excess epoxy can be mechanically removed with a needle or air-scribe, so generous amounts should be used to fill in all fissures. In cases where natural moulds exist in the matrix, this same epoxy can be tinted and thickened with fumed silica; thus creating a cast of any impressions in the rock. Butcher's wax should be used a separator in such cases.

Air Scribe and Manual Preparation

Micro-preparation begins after the specimen has been assembled and trimmed. This reduction of size and weight still leaves a surrounding matrix block whose density and hardness challenges standard pneumatic air scribes, and a specimen within that can take weeks or months to prepare.

The most powerful air scribe I use is the Chicago Pneumatic air scribe. There are more powerful air scribes available, but the Chicago Pneumatic offers the most advantageous combination of power and reduced vibration. Although effective in bulk matrix removal, the Chicago Pneumatic can be used with enough finesse to avoid creating large fissures and cracks during preparation. I follow the Chicago Pneumatic with the Micro Jack 4 air scribe and the Aro Marxal air scribe with a traditional tip. All scribes should be used with carbide needles rather than steel ones, as steel is weaker and less effective on this matrix. Preparators may find comparable air scribes (such as the Micro Jack 2) that work just as well. It is simply paramount that vibration is controlled and more stable scribes are used closer to the specimen. In fact, once the morphology and size of the specimen are clearly revealed, all three air scribes can be used in alternating fashion, avoiding altogether the use of the Chicago Pneumatic close to the fossil. In all cases, the very last air scribe I use is the Aro Marxal with a German tip (Nadelhalter HW 10NH, made by Stone Company, Inc.) The needle, bushing and needle support for this tip are the most stable and precise available for the Aro Marxal air scribe. The high stability allows for its use on the final thin layer of matrix encasing bone; yet is has enough strength to make this dense matrix separate from the fossil without damaging it. The safest way to do this is by using the scribe at a very low angle to the fossil plane, resulting in matrix separation that is much better than that achieved by manual needle work. This technique requires experience and great control of the air scribe.

Final preparation of teeth and their occlusal surfaces should be done using standard manual procedures (using carbide or steel needles in pin vices).

Embedding-One Solution

Broken bone surfaces that have been exposed during collection or by erosion often can be too fragile to handle the pressure and vibration of the standard preparation techniques described above. Often, these specimens have important morphologies such as tooth crowns or delicate cranial elements that have been weakened by such exposure. When this is the case, direct pressure by an air scribe or a manual needle can cause significant damage, or prevent the extraction of the fossil altogether. Thus, we suggest a different approach to preparing these specimens: Embedding the exposed or fragile areas in optically transparent epoxy (Epo-Tek 301-2, made by Epoxy Technology, Inc.). This embedding technique uses a transparent epoxy to protect morphologically critical areas of specimens when preparation poses a risk for loss of data. At times, this is not only a preventative measure, but the only way to fully extract a fossil. Once vulnerable areas are embedded, the specimen is prepared from the opposite side. With epoxy as a base and stabilizer during preparation, an eroded surface can be better preserved, the remaining bone or teeth stabilized, and even natural moulds preserved for study. This embedding procedure has been used at both the Field Museum and AMNH for some time, but is refined here, as follows:

Clear Epoxy Embedding Procedure:

1. Designate the area to be embedded. The aim is to shield the weakest and most important areas of the exposed surface.
2. Create a silicone "cup" around the area, using regular household silicone, by forming successive coils to build a wall around the area to be embedded (Figure 4).
3. Ensure the silicone is fully set and sealed and that no oils or moisture have come into contact with the area to be embedded or with the silicone barrier (these would prevent proper setting of the epoxy).
4. Mix parts A and B of the Epo-Tek 301-2, according to manufacturer's instructions. Clean equipment and precise measurements must be used at all times. Parts A and B are the same color making it difficult to guarantee a homogenous mixture. For proper setting, the two parts should be mixed together thoroughly for several minutes.
5. Pour the epoxy into the silicone barrier and allow it to set according to manufacturer's indications (overnight). In my experience, full setting takes two

to three days. Letting the mixture set longer has no adverse effect.

6. Once the epoxy has set, remove the silicone wall with pliers and then grind away the edges around the epoxy "base", using a hand-held Dremel. Use caution, as these edges may be very sharp.

7. Transparent Scotch tape may be used to prevent scratching of the epoxy face during preparation. If the surface does become scuffed, it may be polished with a rock polisher.

The specimen may now be prepared as previously described.

Discussion

The obstacles presented here are ones commonly confronted by preparators to one degree or another. The goal is not to quantify the difficulty of one matrix relative to another, but to express the challenges encountered and the solutions found. The described volcaniclastic material is unusual in its composition and formation, but matrices of similar density and difficulty also may be amenable to the series of preparation techniques described here.

The benefits of epoxy embedding are numerous: Its protective qualities and transparency (Epo-Tek epoxy is manufactured for optical coating applications), the foundation it provides to allow safer preparation, and its function as a sturdy base for handling, storing and labeling (Figure 5). Although a great option in many cases, embedding is not recommended for every specimen. It should only be implemented when preparation poses a risk of damaging morphologically invaluable areas of fossil specimens. The main concerns include the slight visual distortion through the epoxy, and the fact that it is irreversible. Whether a specimen needs embedding or not should be the subject of careful analysis before proceeding.

Further geological analysis of this matrix may also yield clues as to the specific mineral composition of these fossils and matrices, as well as the variation in mode and quality of their preservation. Such knowledge can be of use to preparators in the search for better preparation techniques.

Although extraordinary in its density and strength, the material described here may be comparable to matrices encountered by numerous other preparators. This protocol has been developed over several years and has proven effective in fossil preparation. However, ample room exists for improvement on this technique and others.

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