Methods in Preparation

Proceedings of the First Annual Fossil Preparation and Collections Symposium

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Cover design by Matthew Brown. Main image: A newly opened field jacket in the preparation lab.

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PREFACE

In April of 2008 Petrified Forest National Park hosted the first in what we hope to be a series of annual meetings concerning topics related to the treatment, care, and preservation of fossil specimens. Professional and volunteer fossil preparators, collections managers, librarians, and other interested individuals attended from across North America. Fifteen talks, three posters, and four workshops were presented during the three day symposium, and attendees were offered tours of park collections, labs, and localities.

Paleontologists have a great ethical, and sometimes legal, obligation to properly care for the specimens that we hold in trust within our institutions. Unfortunately, the sub-discipline of fossil preparation and care is a field with limited established curricula, literature, educational, or training opportunities for professionals, students, or volunteers. Likewise, other workers within paleontology do not always have a full understanding of the broad extent of knowledge and skills required to safely and adequately treat fossil specimens, or the resources or ability to obtain the services of a trained and skilled preparator. We sincerely hope that conferences and publications of this nature will make a significant contribution to that understanding, to provide resources for those interested in fossil preparation, and to provide encouragement to others interested in building professionalism within the field of fossil care.

This volume represents a collection of papers presented at or inspired by the symposium. These papers provide a broad look at some of the methods and challenges presented in the field of preparation, but do not even scratch the surface of the body of knowledge and skill required to competently prepare fossils. Articles by Wylie and Gavigan discuss some of the greater practical and philosophical aspects of fossil preparation. Brinkman provides a look at the development of many tools, techniques and lab practices that modern preparators are familiar with, as well as politics and mindsets that sometimes still persist. Kane and Bergwall discuss evaluation rationale and methods, while Maltese, Davidson, Holstein, Cavigelli, Van Beek, Fox, and Stein and Sander outline procedures for aspects of field and laboratory preparation. Papers by Cherney, Erickson, and Nolan, Atkinson, and Small highlight innovations in the molding and casting lab. Brown and Parker examine a methodology for creating quick, in-house exhibits, and both Hunt-Foster and Smith demonstrate methods for protecting specimens during storage and transit. Abstracts from the symposium are reprinted following the articles.

We appreciate the support of park Superintendent Cliff Spencer and Chief of Resources Patricia Thompson and Paul Dobell of the Petrified Forest Museum Association. Thanks to all contributors of articles and abstracts, and to all attendees of the symposium. Special thanks to all volunteer peer reviewers.

Matthew Brown, John Kane, and William Parker, February 2009

FOREWORD (AND FORWARD)

Preparators have always been, as Gilbert Stucker (apparently quoting tool maker David R. Barton) first described us, the "Jimmy Valentines of science", always inventing, creating, adapting, and accomplishing the seemingly impossible with the fossils in our charge. As they have from the very beginning of our profession, these traits still characterize good preparators, but they do not fully define them. Ours has been, for a greater part of our discipline's history, a gradual evolution of techniques, materials and professionalism. But what we are now experiencing approaches *revolution* in scale. What truly separates us from our predecessors, what defines the modern preparator, is not greater creativity, inventiveness or skill; it is our access to *information*.

Traditionally, preparators' techniques and materials were learned in-house from our immediate predecessors, our own development limited by their expertise and experiences, as theirs was by their predecessors'. More importantly, this form of apprenticeship in the relative isolation of one's own institution gave us little opportunity or encouragement to seek alternative methods, better materials or rationale; things were done the way they were done because that's the way they were done. Publication was rare among preparators, due in part to the lack of potential outlets for their work and in part to the general humility of preparators who believed, wrongly, that they had little of value to contribute.

By the 1970s, this isolation had begun to erode. The publication of the newsletter "The Chiseler" in 1978 signaled a change of attitude, an attempt to reach beyond our own walls and share ideas with others in our profession. In 1979, four preparation papers were presented at the annual meeting of the Society of Vertebrate Paleontology (SVP). In the early 1980's, a Preparators Q and A Bulletin Board was posted at the SVP meeting and the first Directory of Vertebrate Fossil Preparators was compiled, both attempts to provide an information resource and to create a sense of community among preparators. Thus began the quiet revolution. In the ten years between 1996 and 2005, nearly 200 preparation papers were presented at SVP annual meetings; between 2006 and 2008 alone, another 84. A handful of well-executed volumes dedicated to preparation have also appeared in the past quarter century. Preparators have now not only come to expect a body of preparation literature, they have finally embraced the idea that each of them has something of value to share with their colleagues, and each is a potential author.

Paleontology is one of the last collection-based disciplines to adopt the principles of conservation science, perhaps because fossils were long deemed, somewhat naively, as being somehow invulnerable to the agents of deterioration that affect other collections. Today, preparators are keenly aware of the need to choose appropriate materials and techniques if we are to properly preserve the specimens and the data they contain, and are coming to understand that conservation principles lay at the very heart of our discipline. Incorporating these principles into our own practices, papers and presentations, and expecting them in others', has become a hallmark of the modern preparator.

In establishing a standing Preparators Committee and permanent Preparators Session at the society's annual meetings, the value and professionalism of preparators has now been recognized by the Society of Vertebrate Paleontology. Yet the venues available to preparators for formal publication of their work are still fairly limited. The dramatic success of the First Annual Fossil Preparation and Collections Symposium at Petrified Forest National Park and the publication of this Proceedings volume mark yet another defining moment in our history. It is indeed an exciting time to be a preparator.

A. E. Rixon noted that a preparator “is a living contradiction of the old adage, for he must be a jack of all trades in order to be the master of his own; but the most essential piece of knowledge he must have is an awareness of his own limitations. When confronted with a problem which is outside his experience, he must never guess but consult an expert or read up on the subject in text books.” Other than his frequent and exclusive use of the male pronoun, his words still ring true today, but today our access to collegial expertise and a wide variety of publications is greater than ever before. I encourage all preparators to take full advantage of this volume and those surely to follow, to take pride in their contributions to the science of Paleontology, and to continue sharing their own knowledge through presentations and publications.

Enjoy this volume, as we continue (with apologies to Firesign Theatre) to move “Forward into the Past!”

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ARTICLES

PREPARATION IN ACTION: PALEONTOLOGICAL SKILL AND THE ROLE OF THE FOSSIL PREPARATOR

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Abstract

Despite widespread interest in paleontology, few people know *how* paleontologists produce knowledge about past life. How does a fossil change from a fragile eroded rock into a scientific specimen? Fossil preparation, or the processes carried out to make fossils useful for research and exhibition, shapes how fossils are studied and interpreted. This essay explores the work and role of the people who carry out these crucial processes. A case study of a recent preparation project illustrates the elements of technique, science, and art involved in the multifaceted work of a preparator. Based on interviews with preparators at the Natural History Museum in London and the Sedgwick Museum of Earth Sciences in Cambridge, England, this essay argues that preparators serve as mediators between nature and researchers. Thus to understand how paleontology is done, we must understand the roles of preparators and their work.

Wylie, C. 2009. Preparation in action: paleontological skill and the role of the fossil preparator. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 3-12. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

Despite widespread interest in paleontology, few people know how paleontologists produce knowledge about past life. How does a fossil change from a fragile eroded rock into a scientific specimen? Fossil preparation, or the processes carried out to make fossils useful for research and exhibition, shapes how fossils are studied and interpreted. According to paleontologist John Horner, "vertebrate paleontology…is a field of study where the accuracy of collection and preparation of specimens and data is the foundation that determines the ultimate quality of the science" (Leiggi and May, 1994:xiii). This essay explores the work and role of the people who carry out Horner's "foundation" of paleontology: the preparation of fossils.

What work is done to "prepare" a fossil? In the seminal manual on preparation, A. E. Rixon anticipates his readers' ignorance by providing a broad definition of preparation:

> The role of the staff of a paleontological laboratory is the preparation and conservation of fossils for the purposes of research by scientists, exhibition in public galleries or storage in a study collection. The word 'preparation' has been used traditionally to describe a variety of operations ranging from the consolidation and repair of fossils to their extraction from the matrix rock and their final mounting for museum display. (1976:1)

A preparator may therefore perform several tasks to convert a rock-bound, fragmented fossil into an object that is useful for research or exhibition. Is a preparator then a scientist in control of creating knowledge, or an artist who practices a careful and detailed craft, or a skilled but servant-like "invisible technician" (Shapin, 1989:554) like those in Robert Boyle's seventeenth-century laboratory? According to Rixon, "a preparator… must be part chemist, part anatomist and part artist, added to which he must be capable of working in a variety of materials ranging from all forms of plastic to mild steel. He is a living contradiction of the old adage, for he must be a jack of all trades in order to be master of his own" (1976:3). So what is it that these multitalented people actually do?

Examining this question sheds light on the structure of scientific work by addressing the treatment of data. Specimens as paleontological data are not objective pieces of nature but are inherently changed by the methods of preparing them for study (Larsen, 1996:376). It follows that the ways in which data are converted from natural objects to specimens affect the scientific conclusions drawn from them. Anne Larsen notes:

> The amount of information…that a naturalist could glean from any specimen was a function of its physical completeness and its documentation. Both of these factors were dependent upon the skills, resources, and agenda of the person preparing the specimen. (1996:376)

In science, the data preparer acts as mediator between

FIGURE 1: Drawing of *R. cramptoni* specimen from 1863 (Carte and Baily, 1863)

nature and researchers. To understand paleontology, then, we must understand preparators' work as a mediating act that affects how nature is viewed. A recent preparation case illustrates how preparation and thus paleontology are done.

A Preparator's Role: A Case Study

In August 2006, the fossil skull of *Rhomaleosaurus cramptoni* arrived at the Natural History Museum in London to be prepared by Scott Moore-Fay. This 178 million-year-old marine reptile has a long, distinguished history in the scientific and social worlds as well as the geological one. The species was described and named from this specimen in 1863, making the fossil the holotype of its species, as well as of its genus and family (Smith, 2006:26). Known as the Dublin pliosaur (Fig. 1), the specimen is a key part of the National Museum of Ireland's collection (National Museum of Ireland Annual Report, 2006; Smith, 2007:33). Replicas of the fossil are on display at museums around the world, a testament to its remarkable preservation and the rarity of its species.

The scientific and social value of this fossil made it a priority for conservation work to repair past damage and prevent future deterioration. In addition, paleontologist Adam Stuart Smith wished to study the skull, which required preparation to reveal anatomical details hidden by matrix (the rock surrounding a fossil). The preparation involved removing matrix as well as the remnants of nineteenth-century preparation, which included plaster and wax. Once its several large fragments had been prepared, the skull was reconstructed by reattaching the pieces with a weak chemical adhesive and then keeping them in place with a strong external support. Moore-Fay completed the preparation of the sixty-kilogram skull in eighteen months. Thus a natural object that had been a Victorian specimen was converted into a modern specimen through the application of modern preparation techniques.

Moore-Fay's work on the skull includes elements of technique, science, and art. What then is the preparator's role in paleontology, if preparation can be viewed as three distinct kinds of work? We will address this question by examining preparation from these three perspectives.

Preparation as technique

Preparators use an extensive array of tools adopted from different fields, including dentistry, art conservation, and even auto and aerospace engineering. A preparator must know how to operate a tool and how it affects a specimen to decide which tools to use for each fossil. Several tools were used on the pliosaur skull, which offered unique challenges because it was heavy, encased in hard matrix, and had no color distinction between the bone and matrix. It was also covered in materials from previous preparation, which Moore-Fay describes as "horrible bits added on to it – fillers, waxes, animal glues – to stop it [from] falling apart" (Moore-Fay, pers. comm., 31/10/08). Thus preparation was painstakingly slow and required careful use of powerful tools.

Moore-Fay chose tools according to the material to be removed. To remove wax, an air-pen (a pneumatic hand-tool similar to a miniature jackhammer) would have been ineffective and potentially damaging, so instead Moore-Fay chose an air-abrasive (a pneumatic hand-tool that propels a narrow, high-speed stream of abrasive powder to knock matrix off fossils) (Leiggi and May, 1994:116). To remove the Victorian-era mixture of rock and plaster infill from the palate and lower jaw, Moore-Fay first used pneumatic tools. But only the most powerful tools were effective on this hard matrix, and they can cause hand-arm vibration syndrome in preparators ("Hand-arm vibration at work," Health and Safety Executive, accessed 15/11/08). To avoid this hazard and to speed up the matrix removal, Moore-Fay switched to a method that the Victorians knew well: the hammer and chisel. After removing the bulk of the matrix, Moore-Fay used pneumatic tools to allow more precision as he approached the fossil itself.

We have seen that technicians work on material objects by using specific tools in relatively standardized ways, but first "the technician in training must master a considerable body of knowledge of an abstract, scientific character before he can manipulate or even recognize his objects" (Ravetz, 1971:142). This scientific knowledge enables the technician to work with objects, but not to ask questions about them or judge the outcomes of finished work. Preparators are experts in the specific knowledge and skill necessary for preparation. Thus before deciding to have the pliosaur prepared, the

National Museum of Ireland asked Moore-Fay, as an expert, to evaluate the pliosaur's condition and provide time and cost estimates for its preparation. This expert status depends on preparators' ability to use their geological, anatomical, chemical, and physical knowledge to prepare fossils.

Because fossils often look similar to their matrices, preparators rely on geological knowledge of rock formations and mineral characteristics to distinguish a matrix nodule from an unusual bone growth, for example, and thus remove rock while preserving bone. Also, preparators can make more informed tool selections if they can identify matrix rock types, since that information influences how a specimen is best prepared. Moore-Fay, for example, had to identify pyrite in the skull before deciding to remove a layer of wax added by an earlier preparator. Pyrite degrades when exposed to oxygen, so melting wax over a pyrite-containing fossil protects it by sealing out air. But Moore-Fay found the pliosaur "to be fairly free of any pyrite. So possibly it was never going to have a pyrite problem but it did have this black wax painted all over the surface which was obscuring a lot of the detail." Moore-Fay's geological knowledge revealed that it was safe to remove the unnecessary pyrite-protecting wax.

Sarah Finney, preparator and conservator at the Sedgwick Museum in Cambridge, England, believes that preparators "need biology and anatomy to do a good job" (Finney, pers. comm., 29/10/08). Knowing the location of important traits on a skull allows a preparator to search for them while removing matrix, and also to be careful when preparing near the structures' expected locations. For example, Smith wanted to study the pliosaur's matrix-covered internal nares. Moore-Fay describes the process of exposing them as "a case of me preparing up there on the rock until I find them and then revealing as much information as I possibly can around them." Moore-Fay used anatomy to search for the internal nares and avoid damaging them.

Repairing breaks and reconstructing fragments requires chemical knowledge of an adhesive's components to judge its strength, set time, and likelihood to degrade over time. Moore-Fay uses B-72 Paraloid, which he defines as "a conservation-grade clear plastic adhesive." B-72 is a powder solute that dissolves in acetone to create a liquid adhesive that hardens as the acetone evaporates. It has a range of possible strengths depending on the solute-to-solvent ratio, does not degrade over time, and is easily dissolved with acetone after it sets.

Preparators judge where fossils need internal support (e.g. adhesive) and external support (e.g. custom-fit rigid molds called jackets) based on knowledge of physics and weight distribution. Jacketing a fossil involves applying a paste (traditionally a plaster and burlap mixture, more recently resin) over a foil-wrapped fossil and letting the paste harden to create an exact mold. Moore-Fay made the skull's jacket of epoxy resin, which is more chemically stable than similar polyester resin and when dry "creates a super hard jacket, which should be good for one hundred years or more. By then technology will have moved on, as it has since Victorian times when they used wood and plaster." Apart from the use of modern materials, jacketing technique has changed little over time. This effective standard procedure requires skill to handle the fossil while applying the proper thickness of jacket material.

The knowledge required for the technical work of preparation comes from various scientific fields but is brought together by the preparator to convert a natural object into a scientific specimen. Paleontologists use similar scientific knowledge for different purposes, namely to guide research by proposing questions and making decisions. These characteristics of scientific work are also present in preparators' work.

Preparation as science

Aspects of preparation involve scientific problem solving and the application of scientific knowledge. Jerome Ravetz's definition of scientific work is useful in considering the role of the preparator: "Unless [a scientist] can successfully set, investigate, and solve problems, drawing conclusions about classes of things and events and not merely manipulating particular samples, his title is inappropriate" (Ravetz, 1971:143). Thus making decisions based on analysis of problems is scientific work and also an integral part of preparation. Preparators do technical work when following standard protocols, such as placing a fossil on a sandbag during preparation to cushion it from pneumatic tool vibrations. They do scientific work when they evaluate a problem and design a solution for it. Thus it is the kind of knowledge and how it is used that makes work scientific. Geological knowledge

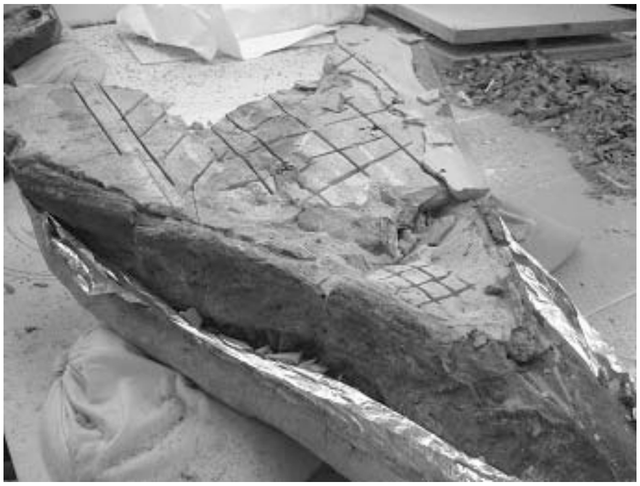

FIGURE 2: Underside of the skull showing Moore-Fay's gridded matrix removal technique (image courtesy of Scott Moore-Fay)

is necessary to extract taphonomic data,concerning where an organism died or how it was fossilized. Often only the preparator sees a fossil in its most complete form, so information like mineral alignment (which indicates subtle riverbed current direction) must be recognized and recorded by the preparator. Thus the preparator is not only carrying out a technical procedure but is identifying and analyzing data, a scientific task.

Like geology, anatomy allows preparators to recognize unusual features and know to preserve them as anomalies. Moore-Fay describes preparators' knowledge of anatomy as different from that of paleontologists:

> You won't know the snout on the little reptile skull you've prepared is a third shorter than its nearest cousin…because you don't know the other animals within that group, but you know that specimen inside out, so you can say to [a researcher], 'By the way, did you notice that up inside the skull there are three little holes where the nerves came in?'

Preparators rely on a physical knowledge of anatomy rather than comparative anatomy or anatomy specific to species classification because preparation focuses on individual specimens' morphology and not on patterns between groups. Ravetz blames technicians as a major potential source of error in science because they are trained only to recognize anticipated data results, so "when unexpected and contrary results appear, [the technician] must make a judgement on their significance, balancing his own limited technical competence against the superior understanding of his master" (1971:97). This problem arguably does not apply to preparators, because they have not only a "technical" knowledge of anatomy as applied to matrix removal but also a physical anatomical knowledge to recognize atypical features.

Preparators also employ chemical knowledge both for technical work (such as mixing adhesives) and scientific work (such as assessing the effectiveness and safety risks of useful chemicals). For example, Moore-Fay ruled out acid preparation (in which a fossil is bathed in weak acetic acid for several hours or days to dissolve matrix) of the skull because he knew the dissolution reaction would occur too slowly to meet Smith's research deadline. Similarly, Moore-Fay applied his understanding of chemical bonds to design a stronger adhesive inspired by the physical structure of concrete: "Rocks hold [concrete] together… they're quite angular, they lock in. So you don't make concrete out of just sand, you use an aggregate. The idea is we could use aggregates in our reversible glue to try and get a stronger bond."

To adhere the skull fragments, Moore-Fay added fiberglass strands to B-72 adhesive to "make the equivalent of a concrete aggregate… that creates physical crosslinks [so] we're not only waiting for

FIGURE 3: Skull supported by Moore-Fay's scaffold to allow the adhesive to set. (image courtesy of Scott Moore-Fay)

FIGURE 4: Skull in its final two-part jacket (image courtesy of Scott Moore-Fay)

chemical crosslinks to occur within the glue." This mixture would be thin enough to fit between tight joins yet strengthened by both chemical and physical bonds. This invention employs Moore-Fay's knowledge of chemical and physical engineering to solve the problem of attaching heavy fragments.

Preparators apply additional aspects of engineering knowledge, particularly when adapting standard procedures to best prepare each specimen. Preparators are responsible for such engineering challenges as protecting fossils during preparation and ensuring that adhesives hold fragments together effectively. For example, to decrease the risk of damage when using a hammer and chisel, Moore-Fay designed a technique to make his motions smaller and more controlled. He used a handheld rock grinder to cut vertical crevices into the matrix, creating a three-dimensional grid (Fig. 3). Then he chiseled off each precut square of matrix "in a controlled manner, as very little force was required to chip them away." Another innovative technique was the scaffold Moore-Fay built to hold skull fragments in place while their adhesive bonds set over the course of several days (Fig. 4).

Moore-Fay also re-engineered the standard jacketing procedure, creating a two-part, extra-padded jacket to support the heavy skull (Fig. 5), similar to the method described by Jabo et al. (2006). Technically, Moore-Fay made two jackets, for the top and bottom of the skull, so that researchers "could turn [the skull] over completely and look at the palate and then turn it back" while still allowing the unexamined side to be supported by its jacket. Also, to keep the heavy skull from crushing the typical foam padding and colliding with the jacket, Moore-Fay designed a jacket construction procedure that created space between the fossil and jacket for thicker padding that was stiffer and could support more weight.

Thus by not strictly following procedures but rather adapting them to the needs they identify in a situation, preparators do analytical and inventive work. This work also involves creativity and leaves a preparator's personal touch on a specimen, unlike a standardized procedure of specimen-production. Therefore, although science and art are often conceived of as distant or even opposite processes, preparation involves aspects of both.

Preparation as art

Preparation includes aesthetic touches to make a specimen attractive and neat as well as scientifically accurate. Based on Moore-Fay's experience preparing Victorian specimens, the artistry of specimens was important in the nineteenth century. He warns, "you have to take everything with a grain of salt from Victorian times because it was done on the beauty of it, the interest you could get from it." Fossil collectors often wanted a specimen to display or sell, so specimens had to fit certain aesthetic ideals and be complete. Moore-Fay observes that Victorian preparators "kept to the profile of the bone so you can see what shape it was, but it's only what they've decided the bone should look like." This artistic sense reflects a view of specimens as objects of beauty and not just data.

Aesthetic value is evident in the Victorian preparation of the pliosaur. It was mounted for display using materials like plaster, cement, and paint that obscure anatomical detail and make a fossil look more like a tidy piece of art than a natural object. Also, the pliosaur, found in a quarry, is missing a paddle, as explained by Carte and Baily in their 1863 description: "The tarsals, metatarsals, and phalanges of the left hind paddle are deficient, this portion having unfortunately been removed to the calcining kiln before the remainder of the fossil was observed" (162) (Fig. 1). Casts of the specimen have a false paddle, perhaps first added when, "after having been set up for exhibition in the spring of the year 1853, [the fossil] was introduced to public notice in a highly interesting lecture" (Carte and Baily,1863: 161). Being "set up for exhibition" could have included mounting

FIGURE 5: Prepared skull (image courtesy of Scott Moore-Fay)

the specimen and adding a paddle. Cruickshank (1994) describes similarly major changes made to another pliosaur specimen prepared in Britain in the 1850s, specifically that the fossil was chiseled flat (destroying its ventral side), nailed to a wooden frame, then surrounded by plaster to hold it in place. Adding a fake paddle makes the specimen appear complete but arguably detracts from its scientific value as true to its natural form.

Modern preparation also has artistic elements, though these are typically subordinate to a specimen's scientific value. For example, for large gaps in the skull where pieces of bone are missing, Moore-Fay molded "removable fills – something we can make that fills in that area, that we can…adhere in place to hold the two other parts but can be removed later on" (Fig. 6). The fills must be exact fits but also aesthetically pleasing. They are usually plaster sculpted as bridges over gaps between bones to decrease the distance between fragments, thus allowing the adhesive to make a stronger bond. Fills are molded between foil-covered bones to keep the plaster from sticking directly to the fossil. Once dried, the fill is removed, the foil is taken away, and the fill is adhered in place with adhesive. A fill can then be easily removed by dissolving the adhesive with acetone. Fills not only hold the skull together but also make it look more complete by imitating the appearance of the missing pieces. Moore-Fay did not have time to paint the fills to match the skull's color, and was frustrated to leave them unfinished. He valued the skull's aesthetic presentation, and worried that other preparators would not select the appropriate paint color.

Though paint color may not necessarily be a vital component of a specimen's preparation, preparators do leave their personal touch on specimens through decisions they make during preparation. Preparation is not a standardized field and fossils are not standardized objects, so each preparator's decisions based on each fossil will vary. The scientific, technical, and artistic choices that each preparator makes create a unique combination of procedures that shape a specimen.

Conclusion

Preparation involves such a unique combination of certain skills and knowledge that preparators cannot quite define what it takes to be a good preparator. Based on their experiences training new preparators, Moore-Fay and Finney describe preparation as somewhat innate and unlearnable. Moore-Fay observes, "I say you can't make everyone into a preparator. You can train everyone, but you won't get the same quality from each person. You can learn the technique – you can learn how to drive a car but that doesn't mean you'll be the best car driver in the world. Some are better than others." Finney takes a stronger view and says some of her trainees never could prepare well, suggesting that in preparation "you can either do it or you can't." What then is the role of these unique workers in paleontology?

Paleontology is a complex production of specimens and knowledge that is divided into tasks done by several different individuals. First a scientist proposes a question that can be answered by examining a fossil. Assuming the fossil has been collected (overlooking fieldwork), the scientist arranges for its preparation to allow access to its information. The curator of the institution that owns the fossil notifies the institution's preparation laboratory (if it has one and if not, the curator contacts another laboratory), where a preparator prepares the fossil. Thus the preparator works to meet the specific needs of exhibitors and researchers rather than according to personal interests.

Moore-Fay views the subjects of his work as "research-driven," in that "if I was allowed to go select what I was going to prepare I'd have a fantastic bench full of oddities, but it possibly might coincide with none of the researchers' studies" and would therefore not be justifiable. However, preparators are responsible for the preparation process itself. According to Moore-Fay, "one of the joys of being a

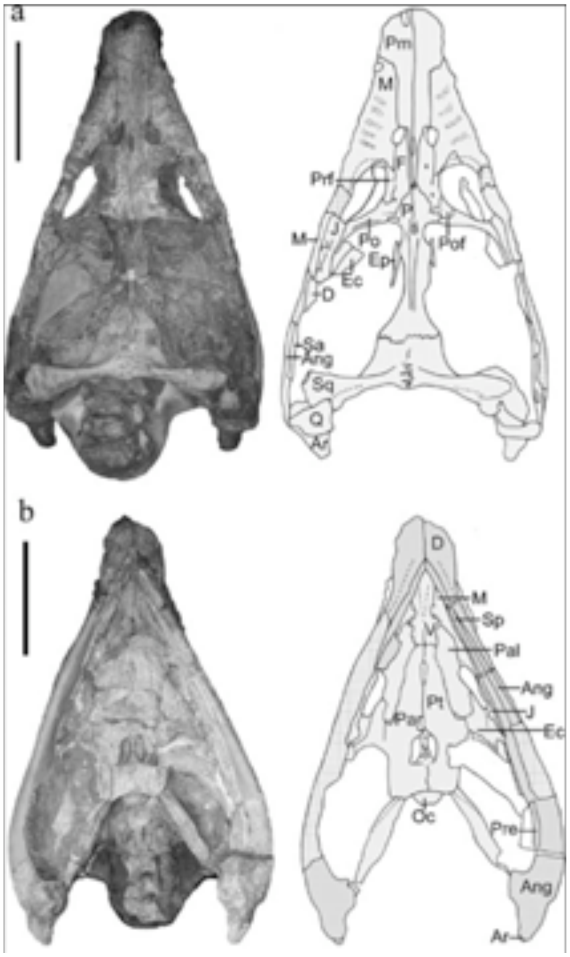

FIGURE 6: Top (a) and underside (b) of prepared skull. The internal nares are the two oval holes in the center of (b). The crosshatching on the diagrams indicates locations of Moore-Fay's removeable fills. The scale bar is 30 centimeters. (Reproduced with permission from Smith and Dyke, 2008.)

preparator is the fact that nobody can tell you how to do it… The researcher…will just say what they want the thing to look like or what they want to see on that specimen. How [I] go about giving them that information is entirely up to me." A major decision for the preparator is how and to what extent a specimen is prepared. Finney believes specimens should not be prepared unless needed for a researcher's specific study, and in that case preparation should be done as required for that researcher's question and no more. Thus as much information as possible is conserved in the natural object, with only the currently useful parts being converted by preparation into a specimen. Moore-Fay agrees with this conservative approach due to preparation's inherent permanence, since when you remove pieces of an object "you've lost that bit of science. That bit of information you can never get back." However, a preparator may also decide to prepare more than originally planned. For Moore-Fay, extra preparation is justified if it is useful for science: "If [the researcher] asked me to stop a half inch from the jaw and I can stop a quarter inch from the jaw then there might be a little bit more information there that hasn't been revealed before." But a preparator's independence in the preparation process is only part of the broader community involved in paleontology.

The division of labor in paleontology is complicated by the sometimes conflicting goals of the characters involved. Although preparation is primarily the preparator's domain, the process can be rushed by the scientist's publication deadlines. In preparator Peter Reser's experience, "staff in the research or exhibit sections want to accelerate the course of preparation. This acceleration can mean taking shortcuts that compromise the long-term integrity of the specimens" (Reser, pers. comm., 27/10/08). This issue is paramount for preparator William Sanders, who believes that "one of the most controversial issues we face is the continuing tension between the aim of preparators…to do the least harm to a specimen and preserve it as well as possible into the future, and the frequent need/desire/preference of researchers to have specimens prepared quickly, reassembled, and cast" (Sanders, pers. comm., 27/10/08). Moore-Fay agrees that "if we let the researchers dictate how we did it [prepared a fossil], then we'd probably have to do it much quicker." Time is an important issue in delicate work like preparation, and control over a worker's time also reflects power relationships in a workplace.

Goal conflicts and power relationships are also evident between curators and preparators. A curator is responsible for the entire collection and thus is concerned about storage space constraints as well as specimen conservation. Moore-Fay describes "a battle I have with quite a few of the curators, that they would possibly like blocks with bones and bits on made smaller because it takes up less space in the collection." Moore-Fay opposes separating associated fossils because it destroys information about bones' relative locations. Echoing Moore-Fay's militaristic view of "battles" in paleontology, Reser believes "preparators have the responsibility to speak for the long-view conservation of specimens to their administrative superiors. We are the first line of defense" (Reser, pers. comm., 27/10/08). This defensiveness may reflect institutional hierarchy, as described by Sanders: "I function primarily as a preparator and conservator…in the SERVICE of research curators. Our roles are defined as support staff for the curators…[so] we are often placed in a position of conflict between protecting the specimen and 'moving things along'" (Sanders, pers. comm., 27/10/08).

While differentiating between technician, scientist, and artist may seem artificial, these distinctions can shape the division of labor and hierarchy in science. To understand scientific knowledge, we must understand the people and work that lead to it. These people are often undescribed or ignored and thus made "invisible," and, as Steven Shapin laments, "in the case of laboratory work, the price of technicians' continued invisibility is an impoverished understanding of the nature of scientific practice" (1989:563). The need for information about the work behind scientific knowledge is echoed by Adele Clarke and Joan Fujimura, who ask, "What needs to be taken into account in order to understand a situation in which scientific work is being done? *Everything in the situation*" (1992:5). This of course includes the procedures that prepare data for scientific use. Therefore, the work of the "invisible" fossil preparator requires closer study to offer a more complete picture of how paleontological research happens.

The different values and goals within paleontology make compromise necessary, which raises issues of authority and highlights workers' differences in training, pay, and acknowledgement. For example, preparators can be considered comparable to Shapin's "invisible technicians" because their work is not described in scientific articles or popular publications (Shapin, 1989). They are only sometimes mentioned in the acknowledgements of articles about specimens they prepared, and they are rarely listed as authors (Finney and Moore-Fay, pers. comm., 10/08). However, preparation is developing into a distinct field of professionals who collaborate through conferences (such as the Society of Vertebrate Paleontology's Preparators' Session (USA) and the Symposium of Palaeontological Preparation and Conservation (UK)), email listhosts (like the Society of Vertebrate Paleontology's PrepList), and a new preparation-specific journal (*Journal of Paleontological Techniques*). As preparators thus become acknowledged, respected, and "visible," we will gain a clearer understanding of how paleontological science is done. Also, as preparators share their knowledge with each other and with paleontologists, the science that they produce together can be more fully understood and better evaluated, and thus theoretically will improve in quality. The effects on paleontology of more communication and unification among preparators merit further study as preparation and paleontology continue to evolve as scientific fields and professional communities.

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WORKING FOSSIL LABORATORIES AS PUBLIC EXHIBITIONS

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Abstract

Working fossil laboratories have been a component of natural history museum exhibitions in the United States since the 1970s and are a growing exhibit trend, although they have not been comprehensively studied as exhibition techniques or as visitor experiences. For my master's thesis project for the Department of Museum Studies at John F. Kennedy University, I investigated how natural history museums can develop and design working fossil laboratory exhibitions to communicate their research and educational missions to visitors. This article was distilled from that project.

I interviewed 21 museum professionals involved in developing or working in fossil laboratories at the following eight natural history museums in the United States: Museum of the Earth, Ithaca, NY; Academy of Natural Sciences, Philadelphia; National Museum of Natural History, Washington, D.C.; North Carolina Museum of Natural Sciences, Raleigh; Dallas Museum of Natural History, TX; Field Museum, Chicago, IL; Denver Museum of Nature and Science, CO; and the Page Museum at the La Brea Tar Pits, Los Angeles, CA.

At the *Fossil Prep Lab* at the Academy of Natural Sciences in Philadelphia, I conducted an in-depth visitor study, which utilized and expanded on a visitor studies instrument developed by researchers at the Smithsonian. My research revealed three primary challenges to a fossil lab's successful operation: 1) concept and design planning, 2) staffing, and 3) evaluating the visitor experience. Addressing these challenges will contribute to their successful operation.

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Introduction

Today, visitors to the Dinosaur Hall at the Academy of Natural Sciences in Philadelphia (Academy) are greeted by a roaring skeleton of a *Tyrannosaurus rex* mounted in a life-like pose. The sounds of mini-jackhammers, which remove matrix from around the fossils that are on display in the *Fossil Prep Lab,* fill the hall. Visitors can observe casts of several *Hadrosaurus foulkii* bones mounted in a life-size silhouette of this dinosaur. These dynamic techniques of displaying fossils were relatively unknown to visitors before 1868. That year, *H. foulkii* was the first, most complete dinosaur to be mounted in a life-size freestanding pose, a dramatic sight that drew many Philadelphians to the Academy.[1] More than 100 years later, dinosaur displays continue to fascinate museum visitors.

Visitor study after visitor study conducted in natural history museums confirm that "everyone loves dinosaurs."[2] "Dinosaur fans," as one 1995 study shows, are mostly comprised of adults visiting with children, but span all genders, age groups, educational levels, and "visitor types."[3] According to Smithsonian Program Analyst Stacey Bielick,

> Whether there was a special exhibition or not, more visitors stayed longer with the dinosaurs than with any other part of the museum…. Visitors who spent most of their time with Dinosaurs (one quarter of all visitors) were disproportionately impressed by seeing the real thing.[4]

Visitors are also interested in watching people work on real fossils of vertebrates, invertebrates, and plants in laboratory exhibitions such as the Academy's *Fossil Prep Lab*. Here, visitors can see the human dimension of fossil research. They can look at fossils displayed on tables, on walls, or with signs. Visitors can watch preparators or volunteers preparing fossils at window workstations and also can talk with them about their work.

Working fossil laboratories have been a component of natural history museum exhibitions in the United States since the 1970s and are a growing exhibit trend. For my master's thesis project, I investigated how natural history museums can develop and design working fossil laboratory exhibitions to communicate their research and educational missions to visitors. My purpose was to understand working fossil laboratories as exhibits within the context of the history of fossil displays in natural history museums and the two hundred-year long debate in these museums over how to balance their core functions of research and public education. I interviewed 21 museum professionals involved in developing or working in fossil laboratories at eight natural history museums in the United States.[5] I also conducted an in-depth visitor study at the *Fossil Prep Lab* at the Academy, which utilized and expanded on a visitor studies instrument developed by researchers at the Smithsonian. My visitor study examined the

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[1] Ken Carpenter, "Dinosaurs as Museum Exhibits," in *The Complete Dinosaur*, eds. James O. Farlow and M.K. Brett-Surman (Bloomington, IN: Indiana University Press, 1997), 151-152.

[2] S. Bielick, A. J. Pekarik, and Z.D. Doering, *Beyond the Elephant: A Report based on the 1994-1995 National Museum of Natural History Visitor Survey*, (Washington, D.C.: Smithsonian Institution, 1995): vi.

[3] Ibid, 35.

[4] Ibid, vi-vii.

[5] The eight natural history museums with working fossil laboratories studied were Museum of the Earth, Ithaca, NY; Academy of Natural Sciences, Philadelphia; National Museum of Natural History, Washington, D.C.; North Carolina Museum of Natural Sciences, Raleigh; Dallas Museum of Natural History, TX; Field Museum, Chicago, IL; Denver Museum of Nature and Science, CO; and the Page Museum at the La Brea Tar Pits, Los Angeles, CA.

This project focused exclusively on working fossil laboratories found in private, non-profit natural history museums in the United States. It didn't focus on laboratories found at national parks, at nature centers or in other types of museums such as children's museums (the Children's Museum of Indianapolis, IN), science museums (Oregon Museum of Industry and Science, Portland), and museums outside the United States (Royal Tyrell Museum of Paleontology, Alberta, Canada; and the Natural History Museum, London).

At least one natural history museum with a working fossil laboratory was selected from each geographic region in the United States (with the exception of the Northwest). Museums were not selected randomly but were derived from my literature review in addition to conversations with interviewees and other colleagues.

relationships between the messages visitors take away, the impact of talking with an expert, the experiences visitors find satisfying, and visitors' experience ratings.[6] Based on the results from interviews and visitor studies, I determined the opportunities and addressed the challenges of operating working fossil laboratories as public exhibitions.

Background

Changes in the methods of displaying fossils like *H. foulkii* occurred in tandem with changes in the function of natural history museums. Since the first half of the nineteenth century, the core functions of natural history museums have oscillated between collecting, research, and public education. As these museums increasingly became intent on merging their collecting and research functions with the needs and desires of their public, more dynamic exhibits such as working fossil laboratories debuted.

In the 1950s, Dinosaur National Monument in Utah displayed a working lab as an adjunct to the fossil excavation located on the site. After the 1970s, natural history museums that didn't have in-situ fossil excavations on their grounds began to incorporate working laboratories into their exhibition menus as a way to disseminate paleontological research to their public.

A synthesis of the visitor studies literature reveals that connecting the museum's research to visitors' natural interests, both in the preparation of specimens and in narratives of scientists' lives, can stimulate visitors' curiosity in behind-the-scenes research. By showing visitors the process of fossil preparation and "scientists-as-people," working fossil laboratories fulfill the recommendations of early visitor studies *and* take them one step further by introducing visitors not only to scientists' narratives but to "scientists-as-themselves."

Conclusions

The appeal of fossils and dinosaurs aside, working fossil laboratories are a popular exhibit trend for several reasons. The first is that a majority of visitors have a natural curiosity about watching people work in authentic, culturally significant settings and in museum exhibitions. Visitors' interest in the work of paleontologists, both in the excavation and in the lab was, indeed, the inspiration for the development of the earliest fossil labs. Not unlike visitors' reactions to the quarry at Dinosaur National Monument in Vernal, Utah, visitors to the La Brea Tar Pits in the 1970s were in awe of the sight of paleontologists working in the pit. At La Brea, visitors were curious not only about the excavation in progress but also about work going on in the adjacent lab. Visitors' desire to tour this lab was the impetus for incorporating a lab into the Page Museum. In the 1980s and 1990s, more working fossil laboratory exhibitions debuted in natural history museums committed to paleontological research.

The second reason for the popularity of fossil labs is the "exhibit replication effect." As fossil labs have become more popular, museums have looked to their museum colleagues with labs for advice, essentially molding themselves after original labs; much the way paleontologists create molds of original fossils. Museums interested in developing labs with other emphases such as anthropological objects, living plants or animals, have also looked at fossil labs as models. Two examples are the Field Museum's *McDonald's Fossil Prep Lab* and the North Carolina Museum of Natural Science's *Fossil Lab.* Since the opening of the *McDonald's Fossil Prep Lab* in 1998, the Field Museum has improved the lab's design. The Field's Fossil Vertebrate Preparator Jim Holstein said to enhance both the physical and psychological comfort of staff working in the lab, the museum added a railing around the exterior of the lab and installed double paned window glass. The museum also positioned volunteers, when available, outside the lab to serve as buffers between the lab and youthful visitors who have a penchant for pounding on the glass. The *McDonald's Fossil Prep Lab's* design influenced the design of the *Regenstein Laboratory*, an exhibit showcasing anthropological research and collections that opened in August 2004. Fossil preparators advised designers of the *Regenstein Laboratory.* The second example is the *Fossil Lab* at the North Carolina Museum of Natural Sciences, which served as a model for the development of the museum's Naturalist Center scheduled to open in 2009. North Carolina's Curator of Paleontology Vince Schneider explains, "fossil labs

[6] As defined by Pekarik et al., satisfaction "…primarily draws on short term memory and a judgment of value, and is more firmly and directly rooted in experience." Andrew Pekarik, Zahava Doering, and David Karns, "Exploring Satisfying Experiences in Museums," *Curator* 42, no. 2 (April 1999): 169.

have led the way for other fields interested in developing working laboratory exhibitions, which have spent less time interfacing their research with the public."[7]

Finally, fossil labs are popular because they exemplify the growing desire of many natural history museums to create experiential exhibitions where visitors have the opportunity to converse with "real museum experts," while seeing "real things." Up-to-date, relevant, and customizable, the interpersonal interaction provided at some working fossil laboratories is both a social and cognitive experience and significantly impacts how visitors rate their experience at the lab. I studied interpersonal interaction between museum experts and visitors at the *Fossil Prep Lab* at the Academy of Natural Sciences during May 2006. I found that visitors who talked with a person in the lab were more likely to have higher visitor experience ratings for their overall experience, effect on their personal enjoyment, and effect on their personal learning than visitors who did not engage with a person in a lab. I also found that visitors who were satisfied with having a chance to talk experts had higher ratings for their overall experience than visitors who did not talk to an expert.

Results indicated that having a chance to talk to experts is significantly correlated with other types of satisfying experiences that are either social (the visitor is focused on an interaction with another person, i.e., "Spending time with friends, family, other people") or cognitive (the visitor is focused on interpretive or intellectual aspects, i.e., "Enriching my understanding"). In other words, visitors who were satisfied with social or cognitive experiences were also satisfied with having a chance to talk to experts.

Visitors to the lab understood the lab's purpose regardless of whether they talked to a person in the lab. A majority of visitors understood that the purpose of the lab was to educate them about paleontology, allow them to see paleontologists at work, or offer them a chance to talk to a paleontologist. The messages visitors took away aligned with several of the lab's intended messages—to show the human element in the process of preparation as well as to serve visitors and answer their questions.

Visitors who talked with a person were satisfied with gaining information or knowledge at the lab. Visitors who reported gaining information or knowledge at the lab also had higher ratings for overall experience. Even more visitors who reported gaining information or knowledge rated their personal enjoyment and personal learning in the top two categories—superior or excellent.

Recommendations

The Academy of Natural Science's *Fossil Prep Lab* provided visitors with a range of satisfying opportunities from seeing "real" fossils, gaining information or knowledge to having a chance to talk to experts and enriching their understanding. Yet, the educational opportunities afforded to visitors at fossil labs present challenges to museum staff responsible for managing, working in, or planning the lab. The three primary challenges to a fossil lab's successful operation that I discovered in my research are: 1) concept and design planning, 2) staffing, and 3) evaluating the visitor experience. Addressing these challenges will contribute to their successful operation.

1) During concept and design development phases, devise an interpretive framework for the lab without competing exhibit messages and plan the lab's design to support these messages.

All the museum professionals interviewed who either developed the labs' concepts or who worked in the labs voiced their commitment to showing their visitors the human element in the process of fossil preparation. Many indicated their labs are also committed to answering visitors' questions. These goals may, however, place conflicting demands on preparators' time. Preparators often are overwhelmed by the number of visitors asking questions at the same time or are required to meet deadlines imposed by exhibits or curatorial staff and therefore, don't have time to talk to visitors. For instance, when the Page Museum's lab opened, preparators had intended to talk with visitors through an intercom system but discovered that answering visitors' questions disrupted their ability to concentrate on fossil preparation. According to the Page Museum's Collections Manager Christopher Shaw,

> When we first opened, in the first year we had over two million people, I believe. It was wall-to-wall people in the first week…Our staff members were spending their whole time answering the same questions, like what are you doing, where do I find a sabertooth tiger, are you building

[7] Vince Schneider, interview by author, 14 March 2006.

> skeletons in there? …You get halfway through the explanation and look up and they would be walking off to look at something else. It was really irritating so we disconnected that [the intercom system].[8]

While in the concept development phase, at least one natural history museum, the Field Museum, recognized the demands placed on preparators' time while working in the lab; as a result, they planned *not* to have preparators talk to visitors and instead to have docents, on occasion, positioned outside the lab to answer visitors' questions (Fig. 1). The Field's *McDonald's Prep Lab* was, at least originally, developed and designed to prepare *Sue* for exhibition. The lab's development team realized talking with visitors would have competed with the time required to quickly prepare *Sue* for exhibition. The Field's Collections Manager Bill Simpson explained, "it was an incredibly tight schedule and…to do the job right, we had to really focus on using all of our preparation time effectively."[9] As at the Field's *McDonald's Prep Lab*, staff and volunteers working in the Dallas Museum of Natural History's *Paleontology Lab* generally do not talk to visitors. As Preparator Ron Tykoski explained, "If staff interacted with visitors, productivity would be cut in half."

Other labs accept that fossil preparation work takes longer if preparators talk to visitors and thus, have devised strategies to address imposing deadlines. According to North Carolina Museum of Natural Science's Curator of Paleontology Vince Schneider, staff and volunteers working in the Fossil Lab initiate interactions with visitors. Staff shares with visitors the name of the fossil they are working on, the appearance of the animal from which the fossil came, the fossil's age, and the reasons they study fossils. Schneider acknowledges that under these conditions, staff and volunteers generally don't prepare a lot of fossils.[10] One solution proposed by the Academy of Natural Science's Paleo Lab Coordinator Jason Poole is to recruit more preparators to explain what other preparators are working on.

FIGURE 1. View of McDonald's Preparation Laboratory at the Field Museum, Chicago. Interpretive panels align the lab's exterior, and window workstations align its interior. Note the message on the window reads: "Please do not tap on the glass- fossil preparators at work."

The other challenge to planning for working fossil labs is effective collaboration between exhibit developers and preparators during the design of the lab's interface. Design of the interface between the lab's interior and exterior is important (Fig 2.), as it is the location where the educational exchange between staff and visitors occurs. However, my research showed that, in general, the lab's design became a "division of labor between preparation and collections management staff on the inside, and exhibits on the outside."[11] As Preparator Bryan Small at the Denver Museum of Nature and Science recalled, "We had the lab up to the window and then Exhibits were responsible for talking with us on the other side of the window. There is a sloper [interpretive panel] with the tools we use, what is the fossil lab, why it is here. Exhibits developed this

[8] Christopher Shaw, interview by author, 26 April 2006.

[9] Bill Simpson, interview by author, 26 April 2006.

[10] Vince Schneider, Curator of Paleontology, North Carolina Museum of Natural Sciences, Raleigh, interview by author, 14 March 2006.

[11] Bryan Small, interview by author, 26 April 2006.

concept on the other side of the glass." Frances Kruger, Exhibit Developer and Interpretive Writer, was responsible for writing labels that tied the lab concepts to the overall exhibition.[12] A similar division of labor occurred at Museum of the Earth. Director Warren Allmon said, "Our collections manager designed the details of the vents, lights, 'the inside of the box.' Our exhibit staff, at the time, worked out some of the details 'outside of the box,' such as the case out in front of the prep lab… There was not a lot of discussion during the design process… The exhibit people should have been more involved in designing the interior of the space."[13] Allmon added:

> I guess what I've learned mostly out of this…is, it really isn't trivial how to design a lab. It isn't just park a dinosaur bone on a table. You need to think more about the whole human architecture….[14]

2) Secure staff responsible for working in the lab during regular museum hours, for coordinating lab personnel and preparation activities, and for training volunteers in preparation activities, and if appropriate, in interacting with visitors.

The second challenge of operating working fossil labs as public exhibitions is staffing. Having sufficient staff to keep the lab open during regular museum hours has been a problem for several labs, including the National Museum of Natural History, Smithsonian and Museum of the Earth. Only a few labs–for example, at the Field Museum, the Denver Museum of Nature and Science, and the Academy of Natural Sciences—have staff or volunteers present in the lab during regular museum hours. Even these labs, which have a commitment to providing staff whenever the museum is open, sometimes find it challenging to staff the lab, especially if a preparator calls in sick or is on vacation. For this reason, having staff to coordinate lab personnel as well as preparation activities is crucial. Several natural history museums do not have even one employee whose full time responsibility is to perform these duties because their museums simply do not have the financial resources to support this position. This has proven to be challenging for the National Museum of Natural History, which for years has attempted, but has not succeeded, in securing funds to pay a FossiLab Coordinator's salary. Particularly at labs without a lab coordinator, collaborations between collections management staff running the operations inside the lab and volunteer coordinators managing retention and recruitment of volunteers, is critical. At Museum of the Earth, Allmon learned that staffing should be a serious consideration in planning a working fossil lab. To this end, he admitted,

> We have had mixed success with our volunteer program since we have opened the museum [in 2003]. Overall, it is remarkably successful. But the museum added a whole new level to our volunteer needs…the collections staff and the volunteer coordinator have to be coordinating, talking all the time. We knew it was a problem. I just laid down the law and said, 'We are going to staff it every single Saturday.' [Even if it meant staffing the lab himself].[15]

Another challenging aspect of staffing the lab is having volunteers who are comfortable talking to visitors or who have sufficient training to answer the range of visitors' questions. Volunteers are drawn to working in fossil laboratories for different reasons. As Allmon put it,

> What we learned is that there are two kinds of people who like to work in the prep lab, those who want to work in the lab because they don't want to talk and then others. We have people sit in the lab with the window closed and that is okay, I guess. And [we have] people who don't prep anything, who spend all of Saturday talking to people. Because it is all run by volunteers, we have to live with this. We would prefer to have people who are prepping and talking…[16]

One solution is to leverage volunteers' strengths, catering the lab's projects to their interests. Preparator Bryan Small at Denver explained,

> We encourage volunteers to work at the window. But we don't force them. Some volunteers don't want to talk to anybody; they just want to work on their fossil. You

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[12] Francis Kruger, Exhibit Developer, Denver Museum of Nature and Science, interview by author, 22 February 2006.
[13] Warren Allmon, interview by author, 17 April 2006.
[14] Ibid.
[15] Warren Allmon, interview by author, 17 April 2006.
[16] Ibid

FIGURE 2. View of visitors observing Paleo Lab Coordinator Jason Poole preparing fossils in the Fossil Prep Lab at the Academy of Natural Sciences, Philadelphia. Note the half-windows with holes that can facilitate conversation between visitors and preparators. Photo by Reid Cummins. Courtesy of the Academy of Natural Sciences

> don't want them up front. Others have the gift of gab. They thrive on being up there and talking to the public…we try to give them projects that are fun to talk about.[17]

Another solution is to pair up volunteers who enjoy talking with those who enjoy prepping fossils.

An additional concern with using volunteers is that those who have minimal paleontological training might offer inaccurate or incomplete answers to visitors' questions. Volunteers do not always know the answers to visitors' myriad questions. Often volunteers only know the details of the fossil they are working on. Museum Specialist at the National Museum of Natural History, Smithsonian Steve Jabo instructs volunteers to tell visitors when they don't know an answer to a question. Should lab volunteers at the Academy of Natural Sciences not know the answer to a question, they are instructed to consult the Paleo Lab Coordinator. As articulated in the Academy's Laboratory Manual, Jason Poole recommends to his staff, "It is okay if you do not know the answer to a question. Don't make it up; ask for help and stick around to hear the answer. It is also okay to look things up for people, or to tell them where they can get the answers for themselves."[18]

3) Conduct additional evaluations of the impact of working fossil laboratories on visitors' experience.

The third challenge to operating working fossil laboratories is evaluation. Though there is a growing interest in evaluation studies of working labs, several museums are just beginning to improve their labs

[17] Bryan Small, interview by author, 26 April 2006.

[18] Jason Poole, Dinosaur Hall Prep Laboratory Manual, Academy of Natural Sciences.

through evaluation. Results of my visitor study conducted at the Academy of Natural Science's *Fossil Prep Lab* demonstrated that the interpersonal interaction provided at some fossil labs significantly impacts how visitors rate their experience. In order to improve this interaction, the next step is to evaluate the quality of the interaction between staff, volunteers, and visitors. For instance, Museum of the Earth has learned they should have done more formative evaluation *before* they built their fossil lab and consequently, would like to undertake some remedial work, particularly of the human interaction they offer.

Staff working in fossil labs should participate in determining criteria by which to be evaluated. Then these criteria should be evaluated with visitors to identify whether they, in fact, contribute to quality interpretation. Evaluator Chris Parsons developed a list of skills for "good guides" engaged in quality unscripted interpretation for the docent program at the Monterey Bay Aquarium in California.[19] This guide could be adapted to fossil laboratory exhibitions at natural history museums.

Literally manifestations of the philosophical merger of the museum's research and educational functions, working fossil laboratories connect museum research to visitors' natural interests in the preparation of specimens and to scientists' lives. Not only do fossil laboratories connect visitors to scientists' narratives, they connect them to the scientists, as themselves. As American Museum of Natural History's Gilbert Stucker wrote about the quarry at Dinosaur National Monument in 1965, giving visitors the chance to become involved, to engage with scientists, is the answer to effective interpretation. "He [the visitor] becomes involved. He enters the paleontological experience and shares in the discovery and the excavating [and in the case of the fossil lab, I would add, in the act of preparation]…It is not coming to him second hand, as something told, something shown; he is living it."[20]

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[19] Chris Parsons, "Evaluating Unscripted Live Interpretation Programs," 169-175.
[20] Gilbert F Stucker, "Dinosaur Monument and the People: A Study of Interpretation," *Curator* 6, no. 2 (1965): 142.

DINOSAURS, MUSEUMS, AND THE MODERNIZATION OF AMERICAN FOSSIL PREPARATION AT THE TURN OF THE 20TH CENTURY

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Abstract

By the turn of the 20th century, the institutional setting for American vertebrate paleontology had shifted from private collections into large, well-funded, urban museums, including the American Museum in New York, Pittsburgh's Carnegie Museum, and the Field Columbian Museum in Chicago. This shift ignited a fierce competition among museum paleontologists to display fossil vertebrates—especially gigantic Jurassic sauropods from the American West. Museums launched ambitious expeditions aimed at collecting exhibit-quality dinosaurs. The net result was an enormous influx of unprepared fossils. Getting these fossils into shape for study and display posed a number of novel challenges for fossil preparators. New material arriving from the field required room for temporary storage and dedicated laboratory space in which to prepare it. Adapting a basic fossil preparation lab to the needs of dinosaur paleontology often involved considerable extra investment in equipment and space. Finding, training and retaining skilled fossil preparators could be very expensive, also. The sheer volume of work, and its unique demands, led to increased specialization and professionalization among the science support staff. This in turn, drove higher standards for the work, leading to important lab innovations. Preparators developed new techniques to handle the workload, some of which required expensive new machinery, entirely new systems (e. g., electricity, or pneumatic apparatus) or new spaces in which to operate the equipment, some of which produced particularly noxious dust, noise, or smells. The essential task of fossil preparation, usually performed in backroom or basement labs by low-paid minions working in relative obscurity, was a vital prerequisite for the higher profile work of publishing original research and putting fossils on display.

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Introduction

By the turn of the 20th century, the institutional setting for American vertebrate paleontology had settled into large, well-funded, urban museums. Prominent among them were the American Museum of Natural History in New York, Pittsburgh's Carnegie Museum, and the Field Columbian Museum in Chicago. A fierce competition to display mounted fossil vertebrates, especially gigantic Jurassic sauropods, then broke out among museum paleontologists. In turn, this contest – the second American Jurassic dinosaur rush – ultimately led to the modernization of American fossil preparation.

During this period, these museums launched ambitious expeditions aimed at collecting exhibit-quality dinosaurs, which netted an enormous quantity of unprepared fossils. Getting these fossils into suitable shape for study and display posed a number of novel challenges for fossil preparators. New material arriving from the field required room for temporary storage and dedicated laboratory space in which to prepare it. Adapting a basic fossil preparation lab to the needs of dinosaur paleontology often involved considerable extra investment in equipment and space. Finding, training and retaining skilled fossil preparators became increasingly expensive. The sheer volume of work, and its unique demands, led to increased specialization and professionalization among the science support staff. This, in turn, drove higher standards for the work, leading to important lab innovations. Preparators developed new techniques to handle the workload, some of which required expensive new machinery, entirely new systems (e.g., electricity, or pneumatic apparatus) or new spaces in which to operate the equipment, some of which produced particularly noxious dust, noise, or smells. Nevertheless, the essential task of fossil preparation, usually performed in backroom or basement labs by low-paid minions working in relative obscurity, was a vital prerequisite for the higher profile work of publishing original research and putting fossils on display.[1]

Making room for dinosaurs

Developing an efficient system for storing and preparing fossils was an essential first step in building a museum program in dinosaur paleontology. At New York's American Museum, a flourishing program in mammalian paleontology, established in 1891, lent the Department of Vertebrate Paleontology (DVP) a considerable advantage over upstart programs at the new museums in Pittsburgh and Chicago. Even so, the influx of Jurassic dinosaur specimens, beginning in 1897, quickly overtaxed the DVP's ability to handle fossils. Fortunately, Curator Henry Fairfield Osborn, who was wealthy and very well connected, had the clout to get what he wanted from museum administrators. His program began in humble quarters, cramped and confined in the museum's basement. By 1898, its three storerooms were filled to capacity with fossils. Osborn used this fact to leverage some new space. Late in 1899, the museum completely remodeled his department, assigning it to new offices on the uppermost floor of the east wing. Osborn was understandably pleased with his "very roomy" accommodations.[2]

The remodeled workspace for the DVP was a boon for fossil preparation. Better lighting and ventilation in the new top-floor fossil preparation lab made the work more pleasant, and elevated its visibility and prestige (Fig. 1). Rooms were retained in the basement, however, both for long-term storage of inferior fossils, and to provide room for the dirtiest and noisiest lab work, which Osborn preferred to keep out of sight. The opportunity to upgrade the lab's systems and appliances was available in 1899, and it was probably taken, although it seems likely that improvements were continuously being made in

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[1] Peter J. Whybrow notes that, "the methods and techniques employed in the [paleontological] laboratory … are seldom clear and sometimes not even mentioned! Vertebrate paleontology must be one of the few "sciences" where the techniques used to establish the facts appear to be of little consequence." See Peter J. Whybrow, "A History of Fossil Collecting and Preparation Techniques," *Curator* 28, no. 1(1985): 5-26, on p. 5.

[2] On cramped quarters and planned improvements, see Ronald Rainger, *An Agenda for Antiquity: Henry Fairfield Osborn and Vertebrate Paleontology at the American Museum of Natural History, 1890-1935* (Tuscaloosa and London: The University of Alabama Press, 1991): 90; and, DVP annual reports for 1898 and 1899. See also letters, H. F. Osborn to J. Wortman (on the commodious new office spaces), 10 November 1899, H. F. Osborn to B. Brown (on basement storage), 25 July 1902, and A. Hermann to H. F. Osborn (on basement lab work), 22 December 1903, DVP Arch., AMNH.

FIGURE 1: The new, top-floor preparation lab at the American Museum of Natural History. (From Hermann, 1909.)

the lab to keep it state-of-the-art. The lab featured an overhead trolley system, with chains and movable hoisting blocks attached to steel rails, which was used both to lift and move heavy blocks, and to suspend specimens while they were being fitted for mounting. The lab was wired for electricity, which provided power for reliable indoor illumination, and to run certain tools, including the "indispensable" portable electric drill. Small electric motors were useful for operating a multitude of essential tools (Fig. 2). A two horse power motor operated a large lathe, which drove a rotary diamond saw used for cutting stone and fossil bone, wheels for grinding and sharpening hand tools, a drill for boring specimens, and a small saw for cutting and splitting metal. A smaller motor ran the blower on a miniature gas-blast furnace used for heating and shaping metal armatures for mounting specimens, or for tempering or re-shaping metal tools (Fig 3).[3]

The generous new quarters acquired in 1899 were insufficient to ward off a storage crisis that occurred in 1903. It was brought about inevitably by the influx of oversized Jurassic dinosaurs, especially from Bone Cabin Quarry (Wyoming), opened in 1898. Assistant Curator William Diller Matthew described the deplorably crowded conditions in several DVP storerooms, and Osborn conveyed this information to the museum president in his annual report. To make his point, Matthew counted 106 stacks of trays filled with fossils, averaging fifteen trays per stack, for which no racks were available, all despite the most diligent economizing of storage space. In order to access fossils, it was necessary to un-pile and then re-pile the stacks, which was difficult, inconvenient, and, worst of all, injurious to the specimens. Also, floor space for tables to store oversized specimens was completely taken up, so that tables had to be stacked as many as three high, the limit of safety. Finally, boxes as yet unpacked were piled "as high as is practicable and higher than is convenient." There was simply no way to fit additional fossil material into the storage space then allotted to the DVP. Osborn recommended that the osteological collections belonging to another department be removed from the east wing of the museum to make more room for his growing collection of fossils.[4]

FIGURE 2: A preparator uses a small electric motor to drive a wire brush. (From Hermann, 1909.)

[3] See Adam Hermann, "Modern Methods of Excavating, Preparing and Mounting Fossil Skeletons," *The American Naturalist* 42, no. 493(1908): 46-47; and, Adam Hermann, "Modern Laboratory Methods in Vertebrate Paleontology," *Bulletin of the American Museum of Natural History* 26(1909): 330-331. There are very few records in the DVP Archives on the fossil preparation lab.

[4] DVP annual report for 1903.

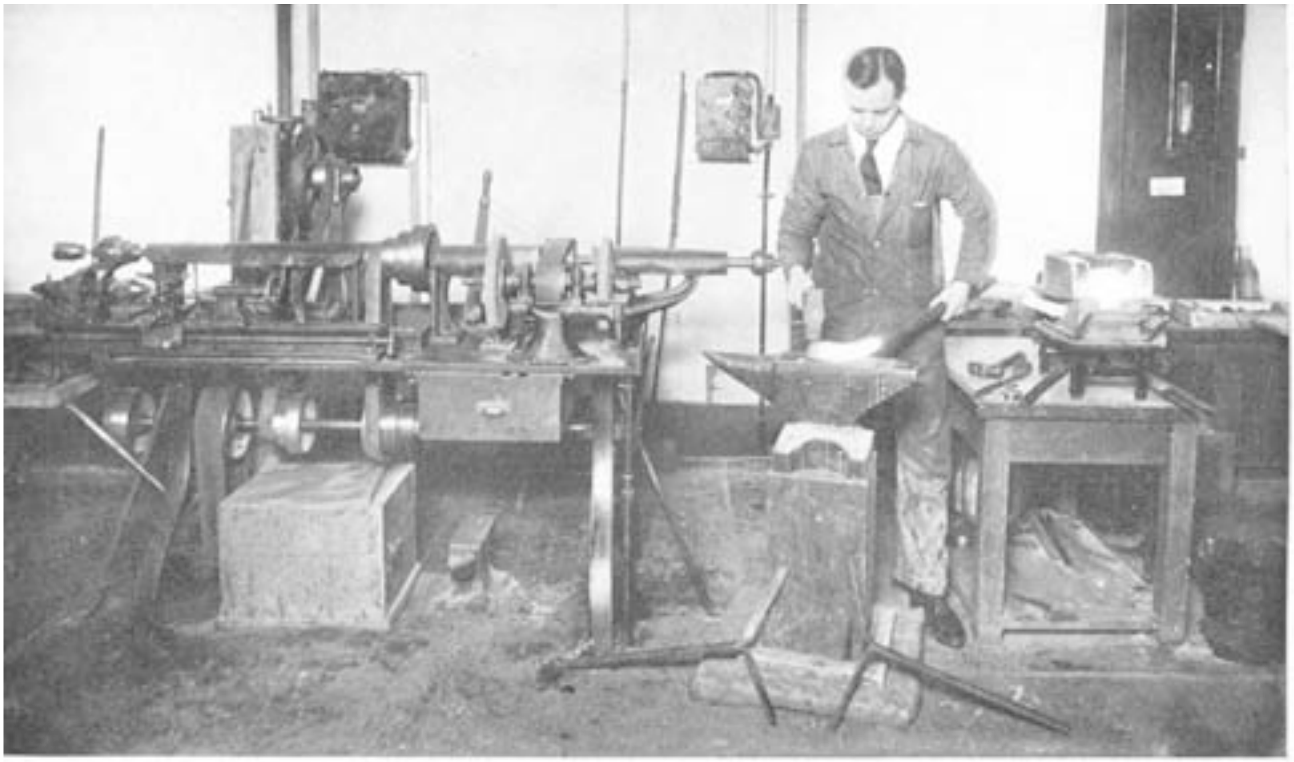

FIGURE 3: A preparator shapes metal at an anvil. On the left is a lathe with appliances for turning, boring, grinding and section cutting. On the right is a gas-blast furnace. (From Hermann, 1909.)

At Pittsburgh's Carnegie Museum, Director William J. Holland was a newcomer to vertebrate paleontology who sometimes failed to anticipate fully the needs of this department. Holland was especially keen to please his patron, Andrew Carnegie, who took a personal interest in mounting a sauropod dinosaur in his new museum. Nevertheless, it was not until October 1899, when collectors were already returning to Pittsburgh with an abundance of specimens from their inaugural field season, that Holland appealed to the Committee on Buildings for space in the museum to establish a laboratory for fossil preparation and an office for Jacob L. Wortman, his new curator. The lab took shape rather quickly, with only a few start-up troubles (Fig. 4). Preparators began slowly turning out specimens in early November. By January, Wortman was well satisfied with progress in the lab. He was less pleased, however, with his overbearing superior, and was forced to resign his position after a heated exchange with Holland. The director hired John Bell Hatcher – recently returned from Patagonia – to replace him. Following Hatcher's first field season in 1900, Holland provided a new, larger space for the preparation lab and storeroom. Hatcher and his staff spent a week arranging these rooms for maximum efficiency. Nevertheless, a growing preparation staff and a steady accumulation of Jurassic dinosaur fossils ultimately overwhelmed the available space. In 1906, preparators fitted up temporary quarters in the basement of the new museum building, which was still under construction. But a lack of adequate space and proper appliances hampered their work. Until the new building was completed, and a permanent lab established, finding room for fossil storage and preparation would continue to be a problem that occasioned considerable inconvenience and loss of time.[5]

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[5] See William J. Holland, "The Carnegie Museum Pittsburgh: Annual Report of the Director for the Year Ending March 31, 1904," *Publications of the Carnegie Museum* Serial No. 28(1904): 24; William J. Holland, "The Carnegie Museum Pittsburgh: Annual Report of the Director for the Year Ending March 31, 1906," *Publications of the Carnegie Museum* Serial No. 43(1906): 29; and, letters, W. J. Holland to T. G. McClure, 10 October 1899, Holland Papers, CMNH; J. B. Hatcher to W. J. Holland, 8 November 1900, Hatcher Papers, CMNH; and J. Wortman to H. F. Osborn, 4 November 1899, and 6 January [1900], DVP Arch., AMNH. For more on the

Money, staff, space, and other resources for paleontology would be comparatively difficult to come by at Chicago's Field Columbian Museum, where no patron had as yet shown any particular interest in dinosaurs. There, Curator Oliver C. Farrington took an *ad hoc* approach to assimilating the new vertebrate paleontology program within the structure of his Geology Department. Following the museum's inaugural paleontology expedition in 1898, space for fossils had to be improvised somewhere in the West Pavilion, without adversely affecting Geology's space. And Farrington, a hard-rock geologist by training, was loathe to give over any of the space devoted to rocks, minerals, ores, etc., in order to accommodate paleontology. Accordingly, Farrington and his new paleontologist, Elmer S. Riggs, found a means to compress the departmental library, in Hall 74, to half its original size. Once fitted with tables and a rack of storage trays, the space gained was just barely large enough to serve as the museum's first fossil preparation laboratory and storeroom (Fig. 5). But when dinosaurs first arrived in 1899, the makeshift lab proved too small for the work. Extra space was afforded by removing the remaining books and bookcases to the increasingly crowded curatorial office in Hall 73. The preparation lab, expanded to fill all of Hall 74, gained a turning lathe, a workbench, and a sink with running water. This, too, proved inadequate once work commenced on a mother lode of Jurassic dinosaurs collected from western Colorado in 1900-1901. To provide more room, Farrington agreed, in the spring of 1902, to swap his spacious corner office in Hall 73 with the undersized preparation lab. The new lab included all the trappings of the old, and added a closet, revolving worktables, and a skylight with sliding overhead curtains. About 300 square feet of additional space for fossil vertebrate storage was found in 1905 by discarding two exhibit cases full of "duplicate specimens of kerosene" from some adjacent space in Hall 71, which was partitioned off and connected to the preparation lab.[6]

Finding good help

At all three museums, a staff of skilled and experienced technicians was the most vital ingredient for operating an efficient fossil preparation lab, but finding the right preparators and retaining their services for the long term could be a difficult proposition. Luring dissatisfied staffers from other institutions became a common practice. Osborn acquired his chief preparator, Adam Hermann, from Yale. Holland, in turn, took Arthur Coggeshall from Osborn. Riggs bagged Harold W. Menke from the American Museum after Osborn turned him away, but then failed to entice Albert Thomson or Charles Christman from the same institution, Charles W. Gilmore from the Carnegie Museum, or even Charles Bunker from the University of Kansas.[7] Few men, it seems, were willing to work for peanuts in Chicago.

history of dinosaur paleontology at the Carnegie Museum, see Helen J. McGinnis, *Carnegie's Dinosaurs: A Comprehensive Guide to Dinosaur Hall at Carnegie Museum of Natural History, Carnegie Institute* (Pittsburgh: Carnegie Institute, 1982); and, Tom Rea, *Bone Wars: The Excavation and Celebrity of Andrew Carnegie's Dinosaur* (Pittsburgh: University of Pittsburgh Press, 1999).

[6] See Field Columbian Museum, "Annual Report of the Director to the Board of Trustees for the Year 1899-1900," *Publications of the Field Columbian Museum, Report Series* 1, no. 6(1900): 447 and 449; Field Columbian Museum, "Annual Report of the Director to the Board of Trustees for the Year 1901-1902," *Publications of the Field Columbian Museum, Report Series* 2, no. 2(1902): 104; and Field Columbian Museum, "Annual Report for 1904-1905," 360. For more on the early history of vertebrate paleontology at the Field Columbian Museum, see Paul Brinkman, "Establishing Vertebrate Paleontology at Chicago's Field Columbian Museum, 1893-1898," *Archives of Natural History* 27, no. 1 (2000): 81-114. (Note, however, that Brinkman (p. 105) was mistaken in identifying Hall 75 as the museum's first fossil preparation lab.) When the Field Columbian Museum was first established as a memorial of the 1893 world's fair it acquired massive numbers of economic geology specimens including, for instance, "coal from every developed coal field in the United States." Many of these specimens were later regarded as duplicates when the museum switched to a natural history format. See Paul D. Brinkman, "Frederic Ward Putnam, Chicago's Cultural Philanthropists, and the Founding of the Field Museum," *Museum History Journal* 2, no. 1 (2009): 73-100.

[7] Letters, O. C. Farrington to F. J. V. Skiff, 11 November 1905, DGC, FMA; and, A. Thomson to E. S. Riggs, 11 January 1906, Riggs Correspondence, Geol. Dept. Arch., FM.

FIGURE 4: An early fossil preparation lab at the Carnegie Museum of Natural History. Courtesy of Carnegie Museum of natural History, Pittsburgh, Pennsylvania.

Seducing another institution's valued staff members was most often interpreted as a hostile act, however. Osborn, for example, remarked bitterly about Hatcher's "absence of a clear feeling of right or wrong," when the latter allegedly (according to Osborn) co-opted his own brother-in-law, Olof A. Peterson, who was then working for the DVP, to accompany him on the Princeton Patagonian Expedition of 1896. However, less than one month later, Osborn asked a Princeton collector in Hatcher's employ to make a special search for certain fossil mammal desiderata on his behalf. Osborn declined to hire the Princeton collector outright, though, claiming that "no man's heart can be in two places at the same time."[8] When Peterson returned from the last of the Princeton Patagonian Expeditions, Osborn wanted him back, but he chose to go to the Carnegie Museum, instead. Early in 1900, Wortman, who wanted to return to work in New York and needed to stay in Osborn's good graces, wrote a letter to his former boss disavowing any role in bringing Peterson from Princeton to Pittsburgh.[9] And Samuel W. Williston felt he owed Hatcher an apology and an explanation when Riggs tried to tempt Sydney Prentice, the Carnegie Museum's talented scientific illustrator, with a similar position at the Field Columbian Museum.[10]

A higher salary, better working conditions, and greater opportunities to do certain kinds of preferred work, like research or fieldwork, were the chief inducements used to lure preparators to switch allegiances. The same were also sometimes used to try to persuade them to stay. Osborn was sometimes proactive in lobbying for his preparators. In 1900, for example, after instituting a new rule requiring his staff to work eight hours per day (instead of seven), he felt they deserved a raise. "I think they all should be encouraged by a *slight* advance of salary [emphasis added]," he wrote in his annual report. Preparators and other support staff also had their own reasons for staying or leaving. Many of these men worked anonymously, and some resented it. Peterson quit the American Museum because of a perceived lack of due credit. On the other hand, those who stayed and did good work could sometimes negotiate for greater official acknowledgement of their efforts. Arthur W. Slocum, for example, wanted a position title "of sufficient merit to warrant publishing the name of its holder in the Annual Reports as a member of the Scientific Staff [of the Field Columbian Museum]." Some preparators used job offers at rival institutions to bargain for better terms. Still others, like Norman Boss of the Carnegie Museum, tried this tactic and were sent packing. Curators and administrators very much resented this practice, and worked to suppress it. Some, including Osborn, seemed to think that the gentlemanly thing to do was to deal preparators among themselves like baseball trading cards.[11]

Osborn expected unflagging loyalty from his subordinates, especially collectors and preparators, although he was sometimes reluctant or even unwilling

[8] The quotations come from two letters, H. F. Osborn to W. B. Scott, 15 February 1896; and, H. F. Osborn to J. W. Gidley, 9 March 1896, DVP Arch., AMNH.

[9] Letter, J. Wortman to H. F. Osborn, 6 January [1900], DVP Arch., AMNH.

[10] Letter, S. W. Williston to J. B. Hatcher, 25 February 1903, Hatcher Papers, CMNH.

[11] Osborn's quotation comes from DVP annual report for 1900. On A. W. Slocum, see letter, O. C. Farrington to F. J. V. Skiff, 9 January 1906, DGC, FMA. On N. Boss, see letter, J. B. Hatcher to W. J. Holland, 16 January 1904, Hatcher Papers, CMNH. Farrington wrote a letter to C. Christman [26 January 1906, DGC, FMA] warning that his museum "would not care to have its offer used to compel the payment of higher wages by a sister institution." For an example of Osborn dealing a preparator, see letter, H. F. Osborn to W. B. Scott, 12 January 1900, DVP Arch., AMNH.

FIGURE 5: Hall 74, the first fossil preparation lab at the Field Columbian Museum. (The Field Museum, negative #CS 3243.

to meet the demands of workers who asked for more rewards, financial or otherwise, in return for their faithful service. He denied Princeton's James W. Gidley a long-term opportunity with the DVP, for instance, because he felt it would be better to "train someone in [the work] whose sole interest is in the American Museum." Gidley stayed for years, anyway, always on a temporary basis, but he grew increasingly frustrated with his lot. In 1899 he complained, "It seems rather hard after all my years of experience … that I should be out here in the field working like a slave for … $50 per month, less than I was getting before I went to college."[12] Barnum Brown pleaded for years for a permanent position under Osborn, but did not get one until sometime after his return from Patagonia in 1900. He negotiated repeatedly for better pay, also, but Osborn was exceedingly slow to raise his salary. Osborn seemed to think that the experience Brown was getting under his tutelage, the reputation he was winning, and the opportunity to publish some of his own results "ought to be sufficient reward" for the persistent low pay and lack of commitment on Osborn's part.[13] Riggs probably fell into permanent disfavor with Osborn after he cancelled a miserable arrangement he had made to work for the DVP for half pay, in order to take a seemingly much more promising position at the Field Columbian Museum.[14] After Wortman quit the DVP and joined

[12] On Gidley, see letters, H. F. Osborn to J. W. Gidley, 18 March 1896; and, J. W. Gidley to H. F. Osborn, 1 August 1899, DVP Arch., AMNH.

[13] Letter, H. F. Osborn to B. Brown, n.d., [May 1899], DVP Arch., AMNH. Other letters express the same ideas. See especially H. F. Osborn to B. Brown, 12 January 1900, DVP Arch., AMNH.

[14] See Brinkman, "Establishing," 94-96.

the Carnegie Museum, taking Coggeshall with him, Osborn feared he would try to lure away more of his collectors. Osborn expected them to feel honor-bound to remain, writing in a thinly veiled warning to his new field foreman Walter Granger that "it would be a decided breach of faith for any man to leave the party before the close of the season."[15] Many of Osborn's subordinates, perhaps surprisingly, did remain loyal to the DVP. Historian Ronald Rainger lists fourteen employees who stayed with Osborn for more than twenty years.[16]

Finding capable young men, with little or no experience with fossils, but with reasonably good mechanical skills, and then training them to be excellent preparators, was another common approach to staffing the preparation lab. Holland and Hatcher were especially keen to find and train their own preparators for the Carnegie Museum. But what were the qualities that suited a person for such a position? Hatcher felt that willing, interested, and modest young men were the best candidates to become well-trained workers. He also insisted on finding someone who would be agreeable, although he seemed to get along with any man who respected him. Holland, on the other hand, seemed not to get along well with anybody. He valued obedience most, and sought men who appeared to be pliant, modest, and willing to obey orders. He preferred to find a "college-bred" man "who has his way to work in the world." But he could be picky. He turned one young man away for being "too sullen." Another was "too raw." Nor did he want a man with too much experience who might come at a high price. "We would do better to try and get a young man and bring him up after our own fashion," he wrote to Hatcher.[17]

Osborn valued loyalty in his subordinates above all other virtues. He also seemed to take particularly well to men from the rural West. Over the long term, he seemed to get along much better with men who earned their reputations entirely under his watch with the DVP, men who owed him their careers. He had much poorer luck with Cope and Marsh cast-offs like Hatcher, Peterson, and Wortman. Hermann, however, was an important exception to this rule.[18] Wortman, who served as Osborn's field foreman for almost ten years, was a poor judge of character. He seemed to have an early flush of enthusiasm for all men, which often wore off at the first sign of adversity. He adored Brown in 1896, for example, but absolutely despised him in 1897. He seemed not to value college experience in his subordinates, claiming, "a little learning is a dangerous thing."[19]

Yet at the height of the second Jurassic dinosaur rush, when the workload in the lab reached its zenith, no museum could afford to be too choosy about its preparators. Men of various skill-levels and experience swelled the ranks of the fossil preparation staffs at all three museums in the first few years of the twentieth century. Indeed, by 1900, the crush of dinosaurs coming in from the field created a terrible fossil preparation bottleneck in the DVP, despite efforts (described below) to mechanize and otherwise streamline the work. Osborn griped that his preparation staff of seven men was too small. "I wish without injustice to other departments," he wrote in his annual report, "that [the preparation staff] were larger because a very careful estimate of materials now in the department shows that without any additions whatever <u>it will occupy 7 men for a period of 10 years</u> to prepare and mount the specimens [which] are worthy of exhibition [emphasis original]." But this report left him vulnerable, such that in his next report he was more careful to state that to cease collecting was simply not an option.

[15] Letter, H. F. Osborn to W. Granger, 5 June 1899, DVP Arch., AMNH.

[16] Rainger, *Agenda*, 80.

[17] See letters, W. J. Holland to J. B. Hatcher, 12 June, 6 July, and 17 July 1900, Holland Papers, CMNH.

[18] More on Osborn's working relationships appears in Ronald Rainger, "Collectors and Entrepreneurs: Hatcher, Wortman, and the Structure of American Vertebrate Paleontology Circa 1900," *Earth Sciences History*, 9, no. 1(1990): 14-21. Insightful firsthand accounts of Osborn's imperiousness can be found in George G. Simpson, *Concession to the Improbable: An Unconventional Autobiography* (New Haven and London: Yale University Press, 1978), 40; and, Edwin H. Colbert, *Digging into the Past: An Autobiography* (New York: Dembner Books, 1989), 168-171. See Robert W. Howard, *The Dawnseekers: The First History of American Paleontology* (New York and London: Harcourt Brace Jovanovich, 1975), 270-271, for some less sympathetic accounts.

[19] Letter, J. Wortman to H. F. Osborn, 26 August 1898, DVP Arch., AMNH.

"Although a large force [of preparators] is employed," he explained, "we are still very much in arrears, and were it not for the very rapid and energetic work of other Museums in beds which will soon be exhausted, I would recommend a diminution of field work until we might gain headway [emphasis original]." Osborn added more and more men, and by 1903, the DVP boasted a preparation staff of fifteen.[20]

When a similar fossil preparation crisis arrived at the Carnegie Museum, in 1903, Hatcher responded by contracting field operations. He kept Peterson in Pittsburgh for the summer to work on the backlog of unprepared fossil mammals. Later, in September, he recalled collector Earl Douglass from the field one month early, both because of a sudden and surprising drain of fieldwork funds, and because of the abundance of work to do back at the lab.[21] Farrington urged the Field Columbian Museum to hire additional preparators in 1902, in order to keep abreast of the mounting workload. His request was denied, not because there was no need for help or no money to cover the cost, but merely because the Geology Department already had seven employees.[22]

Putting preparators to work

The high volume of work to be done during the second Jurassic dinosaur rush led to some increase in specialization and a sharper division of labor in museum paleontology departments. Osborn hired dedicated collectors and preparators from the very start. He would orchestrate the work of the department and reap most of the credit for its accomplishments, but he left the lower status labor to his staff of subordinates. He rarely participated in fieldwork, and seldom, if ever, involved himself with the dirty work of fossil preparation. So large was Osborn's preparation staff that it led to extremes of specialization. Christman, for example, specialized in repairing broken specimens, while Otto Falkenbach excelled at making casts and doing fossil restoration. Rainger has detailed how effectively the division of labor worked in the DVP, and how Osborn profited by it. But it was sometimes a source of discord. Hatcher, for one, was particularly critical of Osborn's brand of fireside natural history. He wrote: "It seems to me that if some of the older workers in vertebrate paleontology [Osborn] would go to the trouble to go out into the field, do their own collecting, and familiarize themselves with the laboratory work, they would have a greater appreciation for the work and efforts of others."[23]

Hermann was the DVP's chief preparator during the second American Jurassic dinosaur rush. Hermann ran the departmental lab, supervised the other preparators, and, at Osborn's urging, developed new techniques for preparing and mounting fossils for display. He hardly ever participated in other departmental activities, however. Coggeshall, who trained under Hermann at the American Museum, later filled the same role of chief preparator for the Carnegie Museum. At the Field Columbian Museum, which had a much smaller paleontology staff than its eastern rivals, the situation was very different. Riggs played the part of collector, chief preparator, researcher, and exhibit developer, and was the only vertebrate paleontologist of his era to make significant contributions in all four of these areas. He was repairing a chair with wire and glue, when a young man with an interest in paleontology turned up in his office, looking for career advice. He explained, "Son, in this field you have to be able to do everything."[24]

Often the men who did fieldwork in the summer spent the winter months working in the fossil preparation lab. Many of these men were particularly keen to prepare the specimens that they had collected. Valuable experience gained in the lab was later applied in the field, often yielding better results and higher standards for fieldwork. Collectors who learned about the capabilities of modern lab work usually made better judgments about which fossils to

[20] DVP annual reports for 1900, 1901, 1903 and 1904.

[21] Letters, J. B. Hatcher to O. A. Peterson, 26 May 1903; and, J. B. Hatcher to E. Douglass, 4 September 1903, Hatcher Papers, CMNH.

[22] Letters, O. C. Farrington to F. J. V. Skiff, 14 November 1902; and, H. N. Higinbotham to F. J. V. Skiff, 29 November 1902, DGC, FMA.

[23] Letter, J. B. Hatcher to T. W. Stanton, 6 January [1904], Hatcher Papers, CMNH. See also Rainger, *Agenda*, especially Chapter 4. On specialization in the preparation lab, see DVP annual report for 1903.

[24] William Turnbull, [Remarks upon Receiving an Honorary Membership in SVP], *Society of Vertebrate Paleontology New Bulletin* no. 172(1997): 42-43.

collect, and what to leave behind. They also learned firsthand the value of keeping careful field notes, drawing accurate quarry diagrams, and carefully packing and labeling all packages from the field – making a special effort to preserve a record of any field associations of bones or fragments that might be useful back in the lab. Preparators also advised fieldworkers on better collecting techniques. At the American Museum, Osborn often acted as the heavy in these interactions. In 1900, for example, he advised George R. Wieland and Granger to be sure to apply a separating layer of linen or paper between the bone and the protective plaster jacket – plaster applied directly to friable specimens had a tendency to pull off pieces of bone when the jacket was removed in the lab. In 1902 he admonished Granger to provide a complete packing list when shipping fossils back from the field, in order that preparators might find pieces in the order in which they were required. This was already a standard practice, so what could Granger say in reply? "I will look after this listing with special care this fall [emphasis original]," he wrote.[25]

Osborn sent a letter to Brown that was very critical of some of the latter's fieldwork. "You will be very much disappointed," he wrote,

> "that the Dinosaur which you collected with so much care and labor has proved almost valueless. We have developed block after block in the hope of finding something of value; but in vain. I have directed Mr. Hermann to abandon work on the specimen, and to move the block down to the basement, although it is hardly worth keeping at all. …This seems to warn us that we should certainly examine material a little more carefully in the field before taking it up…. I know you sent the specimen to us after the best possible methods; but it should have received a more careful examination. I therefore request you to examine all your prospects and bones pretty carefully, so as to make yourself absolutely sure that we are not bringing on material that will not pay the shipment much less the heavy expense of collection."[26]

Brown responded diplomatically, claiming, "I greatly appreciate your criticism." Of course, as Osborn himself pointed out, he had done his best. The specimen had simply not turned out as well as expected, which is a risk inherent in fieldwork. Brown continued to placate his superior, explaining, "every pound of matrix that we can possibly remove … will come off." But this procedure flatly contradicted Hermann's advice "that it is a great fault on the part of some fossil collectors to free the bones too much from the matrix, for this weakens the specimens and makes them more difficult to transport." Brown also pointed out that developing specimens in the field "takes a great deal of valuable time from prospecting," which was inconsistent with Osborn's policy that collectors should spend the majority of their time prospecting, rather than excavating.[27] This exchange of letters seems to lend support to Hatcher's claim (made later in 1904 and mentioned above) that Osborn had become too far removed from fieldwork and fossil preparation to appreciate the efforts of others. Nor was he able to offer very useful criticism or direction, despite Brown's politic reply.

Dedicated preparators also ventured occasionally into the field, sometimes with useful results, often not. Coggeshall joined Wortman at Sheep Creek in 1899, and kept detailed notes about the quarry conditions, which were later very useful for reconstructing the skeleton of *Diplodocus*.[28] But he seems not to have participated in fieldwork thereafter. Hermann joined the DVP field crew at Bone Cabin Quarry in 1899, but he only stayed a week. Camp life, according to Granger, was a "trifle too rough for him."[29]Asher Van Kirk, an apprentice preparator for the Carnegie Museum, gave fieldwork a try in the summer of 1902, but he had a beef with the

[25] Letter, W. Granger to H. F. Osborn, 15 September 1902; see also letters, H. F. Osborn to G. R. Wieland, 27 September 1900; and, H. F. Osborn to W. Granger, 3 December 1900, and 9 September 1902, DVP Arch., AMNH.

[26] Letter, H. F. Osborn to B. Brown, 25 July 1902, DVP Arch., AMNH.

[27] See letter, B. Brown to H. F. Osborn, 12 August 1902, DVP Arch., AMNH; and Hermann, "Modern Laboratory," 286. See also letter, H. F. Osborn to B. Brown, 25 July 1905, DVP Arch., AMNH.

[28] William J. Holland, "The Vertebral Formula in *Diplodocus*, Marsh," *Science* n.s. 11, no. 282(May 25, 1900): 817, footnote.

[28] Letter, W. Granger to H. F. Osborn, 19 August 1899, DVP Arch., AMNH.

FIGURE 6: Hand tools, including hammer, chisels and awls. (From Hermann, 1909.)

expedition cook and made "such a complete fool of himself" that he fled home to Pittsburgh, leaving Peterson shorthanded in the field.[30] And Hatcher, a brilliant fieldworker, was famously ill suited for work in the preparation lab.[31]

Developing newer, faster, and more accurate techniques

The need for greater speed and accuracy drove the development of a number of innovative fossil preparation techniques. Prior to the second Jurassic dinosaur rush, when the high volume of work first began to demand greater efficiency, fossil preparators worked exclusively with hand tools, especially awls and chisels (Fig. 6). Bones were set-up on sandbags for protection in a position favorable for working, and held firmly in place by means of several additional sandbags. A rotating stand or table was useful for keeping the working surface of the bone turned toward the light from a window. Preparators removed the hard matrix from the bones by chipping it away with a tedious, repetitive tapping of light shoemaker's hammers on hardened steel chisels or awls for finer work (Fig. 7). The work was exhausting for the preparator, and sometimes too hard on the specimens. The constant vibration often caused pain or numbness in the chisel hand, and soreness in the arms. The jar from the repeated blows caused much unwanted breakage in soft or brittle specimens, especially when the hardness of the matrix required a heavier hammer stroke to break it. A hardening agent of shellac or gum arabic prevented some breakage, but, other than exercising extreme caution, little could be done to protect thin edges or other delicate structures. Worse still, a wide range of motion was required for wielding a hammer and chisel. On complicated bones with deep and intricate cavities, it was often impossible to find a place of purchase for the chisel, or room to swing the hammer. Sometimes it was necessary to smash a complicated bone to pieces in order to work out the matrix. But the greatest disadvantage of using hand tools was the slowness of the work.[32]

Preparators derived new techniques for speeding the work by adapting the technologies of other, more lucrative industries to fossil preparation. Hermann introduced the electric dental lathe and dental engine at the DVP laboratory. Hatcher, likewise, showed an interest in introducing electric mallets and lathes in the preparation lab at the Carnegie Museum. Both were useful for operating small corundum grinding wheels, dental burs, or small rotary brushes (wire or bristle). A flexible arm attachment provided a greater range of motion and better access to cavities that could not be reached with ordinary hand tools (Fig 2). Hermann also had an extra large dental mallet custom-built for his lab to do very delicate chiseling on smaller specimens. Ideally suited for working on extremely delicate

30 Letter, O. A. Peterson to J. B. Hatcher, 30 August 1902, Hatcher Papers, CMNH.

31 Charles Schuchert and Clara M. LeVene, *O. C. Marsh: Pioneer in Paleontology* (New Haven: Yale University Press, 1940), 219-220.

32 Elmer S. Riggs, "The Use of Pneumatic Tools in the Preparation of Fossils," *Science* n.s. 17, no. 436(1903): 747-749; and, Elmer S. Riggs, [MS] "Hunting Fossils, Grand Valley, Colo.," Riggs Collection, Colorado National Monument.

skulls or teeth, dental appliances were almost useless for the heavier work involved in dinosaur paleontology. For matrix that was too hard to work effectively with metal tools, Hermann experimented with acid preparation. He had some success using hydrochloric acid and potash, both of which were useful for softening hard carbonate matrix. The great disadvantages of this technique were the noxious fumes and the care involved in assuring that the acid dissolved the matrix and not the fossils. In 1903, when the backlog of unprepared specimens grew to overwhelming proportions, Hermann began experimenting with labor-saving tools in earnest. He had his greatest success using sandblasting equipment, which in trials was found to be very practical for cleaning matrix from large bone surfaces, but only where the matrix was considerably softer than the bone. Late in December of that year he urged Osborn to invest in some expensive new equipment and systems in order to modernize the lab for greater efficiency.[33]

Osborn read a paper about Hermann's new technique before a meeting of the (short-lived) Society of the Vertebrate Paleontologists of America. "The writer," he boasted, "has recently been experimenting with a sandblast, driven by a compressed air engine, with admirable results." It is difficult to take this claim literally, however, as it was Hermann who developed and tested the new sandblast. In December, 1907, Hermann gave a talk before the same organization on modern methods of excavating, preparing and mounting fossil vertebrates. He published a short paper on the same subject in the *American Naturalist*. Osborn encouraged him to publish an even longer and more comprehensive article on modern laboratory methods

FIGURE 7: A preparator working with hand tools, sand bags and a rotating table. (From Hermann, 1909.)

in vertebrate paleontology for the *Bulletin of the American Museum of Natural History*, in 1909.[34]

The introduction of pneumatic tools, especially the pneumatic hammer / chisel, was the most important innovation made in fossil preparation during the second Jurassic dinosaur rush. Riggs developed this technique at the Field Columbian Museum early in 1903. He tried ordinary stone cutting tools at first, but found them to be brutal instruments ill adapted to fossil preparation. He then spent two months making and trying various modifications. To obtain a more controlled stroke, he experimented with a special chisel holding attachment that threaded onto the end of the pneumatic hammer. The attachment served to soften the blows of the hammer by means of a coil spring, which absorbed some on the impact. Its square fitting also prevented the rotation of the chisel. Finally, an air escape vent directed forward blew dust and fragments away from the working surface.[35]

The complete pneumatic apparatus consisted of an air compressor with an engine to run it, air tank, pressure gauge, piping and fixtures, and a suite of air tools, including pneumatic hammers and drills. The entire outfit cost between $800-$1000, and could supply pressure for up to eight air tools at one time. The basic tool was the pneumatic hammer / chisel,

[33] Hermann, "Modern Laboratory;" letter, A. Hermann to H. F. Osborn, 22 December 1903, DVP Arch., AMNH; and, letter, P. Russell to J. B. Hatcher, 14 March 1902, Hatcher Papers, CMNH. Francis A. Bather, a British paleontologist, had also been experimenting with acid preparation at about the same time. Hermann, "Modern Laboratory," quotes from Bather's work extensively. Henry M. Bernard, meanwhile, had used a sand-blasting device to prepare trilobites, although it is not clear that Hermann knew about this work. See Francis A. Bather, "The Preparation and Preservation of Fossils," *Museums Journal* (1908): 76-90; and, Henry M. Bernard, "On the Application of the Sand-blast for the Development of Trilobites," *Geological Magazine* 1(1894): 553-557.

[34] See Henry F. Osborn, "[Abstract] On the Use of the Sandblast in Cleaning Fossils," *Science* n.s., 19, no. 476(1904): 256; Hermann, "Modern Methods;" and, Hermann, "Modern Laboratory."

[35] Riggs, "Pneumatic Tools."

which was adapted from tools designed for stone cutting or riveting metal. This hand-held, cylindrical device housed a hollow chamber where an air-driven hammer played lightly upon the head of a chisel at a rate of at least 3000 strokes per minute. This succession of blows caused the chisel to vibrate rapidly. When the operator pressed the tip of the chisel to rock, the rock tended to shatter at a remarkable rate. Work with the pneumatic hammer was faster, more accurate, more versatile, and easier on the fossils and the men who prepared them.[36]

Once past the experimental phase, Riggs was quick to share specifications of this important new technique with colleagues at other institutions. He published a detailed article on the pneumatic hammer in the May 8th, 1903 issue of *Science*. He was also eager to demonstrate it to visitors who stopped in Chicago on their way to or from the field. Brown was astonished at its cutting capacity, and he urged Osborn to introduce it at the American Museum. Osborn saw it for himself later that same year. Riggs also wrote letters to Hermann, at the DVP, and Alban Stewart, at the National Museum in Washington, DC, singing its praises, and encouraging them to adopt the technique in their own labs. Stewart began using pneumatic tools for fossil preparation late in 1903 with great success. Hermann recommended the introduction of air tools and sand blasting equipment, both of which required a compressed air plant, in December 1903. He warned that both systems would best be confined to the basement, because of excessive noise and dust. Consequently, new and better lighting would also be required. Strangely, Osborn was slow to approve this change. Hermann hoped to get a complete pneumatic set up by the spring of 1905, when his lab was upgraded with a new power plant and other new machinery. Riggs claimed that a man could turn out twice as much work using the pneumatic hammer. The noise was annoying at first, and intolerable to anyone trying to read or write in the same room. But the men who operated the equipment quickly grew accustomed to the noise, and indeed, spoiled by the relative speed and ease of the work.[37]

Conclusion

By 1908, the second American Jurassic dinosaur rush was essentially over. Giant sauropod dinosaurs had been mounted for display in New York, Pittsburgh and Chicago, and more would quickly follow. Mounted dinosaur skeletons proliferated widely in the aftermath of the rush. Another, less visible, but just as lasting legacy of the rush was the modernization of American fossil preparation. Large public museums ultimately provided ample, dedicated lab space, along with the requisite money, equipment and labor to do fossil preparation properly. Likewise, the demand in museums for a large number of cutting-edge, mounted dinosaur exhibits created a mandate for innovation, and for newer, better, and more efficient techniques for streamlining the work while improving the results. Larger staffs and a finer division of labor brought increasing specialization. This, coupled with prolonged, steady employment at ambitious museums provided certain preparators with the opportunity to hone their skills. Presentations on fossil preparation at professional meeting, and technical papers published in scientific journals spread information about the best new materials, tools and procedures from one museum to another. Publications by Riggs, Hermann and others, were the first, tenuous steps in the professionalization of American fossil preparation. Other, informal vectors for the spread of new techniques included personal correspondence, courtesy calls at rival museums, and the swapping of lab personnel.

Most important were the critical lab innovations that dramatically improved the speed and quality of fossil preparation, including acid preparation, sand-blasting, and especially pneumatic hammers and chisels. A century later, these same tools and techniques are still the mainstays of modern fossil preparation.

[36] Riggs, "Pneumatic Tools;" and, letter [draft], E. S. Riggs to A. Hermann, 30 June 1903, Riggs Correspondence, Geol. Dept. Arch., FM.

[37] See letters, E. S. Riggs to A. Hermann, 30 June 1903; B. Brown to H. F. Osborn, 31 May 1903; A. Hermann to H. F. Osborn, 22 December 1903, DVP Arch., AMNH; A. Stewart to E. S. Riggs, 29 August 1903, and A. Hermann to E. S. Riggs, 16 December 1904, Riggs Correspondence, Geol. Dept. Arch., FM; and, Riggs, "Pneumatic Tools."

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FOSSIL PREPARATION TEST: AN INDICATION OF MANUAL SKILS

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Abstract

When considering candidates for fossil preparation positions, Field Museum preparation personnel issue a skills test to evaluate basic levels of manual dexterity. The test requires candidates to prepare the caudal fin of a *Priscacara* one ray at a time, from the relatively large base to the more delicate tip. The preparation test allows evaluators to determine an individual's micropreparation capabilities on an abundant species before allowing preparation of rare and scientifically valuable specimens. Monitoring progress over the duration of the test is informative, regardless of whether the interview is for a volunteer or staff position. After several years of testing, a comparative "library" of specimens can be amassed, allowing evaluators to establish a baseline for minimum acceptance. The test is described here with a discussion on evaluating results.

Bergwall, L. 2009. Fossil preparation test: an indication of manual skills. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 35-40. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

Rationale

The fossil preparation test administered to prospective staff and volunteers at The Field Museum of Natural History (FMNH) was designed as a way to fairly assess the skill and potential in individuals who desire to perform fossil preparation on vertebrate specimens within the department. This serves to protect the fossil collections from potential damage done by individuals who do not possess the manual dexterity required to adequately prepare specimens. While verbal interviews will provide a feel for an individual's knowledge of paleontology it does not convey the physical prerequisite needed for superior preparation.

For those who have not previously experienced fossil preparation, performing the test helps fully grasp the concept of fossil preparation. In some cases candidates realize that while they have knowledge and a strong interest in paleontology the act of fossil preparation does not suit them. This occurs with roughly 15-20% of applicants for volunteer positions. Candidates with these qualities can be directed towards alternative departmental projects such as assisting with collections management.

History of Development

The preparation test was designed and implemented in 1982 by Bill Simpson, former Chief Preparator of Vertebrate Paleontology in the Geology department. Since its inception, the test has been a requirement for candidates of paid fossil preparation positions as well as volunteers. While it appears to be a procedure that is unique to FMNH it is a process that would benefit any institution that values specimen conservation and desires to maintain a high standard for preparation.

Methods

Candidates

The vast majority of candidates who come through the system are applying for volunteer positions. Roughly a dozen or so a year are processed. Volunteer applicants far outpace staff applicants at FMNH as there are a very limited amount of staff positions and turnover is extremely low. Volunteers are required to commit one day per week to fossil preparation.

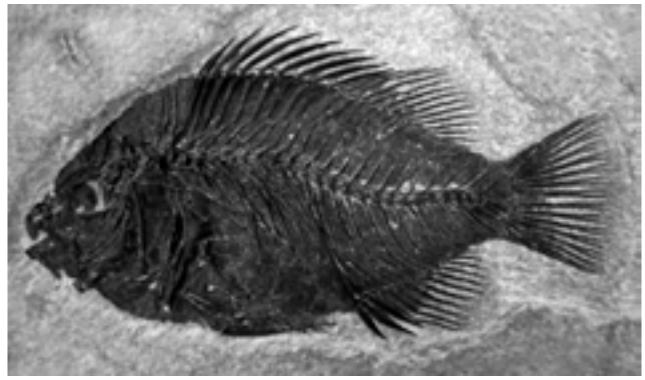

FIGURE 1: Fully Prepared *Priscacara liops* PF12107

Materials

The test is performed on the caudal fin of a *Priscacara* (Fig. 1) from the Green River Formation of Wyoming. *Priscacara* are one of the most common species from this fossil rich locality, and are thus both well described and abundant in the collection. The caudal fin is solid and sturdy at its base and progresses outward to a fine, segmented, and fragile tip. This provides an ideal measure as to where along the fin any given individual reaches the limit of their manual dexterity. A successful candidate should be able to reach the end of a fin without losing any material. Specimens from this locality are ideal for this test because matrix coverage is minimal, therefore adequate preparation can be accomplished in a 3-6 hour window. Additionally, these specimens are fairly uniform in size (4-6 inches in total length with the caudal fin averaging 1-2 inches) and preservation so as to give a standard of comparison among all samples.

Candidates are given a sharpened pin-vise, microscope with foot pedal air supply, and a preparation reference sheet (Table 1). They are instructed on the importance of keeping the pin vise sharp either by sharpening it themselves (with instruction) or having a staff member sharpen it for them. Occasionally candidates are allowed to use cyanoacrylate in small quantities to stabilize unsecured bone, however it is usually unnecessary.

Test Administration

A member of the preparation staff administers the test by orienting the candidate and monitoring their progress throughout the day. Candidates work for a minimum of three but up to six hours. For individuals who have never prepared a fossil before, a brief demonstration and detailed verbal instruction

Instructions for preparation of a Green River Priscacara
The Procedure 1. You have three hours in which to work on this fossil 2. Begin by working on a fin a. Start near a fin base and work away from the body one fin ray at a time b. Go to the base of the next fin ray and again work out to the tip c. Prepare parallel to the bones, with the "grain" of the ray, not perpendicular to it d. Don't dig deep pits in between the rays. Prepare only half way down the sides of any bone 3. If you have prepared several fin rays, switch to a section of the body
Tips for Preparation 1. Keep you pin vise sharp, this will give you more control than trying to press harder with a dull point. 2. Control of the pin vise is enhanced by increasing the number of contact points between the pin vise and your hand. You can do this by placing the pinky finger edge of you hand on the table or matrix surface (but not on the prepared fossil surface). 3. Rock is referred to as "matrix". 4. Fossil bone is referred to as "bone". 5. The smaller the piece of matrix you remove, the better you will do. 6. There is usually a separation zone between the matrix and the bone surface allowing you to pop small pieces of matrix off the bone. Try to use this to your advantage, it will allow you to keep from touching and/or nicking the bone surface some of the time. 7. Use the air supply controlled by the foot pedal to blow accumulations of matrix dust away from the portion of the bone you are preparing.

TABLE 1: Instructions issued during the preparation test.

are given. It may be necessary to redirect errant individuals at some point during the test to give them the best chance of improving with time.

Test Criteria

General Criteria

Performance assesment varies depending on weather the candidate is applying for a volunteer position or a paid position. The main difference between the two is how strictly the quality of work is assessed. A volunteer can be given simple, robust specimens that require a lower skill level. However, a paid preparator MUST be able to handle specimens at any scale or level of difficulty. Likewise, if the candidate has preparation experience he/she should be able to demonstrate how to properly use and sharpen a pin vise as well as show a higher level of proficiency in quality of work than a person who has no experience.

Specific scoring criteria

- Did the person follow instructions? It is often necessary to check on progress and then redirect candidates towards a better technique or correct problems with method of preparation. Some candidates repeatedly ignore directives and continue poor techniques that could easily be modified by following instructions.

- How does the specimen compare to other specimens in regards to preservation and articulation? Small differences in the quality of preservation, hardness of matrix and level of articulation can make a difference in the level of difficulty in preparation. Each specimen should be evaluated for these variations.

- Was the candidate able to sit for the duration of the three hour test? Did they seem to get bored? For some individuals it is very difficult to maintain focus for long periods and for this reason are poor candidates not because manual dexterity is lacking. Many people go into lab work thinking they will love it because they have a strong interest in paleontology and end up realizing they just don't have the patience or ability to focus.

- Does the candidate seem to be a good fit with the rest of the preparation staff and laboratory environment? It is important that all individuals fit well with the environment of the laboratory and are able to work in a space that is on display to the public. Volunteers are often recruited to work in the McDonald's Fossil Preparation Laboratory at FMNH, which is a publicly viewed space. Some individuals have a hard time being on display and dealing with crowds of onlookers.

- Was there improvement as he/she progressed? For some, it takes time to become acclimated to using the pin vise in conjunction with a microscope or learning the limits of the matrix and bone. A visible improvement is a positive sign that the individual has the propensity to learn.

Results

Examples of Preparation Tests

The following are examples of preparation tests that are in residence in the collections at The Field Museum with a brief description of how each test can be assessed.

An ideal result shows no damage to the bone as well as little or no errant scratches or gouges in the surrounding matrix, with fin rays that are prepared fully from the base to the tip (Fig 2a). Some individuals were hired as preparators largely due to their impressive preparation (Fig. 2b).

When multiple tests are given on a single specimen it is much easier to compare due to the uniformity in preservation. If one individual is able prepare the ray with few mistakes or loss of bone, while another individual leaves the ray looking incomplete or uneven it can be safe to conclude that the fault is with the individual rather than as a result of poor preservation. Figures 2c and 2d are examples of the variation that can be seen in a single specimen with multiple individual's work. In figure 2c, the top half of the tail has many missing sections and mistakes that can be seen without the aid of a microscope. The bottom half of the tail is more uniform and appears to have been prepared with more skill and dexterity. Figure 2d shows four separate individual's preparation tests with alternating success. The very top is acceptable as well as the middle section while the second and bottom sections show many gaps in the continuity of the ray.

In some instances, it is not known until preparation that the caudal fin is not preserved articulated. This condition adds additional difficulty to the preparation of the specimen and should be taken into consideration when assessing quality of work. In Figure 2e the individual who prepared the specimen successfully navigated the disjointed rays to expose the mottled fin.

While evaluating the quality of preparation can occasionally be difficult and opinions may vary, there are some cases in which the results are indisputable and serve to reinforce the value of testing individuals skills before taking them on as either a staff member or a volunteer. Figure 2f is merely one example of unacceptable preparation. This individual was repeatedly guided towards a better approach to the preparation of the specimen with little impact on the outcome.

An additional factor in specimen quality that is difficult to illustrate here is the relative hardness of the matrix and bone. Each specimen is slightly different depending on taphonomic variables such as exact location of fossilization (e.g. near-shore versus off-shore). Experienced preparators can determine this by looking at the specimen and direct candidates accordingly.

Discussion

The fossil preparation test is a useful tool to assess not only manual dexterity but also ability to follow instructions, focus, and adapt to new equipment. Using the same species from the same locality on all tests allows for useful comparison from person to person. The fin ray of the *Priscacara* presents a gradation from simple to difficult and it is easy to see where any individual fits along that line. Assessment of the test is divided by prospective paid preparators and volunteers and should be treated differently. For prospective employees the test adds an additional dimension to the interview process by allowing the candidate to demonstrate their skills first hand. Candidates should be able to demonstrate the ability to prepare the fin ray from base to tip with little damage. They should be able to leave the matrix smooth with no visible scratches or gouges in the surrounding rock. In any paleontology lab one of the most important aspects of specimen preservation and exemplary research is the quality of the specimen

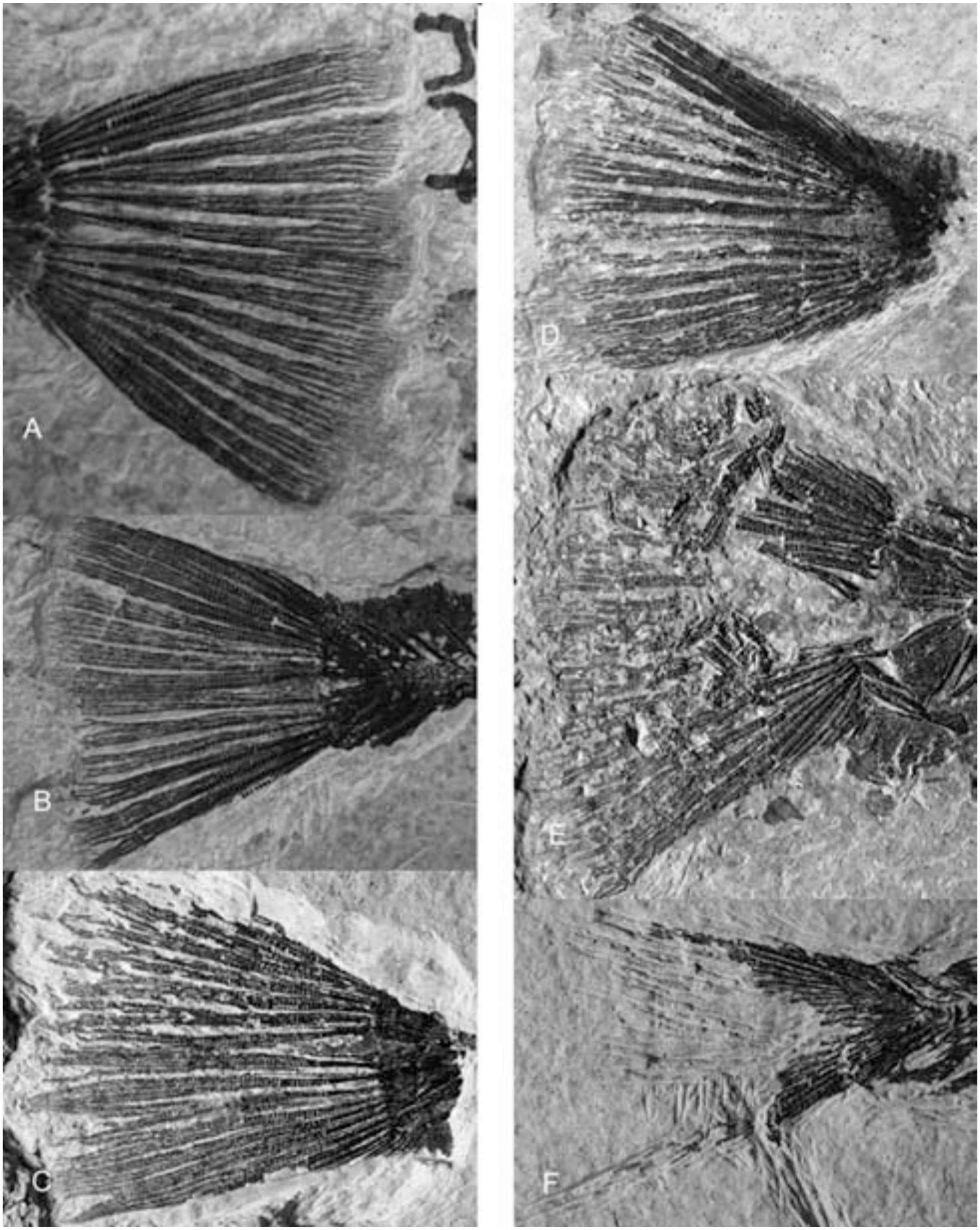

FIGURE 2: **A**. Model test; *Priscacara liops* PF 12090. Uncataloged specimens, **B.** Uniform quality preparation **C.** Mixed quality **D.** Alternating quality **E.** Disarticulated fin. **F.** Failed test (not a *Priscacara* but a *Knightia* from the same locality. Specimen size, preservation, and quality are similar enough to provide an accurate sample.)

post preparation. Therefore the manual ability of a preparator is at least as important, if not more important, as cerebral or scholarly knowledge and should be considered when hiring.

While it is recommended that volunteer applicants be accepted with a little less stringency, the test still plays a critical role in filtering candidates. This is not only important for the individual but for the laboratory as well since training volunteers takes a moderate amount of investment in time.

Summary and Conclusions

The presented results suggest that:

- The specimens described can be used as models of superior preparation (Fig. 2a and Fig. 2b). They provide standards against which performance of candidates can be compared.

- It is possible to evaluate the quality of work of several individuals using a single specimen (Fig. 2c). The study also revealed that comparing the work of several individuals side by side on the same specimen can help to more clearly identify persons with superior skills as well as individuals who are less skilled (Fig. 2d).

- Exceptional preparators can be identified by examining their skill at preparing poorly preserved and disarticulated fish specimens (Fig. 2e).

- Unsatisfactory candidates can be identified and redirected to other pursuits within the museum (Fig. 2f).

- Finally, volunteer candidates can experience preparation first hand and determine if they would like to commit a minimum of one day per week. Some candidates discover that they do not have the patience or focus for preparation and can be more useful in an alternative capacity at the museum such as assisting with collections, docent or even microsorting screenwashed sediment.

The field of fossil preparation has expanded steadily since its inception and with the implementation of new equipment, tools and materials a higher standard has evolved. Flawless preparation of paleontological specimens is a key component of scientific research that relies on a physical specimen to determine morphologic relationships and evolutionary patterns, and to describe new species. Based on our experiences implementing this program we encourage other institutions to adapt similar programs when either hiring or accepting volunteers. Recently, The Smithsonian Institution (NMNH) successfully implemented a similar training program for volunteers using Eocene leaf fossils from Montana (M. Brown, pers. comm. 2009). This program is more detailed and involves formal training, written testing as well as a final preparation test.

Candidates who do not meet requisite standards of preparation ability can be filtered out before damage is done to important and rare specimens. This occurs at an approximate rate of 60-65% pass 35-40% fail. Volunteers who fail the preparation test can be directed to alternative paths to donate their time to the institution. Finally, spending several hours with a candidate gives staff an opportunity to ensure personality compatibility that will help to maintain a dynamic working environment for everyone in the laboratory.

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MICROPREPARATION… ONE SAND GRAIN AT A TIME

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Abstract

Many vertebrate (and invertebrate) fossils are quite small and need to be prepared with the aid of a microscope. Many of the techniques used for preparation of large fossils can be modified to be used under the microscope. A variety of tools are useful in micropreparation of fossils, from the microscope to needles, glues, air-abrasives and temporary supports, and more. This paper discusses techniques and tools used for micropreparation.

Keywords: Micropreparation, Fossil Preparation, Carbowax, Cyclododecane, Pin vise, Sandblasting

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Introduction

The term "micropreparation" is used in paleontology to describe fossil preparation performed under a binocular microscope. A magnifying lamp can also be used, but this paper will focus on microscope work. Small fossils are the obvious target of micropreparation, but preparation of larger fossils can also be aided by the use of a microscope. Special tools and techniques are used to prepare fossils at this scale. Much of this paper is based on my own experience and represents my own biases. My own experience is based on years of trial and error, published sources and discussions with other preparators. This paper is meant to augment Amaral (1995). It is the writer's hope that beginners will find much useful information in here, and that seasoned professionals will also find some new ideas.

Tools useful for micropreparation include (but are not limited to) a binocular microscope, lighting, sharpened needles, blowers, glues, air-abrasive machine, paintbrushes and Carbowax™ or cyclododecane. Each of these will be discussed below as well as their uses in micropreparation.

FIGURE 1. The essential tool for micropreparation; the binocular microscope on a boom. Other tools seen in immediate work area include three pieces of wood placed in the field of vision to elevate the working surface if needed, a dental pick, a poofer, metal tin with scraps of paper, plastic tub with glue dispensers, hand exercise ball and rubber bands, sharpening stone, a paintbrush and a diamond nail file. The boom swings to the right in this photo allowing the microscope to be places over the glass-covered sandblasting work chamber seen on the edge of the photo.

Tools and techniques

Microscope

The primary magnifying tool used in micropreparation is the binocular microscope. A magnifying lamp may be useful, but is fairly limited in its usefulness. A magnifying lamp has only one magnifying power, needs to be well aligned with the worker's line of sight, and is subject to shaking and vibration.

The binocular microscope allows the worker to see depth (or three dimensions) within the field of view. Monocular microscopes do not allow three dimensional viewing, and are generally too powerful for microvertebrate fossil preparation. I commonly work on small teeth at 30x magnification. Others regularly work at higher magnifications (Amaral, 1995). The binocular microscope should be fully adjustable for each user. The distance between eyepieces can be adjusted to match user's interocular distance. The eyepieces can be focused individually to accommodate a user's eyes if they focus differently.

Features of a microscope that make it most useful for fossil preparation include a continuous zoom, a boom stand and a Barlow lens. Some microscopes offer only a few fixed zoom settings, for example 1x and 3x. A continuous zoom, on the other hand, is a zoom that moves smoothly through all values between the lowest and highest magnification. This allows the user to maximize the view of the specimen in the field. Microscopes are often equipped with a microscope stand or with a stage below the objective. In the case of fossil work, the stage and stand limit the size and placement of fossils under the microscope. A scope mounted on a boom maximizes the working space (Fig. 1). A boom that can easily be swiveled allows for easy movement of the scope from one work area to another. For large blocks, a long boom can be used. It may have to be custom made. If it is too long it may lose stability. A simple tripod set up near the microscope head can be used to stabilize the scope. The tripod's feet can be placed on the block resting on matrix, and avoiding the bones.

A Barlow lens is an accessory lens screwed on the bottom of the objective. Its usefulness in fossil preparation is to increase the working distance between the microscope and the specimen. This comes at the cost of an inverse in magnification. A x0.5 Barlow lens will double the working distance. This can be very useful when the preparator needs additional vertical space to maneuver tools under the scope. For additional magnifying power, use higher magnification eyepieces.

Large specimens are generally not prepared under a microscope, but in some cases doing so can be advantageous. A microscope can help the preparator see and stabilize cracks in the bone before they become unstable breaks.

The preparation laboratory tends to be a dusty place, so the microscope should be protected from dust when not in use. A plastic dust cover is useful. Covering the eyepieces with old film canisters or prescription bottles works well. Keep a supply of lens cleaning paper and fluid in a dust-proof container, and use it as often as needed.

Lighting is a key part of microscope work. A well lit work area allows the preparator to better see what he/she is doing under the microscope. Specialized microscope lights, such as fiber optic illuminators and ring lights, are very useful, but can be expensive. A simple flexible desk lamp can be used, but an incandescent bulb may be too hot for extended work times, so a compact fluorescent bulb should be used. At higher magnifications, this sort of inexpensive lighting will not provide enough light.

Manual tools

The primary tool for micropreparation is the probe. Probes are sharpened pieces of metal used to pick away matrix leaving a cleaned fossil. Pin vises make excellent holders for probes. Some pin vises are double ended; you can put sharpened needles in both ends. On a pin vise with sharp pointy things sticking out of both ends, the end not in use becomes more of a painful hindrance than an advantage. I prefer to have one working end on each pin vise. Some collets allow long pieces of rod to fit through a hollow handle. This allows for use of longer pieces of carbide rod. Foam sleeves that fits over the pin vise handle to reduce stress are also available for pin vises. For soft enough sandstone or shale matrix, simple sewing needles work well. For harder matrix, tungsten carbide rod is a good choice. A mineralogical hardness test shows that it has a hardness of more than 9 on the Mohs hardness scale. Carbide rod is available in diameters as small as 1/64th inch. It is usefully tough when used in a direction more or less parallel to the length of the rod, but it is very brittle when used for scraping in a perpendicular direction, and can break easily. Steel insect pins come in many sizes from 000 (.25 mm in diameter) to 7 (.7 mm in diameter) and are not expensive. Although the smallest insect pins may be too delicate for most fossil preparation projects, it is useful to have some of the larger ones on hand to use as probes. A rotary tool, or a wire-cutter can be used to remove pinheads to allow them to fit into the pin vise. Some workers use a hypodermic needle re-moved from the syringe and held in a pin vise (McCabe, pers. comm. 2008). Dental picks also make good probes, but tend to be soft and will not keep a sharp point in hard matrix. Old dental picks can be obtained from most dentists for free. They have the advantage of offering many different shapes and angles that the preparator may find useful (Fig.2).

Conventional wisdom states that probes should be kept sharp. The sharper the probe, the better it works. Carbide rod can be an exception to this. If it is too sharp and used on hard matrix, carbide will easily break a sliver off of the tip. In this case, the angle of the point should be increased. I have also found that occasionally a matrix will present itself where an extra sharp point is less useful than a slightly rounded point. For example, soft shales from the Willwood Formation containing Eocene mammal teeth and jaws allow for use of a slightly dulled point. The matrix tends to flake off of the enamel cleanly with a dull point, but with a very sharp point, the point is more likely to penetrate the matrix and scar the tooth before matrix/fossil separation occurs. There may be times when a strategically dulled point may be advantageous.

A hand held rotary tool, such as that made by Dremel® or a similar flexible shaft rotary tool made

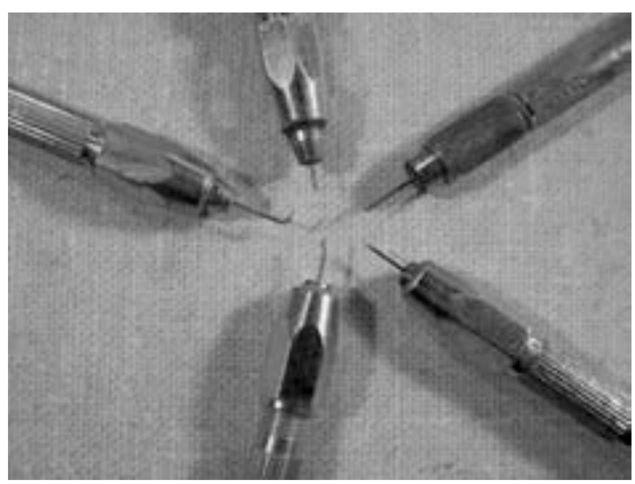

FIGURE 2. A variety of probes. The upper right one is a 1/32 inch carbide rod. All others are sewing needles. Clockwise following the carbide, longer needle, slightly bent needle, very bent needle and short needle.

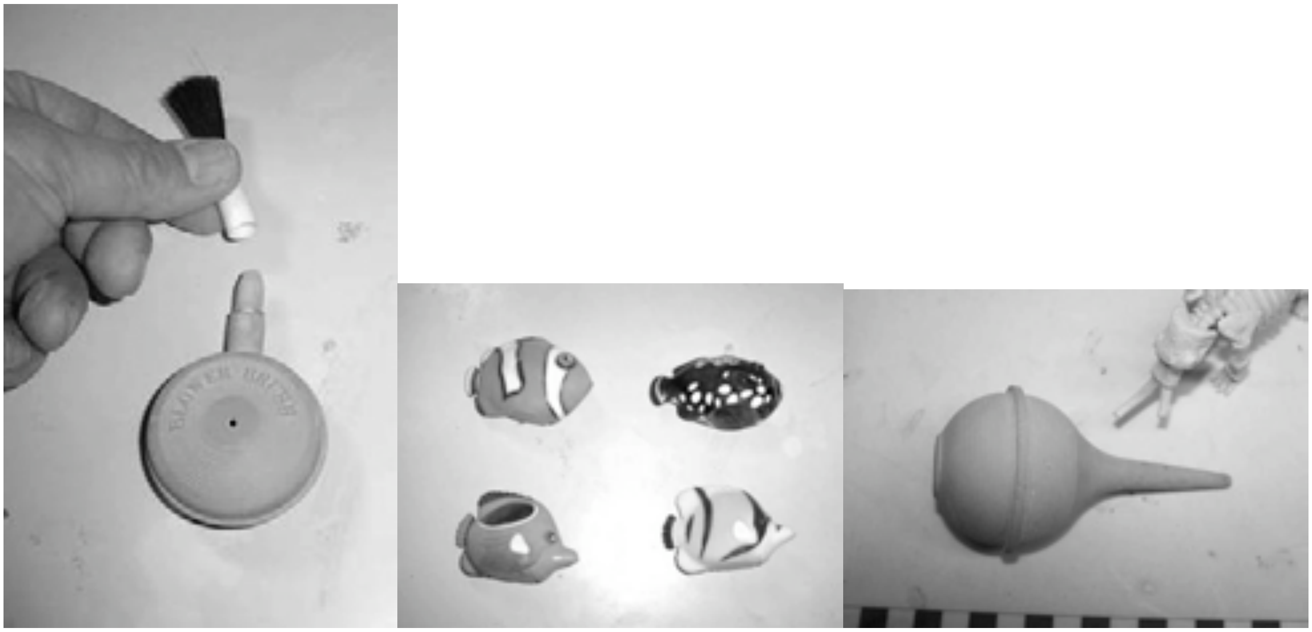

FIGURE 3. Three examples of poofers. **A**) A camera lens cleaner with the brush being removed. **B**) A selection of rubber toy fish. **C**) An ear cleaning bulb for babies.

by Foredom®, is good for sharpening probes. Initial sharpening of dental picks, insect pins and sewing needles is done on a whetstone, or a rotary tool with an abrasive or grinding stone bit. The grit size of a whetstone and the wobble inherent in the rotary tool often prevents a good microscopic sharpness. Softer probes (e.g. sewing needles and insect pins) can be further sharpened with sandpaper. A series of wet-dry sandpapers of 220, 320 and 400 grit on a flat surface such as 1/4 inch thick glass works well. The probe can be sharpened on the edge of the sandpaper, which sits on the edge of the glass. As sandpaper becomes worn, the used part can be trimmed off. Each sandpaper piece is labeled with a self-adhesive label showing the grit to avoid confusion. Carbide rod should be sharpened with a diamond bit on the rotary tool. A diamond surface should also be kept handy for detailed sharpening. Larger grit diamond wheels for rotary tools can often be obtained from discount tool suppliers such, but you may not know what grit size you are buying. Otherwise, dental suppliers are a reliable source of diamond disks of varying grit sizes. Mini-Hone™ made by Dia-Sharp® comes in a grit of 325, 600 and 1200. The 325 grit is fine for sharpening carbide rod. The latter two sizes may create too fine a point.

Probes can also be shaped with different points, chisels, angled chisels, three-sided pyramid points, etc. If a needle is too thick to reach into a cavity (in the fossil, it can be shaved, or thinned, using the sharpening tools. Sewing needles can also be bent to reach into undercuts. Sharpening bent points can be a challenge, and may have to be done under the microscope. Points can also be made of varying lengths. For reaching into tight spots, a long point may be used, but are more susceptible to bending or breaking. They also have a more spring-like rebound property when the matrix gives way, which may be harmful to the fossil, especially in tight crevices. It may be useful to keep a variety of pin vises handy, each with a different point. To avoid confusion they can be marked with different colors of paint, foam handle or electrical tape, so that the preparator can immediately chose the one he/she wants without having to investigate each point.

The basic idea behind using probes under a microscope to remove matrix is similar to doing so without a microscope, except that through the microscope you might be removing sandstone one grain at a time. As debris accumulates in the work area, it must be removed. The preparator could blow on it to remove dust, but more effective methods exist. A camera lens cleaning blower brush with the brush removed (called a poofer in our lab) is ideal for this. Aiming the nozzle at the work area and compressing the bulb clears dust from the specimen. Children's bathtub toys can also be very good, but vary considerably in the amount and aim of poof;

they are available in all sizes and shapes. Bulbs used to clean babies' ears are less useful, as the tube bends off in random directions when squeezing the bulb, making it difficult to aim (Fig.3). Pneumatic or electric air sources (power poofers) have also been used to clear dust from a work area. One can be adapted from a fish tank air pump by simply plugging it in and directing air flow at the work area. A problem with this continuous flow of air is that if a piece of bone should accidentally be lost, it may be difficult to find if it immediately gets blown away. Davidson (1998) describes a foot-operated version of this which feeds a regulated air flow from a compressor through the pin vise. Stepping on a foot pedal allows air to blow through a tube passing through the pin vise clearing dust away from the work area. This allows the user to control when and where the air is delivered without having to put down the probe and pick up a poofer.

Air scribes are common tools used in fossil preparation. They can also be used in micro-preparation. These small hand-held jackhammers come in many sizes and run on compressed air. The smaller models are very useful tools and easy to use under a microscope, but even the larger ones such as the Chicago Pneumatic®(CP) can be used delicately under the microscope. I have successfully used a CP airscribe on very small ammonites from the Pierre Shale in hard concretionary matrix. As with pin vises, if a laboratory has several different airscribes of different sizes that look alike, a color-coded dab of paint or electrical tape can make it easier to find the right one. PaleoTools® makes a variety of airscribes in different sizes and has worked extensively with many preparators to design their tools. A German paleo-tinkerer has developed a fine detail microtip for Aro® style airscribes, which can be ordered with extra long tips. This tool is just as delicate as PaleoTools' Micro Jacks and can be used with a long stylus allowing access to deep recesses. Its main drawback is that it is difficult to replace the tip when it breaks or wears down. I keep two such tips on hand so that I can keep working while one is in the mailing and repairing stage.

Holding small fossils

The hand—The preparator will often set a fossil or block of matrix on a sandbag for stability. This is counter-productive when working under a microscope because as one works, and applies even minute pressure to the specimen to remove matrix, it will sink into the sandbag and very quickly work its way out of focus. Sturdy small fossils (especially teeth) can be held in the hand, gently between the index finger and thumb (Fig. 4). This manual vise allows good control of the surface to be worked on. It is also very easy to keep the fossil in focus by gently moving the fingers up or down while resting the wrist on the work surface.

FIGURE 4. A multituberculate tooth held between the thumb and forefinger. Fingerprints used for scale.

Tweezers and more— A pair of tweezers can be used to pick up small fossils, but must be used gently. Holding a small fossil in tweezers while working on it is not recommended. Pressure of the tweezers may send it flying across the room, similar to squeezing a slippery watermelon seed between one's fingers (the "Watermelon Seed Affect"). A good pair of precision tweezers is recommended. At a microscopic level, cheaper tweezers often make contact elsewhere than the actual tip. A good method for picking up small fossils and smaller pieces of fossil is to use a natural bristle paintbrush. A size 00 or smaller is good for this, but a variety of small sizes of paintbrushes should be kept available. The bristles can be moistened with saliva, and the fossil can be picked up by salivary adhesion. Wetting the brush with water works, but not nearly as well. With saliva, one can effortlessly control the amount of moisture needed to pick up the specimen (Fig. 5).

FIGURE 5. A small natural bristle paintbrush used to pick up the tip of a small crocodilian tooth broken off during sandblasting. The broken surface is facing left. Much of the tooth is covered in sandblasting medium (dolomite). An empty (no medium in the tank) sandblaster at low p.s.i. can be used to clean the powder off. Before gluing, the tooth will have to be repositioned. As it is held now, the tips of the bristles will obscure the gluing surface.

Carbowax™ and cyclododecane— If a fossil is very delicate it may need to be imbedded in a temporary support such as Carbowax™ (Rixon, 1965; Polyethylene glycol, 2006) or cyclododecane (Brown, 2004; Cyclododecane, 2006). Carbowax™ is a water-soluble wax. It is poly-ethylene glycol and comes in molecular weights from 1450 to 8000. Cyclododecane is a wax that sublimates at room temperature. The basic concept for both is very similar. The preparator makes a small mount that will hold the fossil in a bed of wax allowing him to stabilize the fossil while he works on it. The wax gives support to thin and delicate bone while it is being worked on. The mount also provides some-thing larger than the small fossil to hold on to. After the matrix is sufficiently removed, the fossil and mount are allowed to sit in either water or air to remove the waxy support. Fossils that are water-sensitive should not be treated with Carbowax™, as removing it involves getting the fossil wet. Carbowax™ and cyclododecane can also be painted onto one side of a delicate fossil to give it stability as the other side is prepared.

A Carbowax™ mount can be made of anything. I have used clay, paperboard (e.g. cereal boxes) and even Lego® blocks. Primarily I use paperboard: A base is cut slightly larger than the fossil, and then walls are cut and glued into place perpendicular to the base, creating a small container that will be filled with Carbowax™ and the fossil. I use thick cyanoacrylate to glue the walls to the base. The base should be shaped to fit the fossil. The Carbowax™ is melted in a small container on a heat source (e.g., a single burner hot plate). While melt-ing the Carbowax™ it is important to monitor the process closely, overheating will result in a lot of smoke in the laboratory and bad odor. Overheated Carbo-wax™ may lose its usefulness (Dow® rep-resentative, pers. comm. 2006), but I have acid-entally overheated Carbowax™ repeatedly, and have continued to use the same batch with no adverse affects, other than its turning a brownish color.

When the wax is melted, spoon some into the bottom of the mount (I have an old spoon dedicated solely to the Carbowax™). One can also pour some into the mount, but this invariably leads to some Carbowax™ spilling down the outside of the pot that will unpleasantly burn off the next time it is heated up. The fossil should be placed in the wax as it cools. If a fossil is small enough it will need to float on the Carbowax™ surface (if it sinks you will have to find it). If this is the case, you should wait until the wax begins to congeal in small white spheres. Place the fossil into the Carbowax™ deep enough to allow the necessary work to be done on it. Tweezers or a small paintbrush, and the microscope may be very helpful for this step. Larger fossils can sit on the base of the mount be surrounded with Carbo-wax™. If one side of the fossil is already prepared, that side should sit in the wax, allowing access to the unprepared side. Figure 6 outlines this process.

After the wax has cooled, the preparator can expose the top side of the fossil. While doing this, he should glue any cracks that appear (see gluing section). After the top side is prepared, the fossil can be removed

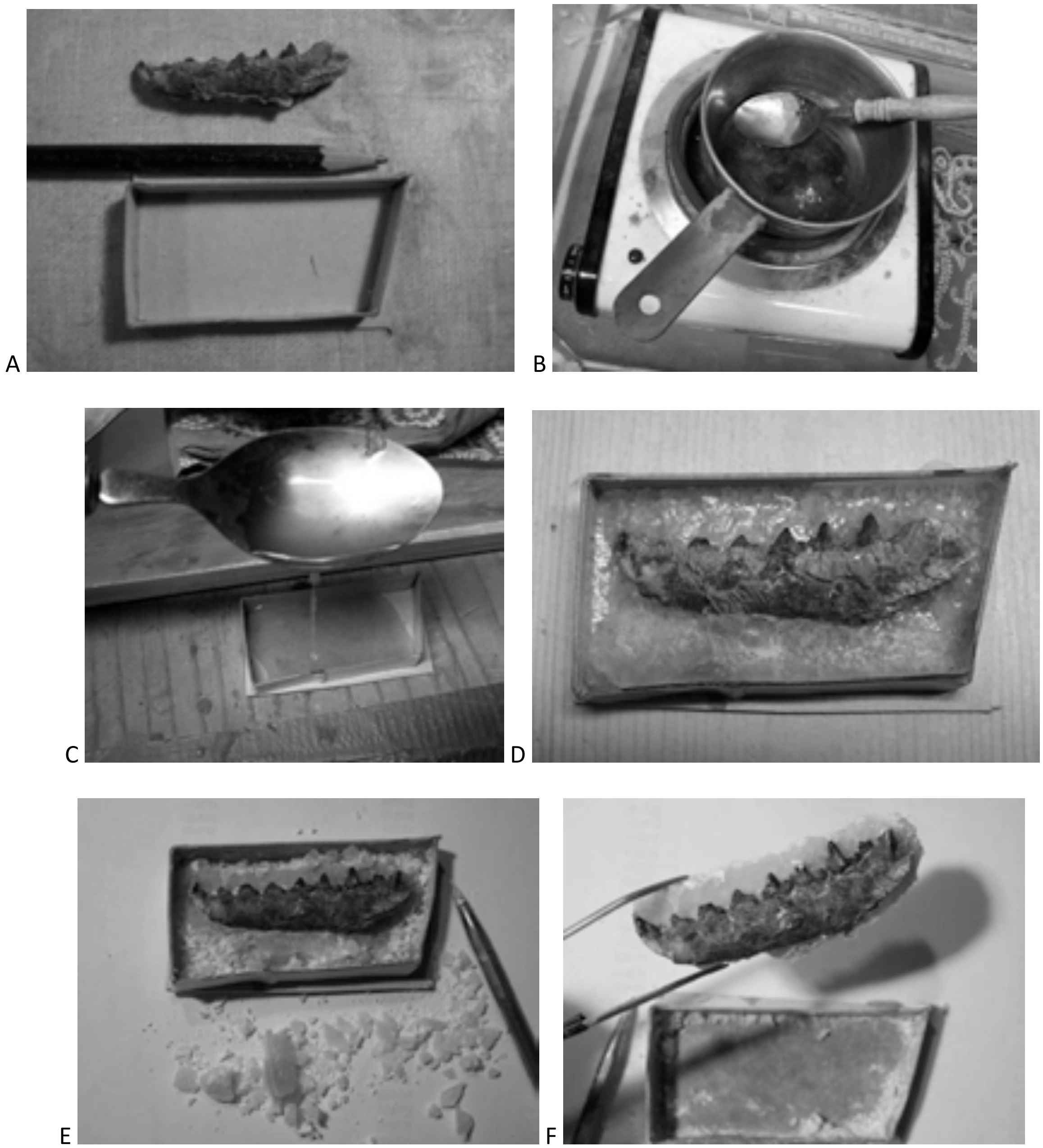

FIGURE 6. A Carbowax™ Tutorial. **A**) The fossil with a custom made mount. **B**) Melting the Carbowax™. **C**) Pouring Carbowax™ into the mount. **D**) The specimen in Carbowax™ after it has cooled. It is now ready to be prepared. **E**) After preparation, excess Carbowax™ is removed manually. The excess Carbowax™ can be recycled. **F**) If the fossil is sturdy enough, the Carbowax™ can be removed from the mount to be soaked in water, as in this case. With a more delicate fossil, the mount with wax and fossil can be put in water.

from the wax. The mount, fossil and Carbowax™ unit can be set into a small amount of warm water to dissolve the Carbowax™. Excess Carbowax™ can be removed with a chisel-ended probe or a sharp blade before the soaking. Do this under the microscope to make sure the fossil is not being harmed. Extra Carbowax™ can be recycled.

In some situations, the matrix may be water-sensitive. If this is the case, the sample should not be soaked until all matrix is removed. It is often possible to prepare the specimen out of the mount in its own little cocoon of Carbowax™, then re-set in into the mount with another dose of Carbowax™, with "back" side of the fossil and the original

Carbowax™ up. One can then prepare through the original Carbowax™ to remove not only the wax, but also the remaining matrix on the "back" side of the fossil. This may be necessary with clay-rich matrix expands in water.

After dissolving the Carbowax™ in water (warm water works faster), the fossil is removed, rinsed in a cup of warm water to remove excess waxy residue, then set to dry. Paperboard mounts can also be dried and used again. The water can be left to evaporate, leaving a re-usable film of Carbowax™. Some people claim that Carbowax™ leaves a waxy residue on the fossil, but it is negligible and doesn't seem to hinder gluing.

Cyclododecane (CDD) was recently introduced to the vertebrate paleontology preparator community (Brown, 2004). It is used in very much the same way as Carbowax™. The main difference is that since CDD sublimates at room temperature, one does not need to wet the fossil or the matrix to remove it. This is very useful for fossils that are water-sensitive or in water-sensitive matrix. It will solidify much faster allow-ing only a small window of time when it is of useful viscosity. Cyclododecane has a slightly unpleasant odor, whereas Carbowax™ is odorless (until it is overheated). Carbowax™ is a very safe product. It has many industrial uses including in cosmetics and in food products (e.g. wax on fruits and vegetables). On the other hand, cyclododecane has yet to be proven food safe, and the safety properties are still largely unknown. Therefore it is advisable to heat and sublimate cyclododecane in a fume hood. In either case, as with the use of any chemical product, the MSDS for each should be obtained, read, and kept handy. These are usually available from the man-ufacturer. Since cyclododecane sublimates at room temperature, it must be stored in an airtight container. A smaller vessel can be used to melt the CDD, for example, an old coffee cup, which can also easily be stored in an airtight zip lock bag. A specimen em-bedded in cyclododecane should also be stored in an airtight container when not actively being worked on. Cyclododecane takes much longer to sublimate than Carbowax™ does to dissolve. A small Carbowax™ mount can dissolve in warm water in an hour, several hours in room temperature water. A similar sized CDD mount will take several weeks to sublimate.

Focusing Block

A fossil (embedded in wax or freestanding) can be placed on the tabletop in the working area of the scope. If the fossil has much three dimensional relief and you are working at higher magnification, some of it may be in focus and other parts may not be. Keeping the fossil in focus can be challenging. I have several pieces of wood cut at roughly 30, 45 and 70 degree angles that I use as focusing blocks, (Fig. 7). The fossil and matrix, or the Carbowax™ mount is placed on a block, usually the low angle block, in the field of view of the microscope. You can then focus on it. Again, the whole fossil may not be in focus all the time. As you slide the mount up and down the slope, different parts come into and out of focus. This allows the preparator to focus using the same hand he is holding the fossil with. It is fairly easy to also move the block so that the portion in focus remains in the center of the field of vision. The focusing block also allows easy access to matrix inside overhangs. The block can also be spun around offering access to the fossil and matrix from different angles. The higher angled blocks are especially useful for preparing into undercuts.

Glues and gluing

Many small fossils come in from the field with a thin coating of some sort of preservative, usually a plastic such as polyvinyl acetate. At the micro-scopic level, these coatings can often be removed simply by applying gentle pressure to them, separating them from the bone or tooth below, or by using a sharp chisel end of the probe to lift the plastic off the specimen. Cyanoacrylate can be much more difficult to remove and should be avoided as a field preservative. Any small cracks that appear under the microscope should be stabilized as soon as possible. I find thin cyanoacrylate glues to be best for this, as they easily wick into a crack. Other glues do not wick as well. A technique for applying minute amounts has been called the scratch technique, described in Amaral (1995). A small drop of glue is placed onto a scrap of paperboard. With a sharp probe (dental picks work well), the drop is scratched picking up a little wad of paperboard fiber and glue. This wad can then be applied to the crack by lightly touching the wad to the crack. The glue will be drawn into the crack. For extremely small quantities of glue, one may be able to scratch the glue drop and find a micro-droplet of glue at the end of a paperboard fiber. This is much more difficult to do than a simple fiber scratch. With a simple fiber scratch, the amount of glue may still be too much. The wad can initially be touched to a neutral surface

FIGURE 7. A focusing block set up in the field of view of the microscope. A fossil in Carbowax™ can be placed on it and worked from many different angles by spinning the block and the specimen, either together or independently.

releasing most of the glue before applying the remaining smaller quantity of glue to the fossil. A neutral surface may be the preparator's fingernail or the Carbowax™ mount. The excess glue will dry onto the end of the dental pick. This can be sharpened off on the whetstone.

When working on small fossils, eventually the preparator will need to repair a small broken piece such as a small tooth cusp. Sometimes the work area may need to be swept, sieved and screened to find the missing piece. Soil sieves can be used to remove very small dust from the swept up debris. The remaining material can be sorted under the microscope in search of the missing piece. Gluing the piece back on can be challenging, as it is way too small to actually hold in one's fingertips. If the main piece of the fossil is large enough to hold with one hand, or is made so by a temporary mount, gluing the broken piece back on is simply a question of aligning it correctly. Again, handling such a small piece can be challenging. The paint brush and saliva technique works well, but not always. Other methods I have found to work well for holding these small fossil bits is to put a very small amount of clay on the tip of a dental pick, and use the clay's stickiness to pick the fossil up. For some fossils, tweezers can be used, but they should be avoided in the case of cusps. Cusps are highly susceptible to the watermelon seed effect. The trick to picking up these small bits is to pick them up from a direction that will make positioning easy. Often the piece will have to be picked up several times to perfect the positioning. Once the preparator has found the correct positioning, he should practice positioning it several times, so that when it is done with glue, there is less chance of making a mistake. Then the piece and its holder should gently be placed on the work surface (so as not to jar the piece free of its holder), freeing the working hand. Make sure the piece is still on the holder. A small drop of thicker glue should be used to glue the piece back into position. Thick glue allows the worker more working time to carefully place the piece into the correct position. Apply this glue to the main body of the fossil where the piece fits, then pick up the piece and holder and carefully place the broken part where it belongs. Be careful not to glue the holder to the fossil. Keep two sharp glue-free probes on hand to help fine tune the positioning of the piece correctly after the glue has grabbed it. This may have to be done ambidextrously. Extra glue that squeezes out of the crack can be scraped off after it dries, or ideally, after it thickens but before it sets up. If the piece is incorrectly fitted and the glue prevents it from being pulled off for a second attempt, the joint should be loosened with a paintbrush (natural bristle) dipped in acetone before it sets up. When this happens, the glue will have to be removed from both connecting surfaces and the process begun again. To help avoid this situation, practice joining the surfaces before applying adhesive.

If a need arises to glue two very small pieces together, one of them may need to be embedded in wax or supported in clay with the broken surface above the wax/clay, and the above techniques used.

When a piece does break off, the preparator needs to decide "Should I replace it now, or later?" If the answer is to do it later, detailed notes and drawings should be made to help relocate the fit at a later date, especially if a few pieces need to be fixed. The broken piece should be stored in something like a gel capsule, and labeled in agreement with the notes and drawings. Should the preparator fail to find a broken piece, or cannot glue it back on, a note and drawing should be made and kept with the fossil explaining exactly what was broken. If a microscopic fossil needs to be stabilized, a very thin solution of consolidant should be used. All but the thinnest consolidant may end up as just a coating on the fossil.

Air abrasion

An air abrasive machine (tabletop sandblaster) is commonly used to prepare macroscopic fossils. The same can be used with impressive results under the microscope. To do so, the machine must be equipped with the smallest available orifice plate (that which allows the medium to leave the tank and enter the stream flow towards the hand piece), and a small aperture on the nozzle. The sandblaster will likely have to be used at low pressure. One should have a work chamber with a glass top where the microscope can be set up to look into it. The glass should be ¼ inch thick, as things will invariably end up sitting on the glass. It should also be easily changed in case it gets frosted by the blast media or excessively scratched. The work chamber's dust collector connection should be above the floor of the chamber, minimizing the chances of a lost piece getting sucked up into the dust-collector. As much lighting as possible should be used. At this scale you may be working through a slight fog of floating blast medium. I use a lamp inside the work chamber, a flexible arm desk lamp and a fiber optic light all aimed at the work area. When using dolomite as a blast medium, you will need to constantly wipe the inside of the glass, as dolomite powder tends to stick to everything.

At a microscopic scale, it may be good to use the edge of the blast spray as the working part of the spray. This allows an additional level of control. A sweeping motion may have to be used, starting on matrix away from the fossil and sweeping down towards the fossil. This allows the preparator to stop sandblasting as soon as more fossil is exposed. It may be counterproductive to concentrate sandblasting at the fossil/matrix interface as this may erode some of the fossil surface. This is especially true if the specimen and matrix are of similar hardnesses. Try it on a scrap piece first.

Often when manually removing matrix from a small specimen, a final residue of matrix will remain on the fossil that can be very difficult to remove. The air abrasive machine set at 5 p.s.i. and minimum powder flow can be very useful to remove this last layer. It is important to double check the pressure any time one is using an air abrasive machine at low pressure. It is better to continuously recheck the pressure than to accidentally blast away at a small fossil at 90, or even 20 p.s.i.

All aspects of microscopic sandblasting should be practiced on a spare piece of fossil from the same site as the fossil to be prepared. And remember this, practice makes perfect. Prepare that broken rib piece before working on the complete skull. Having said all this, some fossils and matrices may benefit from scratch and blow others from sandblasting.

Miscellaneous notes

Gelatin capsules make excellent temporary holders for small fossils, and especially for broken pieces that will be glued on later. You can make very small labels to put inside the gel cap with the specimen. Empty gel caps can be bought at health food stores and pharmacies. At the pharmacy, be sure to buy empty gelatin capsules, as they also sell gel caps full of gelatin.

Caffeine and sugar should be avoided when working under the microscope. Both these products can contribute to manual unsteadiness which will be multiplied under the microscope making detailed work unnecessarily challenging.

Microscopic work requires concentration and a steady hand. It is not for everyone. Most volunteer preparators at the Tate Museum refuse to even try. For those who do micropreparation, it is a good idea to take a break as often as needed. I keep a hand exercise ball (a racquetball will do), and a hefty rubber band at my workspace. When I do a lot of micropreparation, I will take a break every hour or so and squeeze the ball for a few minutes. I have been told that a sack filled with corn meal works even better. I also stretch the rubber band around all five fingers and repeatedly spread them outward. Exercises such as these allow my hands to do something other than be tight and focused for too long, which can lead to cramping.

Conclusions

A binocular microscope and good lighting are the key tools for the preparation of small fossils. Other tools that are useful include probes, temporary supports and a sandblasting machine. A creative mind to solve problems is very helpful. This may include using items not used before or using known tools in new ways. Lastly, as with all fossil preparation, patience is the key. It is better to slowly do a good job than it is to quickly do a bad job.

Acknowledgments

Some of these ideas and techniques I came up with myself. They are not the only correct way. They are but one way of doing things. I'm sure there other preparators out there who have solved similar problems with different answers. And others who have clever solutions to problems I haven't encountered. Some ideas and techniques I have come across in publications. These are referenced as much as I can. Some are lost in my memory and cannot be found. Other ideas come from fellow preparators, whether in formal training sessions and workshops, or in informal discussions over a beer or on listserves. Thanks for all the ideas and thoughts goes out to the whole vertebrate paleo preparator community, academic, private and commercial. Thanks also to all the working paleontologists who have trusted me with their small fossils over the years. Thanks to Bill Wahl at the Wyoming Dinosaur Center for good discussions and a library loan. Thanks to Bill and Jane Murray of Paleo Tools, and Bill Mason of Uncommon Conglomerates for being enthusiastic supporters of the prep community. Special thanks to Matthew Brown and the staff of Petrified Forest National Park for organizing the first (hopefully) annual Preparator's Symposium at their facility in March of 2008. Thanks also to the staff of the Tate Museum and Casper College who support professional development for their employees.

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Appendix 1: Suppliers

Many of the products mentioned in this paper are readily available at local hardware shops. A web search will help find many others. Below is a list of suppliers of some of the more difficult to find items mentioned in this paper.

<u>Diamond sharpeners</u>.
Woodworker's Supply
http://woodworker.com
Kent's Tools
http://www.kentstools.com/
American Science Surplus
http://www.sciplus.com
Pfingst
http://www.pfingstco.com

<u>Aro Tool Microtip</u>.
The Stone Company
http://www.stonecompany.com/tools/index.html

<u>Carbowax</u>™.
Dow Chemicals
http://www.dow.com/polyglycols/carbowax/
Small samples are free from Dow and will last a long time in the prep lab.
<u>Cyclododecane</u>.
Kremer Pigments228 Elizabeth St.
New York, NY 10012
Tel: (800) 995-5501; Fax: (212) 219-2395

<u>Carbide Rod</u>.
Paleo Tools
http://www.paleotools.com

AN INTRODUCTION TO SOLUTION AND REACTION ADHESIVES FOR FOSSIL PREPARATION

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Abstract

Fossil preparators have a range of adhesives to choose from and it is often difficult to select one most suitable for any given task. The adhesives that preparators use can be divided into two basic categories: solution adhesives, which include Paraloid B-72, Butvar B-76, Butvar B-98, and McGean B-15; and reaction adhesives, which include various brands of epoxies and cyanoacrylates. Both types of adhesives share some basic characteristics, however, solution and reaction adhesives differ fundamentally in the manner in which they set or solidify. Understanding the distinction between these two types of adhesives helps to explain differences in both their working and final properties. This information can assist the preparator in making an appropriate and successful adhesive selection when joining, consolidating or coating a specimen.

Davidson, A. and S. Alderson. 2009. An introduction to solution and reaction adhesives for fossil preparation. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 53-62. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

Fossil preparators regularly use a range of adhesives in their work. Those most commonly utilized include Paraloid B-72 (an ethyl methacrylate co-polymer formerly called Acryloid), Butvar B-76 and B-98 (polyvinyl butyral), McGean B-15 (a polyvinyl acetate formerly called Vinac), and various brands of epoxies and cyanoacrylates.

With this collection of adhesives, preparators are required to perform a multitude of tasks including joining, consolidation, coating, and gap filling on a range of fossils which can differ greatly in size and state of preservation. Although these materials are used for considerably more than simply joining parts, collectively they can be referred to as "adhesives" because in all their applications it is their ability to adhere to themselves and other materials that makes them useful to the preparator.

Selecting the most appropriate adhesive for the task at hand is an important part of successful fossil preparation. No two fossils are exactly alike, and even the most experienced preparator is often faced with new challenges that require them to reevaluate an old approach or develop new solutions. Key to making a suitable selection is understanding that not all of these adhesive "tools" are interchangeable - some are more appropriate for particular tasks than others. There is no single adhesive that works best in every preparation situation.

The adhesives listed above can be divided into two basic groups according to how they set or dry: solution adhesives, which set by evaporation of a solvent; and reaction adhesives that set by chemical reaction. This paper will examine these two categories of adhesives as knowledge of the fundamental difference between these two types is an essential first step in making a successful adhesive selection.

What makes adhesives stick?

To understand what sets reaction and solution adhesives apart we must first examine how they hold things together. We know these adhesives stick things together - but how? The following is a brief answer to this question that relies heavily on several useful texts, including Horie (1987) and the three volume Science for Conservators series (Wilks, 1987 a-c). All the adhesives commonly used by preparators are applied as flowing liquids that spread onto or "wet" the surfaces or substrates to be joined.

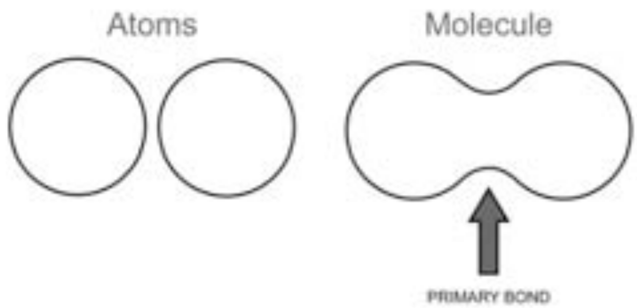

FIGURE 1: Primary bonds are very strong chemical bonds that hold atoms together to form molecules.

Wetting is something we understand intuitively when we lick a finger to pick up a crumb or use wet sand to build a sand castle: a liquid on its own can act as an adhesive. This is due to an attraction called ***secondary bonding*** that exists between molecules, in this case between the molecules of the water and molecules of the sand or crumb.

Secondary bonding occurs when there is very close contact between molecules with positively or negatively charged sites or groups of atoms in their structure, causing the molecules to stick to each other like tiny magnets. These forces are significantly weaker than those involved in ***primary bonding***, which is what holds atoms together to form molecules. Primary bonds are the very strong chemical bonds that hold the hydrogen and oxygen atoms together within a molecule of water (H_2O), while secondary bonds are the much weaker forces that exist between the molecules of water themselves (Figs. 1, 2). These forces are strong enough to hold water together so that it can form drops, but weak

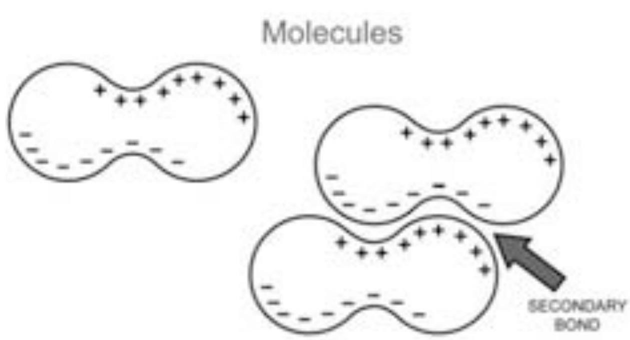

FIGURE 2: Secondary bonds are relatively weak forces that occur when there is very close contact between molecules with positively or negatively charged sites or groups of atoms in their structure.

Enough that the molecules of water can easily move apart and roll past one another so that water can flow.

Water can hold sand together but the resulting "castle" can easily be toppled or pushed apart; plain liquids can act as adhesives but they are generally not very strong ones. However, if the pile of wet sand is frozen, the adhesive strength of the water increases as the water solidifies, making it much more difficult to push it apart. This illustrates two important properties required of an adhesive: first, it must be liquid so it can properly wet or cover the surface; second, it must set or become rigid to prevent shifting or slippage when pressure or stress is applied from gravity or other outside forces.

Once the adhesive solidifies, the strength of the resulting bond depends on several factors. In the case of porous, rough, and irregular surfaces- such as those commonly encountered in fossil preparation- the strength of the bond is largely due to ***mechanical interlocking***. The liquid adhesive flows into all the pores and crevices of the substrate, and once hardened, it mechanically locks the parts together. Surface contact and secondary bonding between the molecules of the adhesive and the molecules of the substrate continue to play a role, but the strength of the bond is greatly dependent on the cohesive strength of the adhesive, i.e. the strength of the bonds between the molecules of the adhesive itself.

Reaction and solution adhesives are both applied as liquids that become solid or "set" after application. Both bond to materials following the same set of rules described above: bonding relies on good wetting, surface contact, secondary bonding between the adhesive and the substrate, mechanical interlocking, and the cohesive strength of the interlocked adhesive. However, the structure and physical properties of these two types of adhesives fundamentally in both their liquid and solid forms, resulting in substantial differences in both their working and final properties.

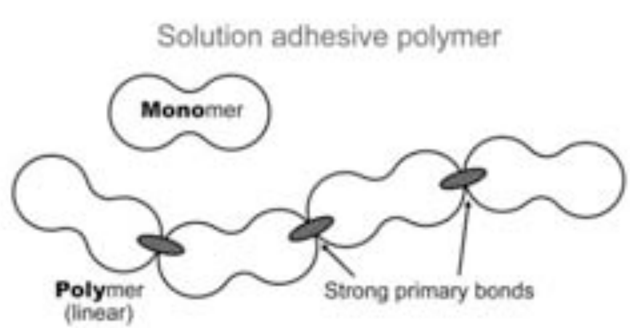

FIGURE 3: Solution adhesives are giant polymer molecules formed with primary bonds linking many small, simple molecules called monomers. They can be linear or slightly branched in structure.

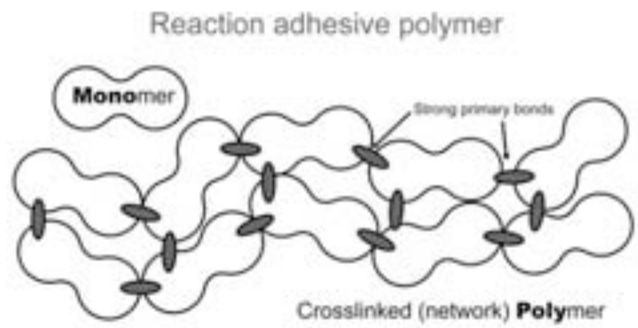

FIGURE 4: Reaction adhesives are often networked or crosslinked with primary bonds.

How are solution and reaction adhesives different?

Solution and reaction adhesives are both ***polymers***. Polymers are giant molecules formed by linking many small, simple molecules called ***monomers***. Polymers make good adhesives because the many repeated units multiply the sites for attraction or secondary bonding. This structure enhances the ability of these macromolecules to entangle and attach to themselves or other materials. However, there is a fundamental difference between the structure of the polymers formed by solution and reaction adhesives.

Solution adhesives are linear or slightly branched polymers. This means that the monomer units of which they are formed are strung together in straight chains (Fig. 3), which sometimes have small chains or side branches. They are applied as pre-made linear molecules that do not change their basic chemistry or structure as they set or dry. Reaction adhesives on the other hand, are applied as liquid monomers that chemically react to form solid polymers (polymerize) in place after application. The resulting structure is rigid, linked with primary bonds and often cross-linked into a network (Fig. 4). In other words, the solution adhesives remain a collection of individual molecules, while reaction adhesives basically form one large polymer molecule.

Solution adhesives such as Paraloid B-72, Butvar B-76 and B-98, and McGean B-15 are often purchased as solid polymeric materials (in the form of powders or beads) that can be mixed with organic solvents such as acetone or ethanol to form liquids for application. Both the molecules of the liquid solvent and those of the solid polymers are held together with weak secondary bonds. If the attractive forces within the polymeric material are weaker than those between the solvent and the polymer, the polymer molecules will be pulled apart and go into solution. The linear polymer molecules are still intact but are separated and floating in the solvent like strands of pasta in water.

As the solvent evaporates the polymer strands come into closer contact, re-establishing secondary bonds with each other and also becoming physically entangled, forming a solid mass (Fig. 5). If solvents are reapplied at a later date the chains can still untangle and separate again forming a liquid. Some solution adhesives can be redissolved in this way repeatedly and indefinitely, because the polymeric material remains chemically unchanged before and after "setting".

Reaction adhesives such as epoxies (Devcon, Epo-Tek, etc) and cyanoacrylates (Aron Alpha, Paleo-bond, etc) are purchased as liquid monomers which chemically react after application to form very large, rigid, polymers (Fig. 6). However, epoxies and cyanoacrylates form these structures in different ways. Epoxies are sold as two separate liquids: a resin and a hardener, which chemically react to form a cross-linked network when they are mixed together. Cyanoacrylates are sold as a single liquid which is a monomer, usually combined with an acid which prevents formation of the polymer before application. When the monomer comes in contact with the trace moisture naturally present on the surfaces to which it is applied, the acid is neutralized and polymerization occurs. The structure of cyanoacrylates is variable and may or may not be cross-linked, but it is generally strongly interconnected like the networked structure of epoxies (Repensek, 2003; Petrie, 2007).

Both types of reaction adhesives undergo chemical change in the solidification or setting process, and unlike solution adhesives, strong primary bonds are formed. Once set, the resulting material can not easily be dissolved or broken down. Some organic solvents may swell or soften the structure making it easier to break it apart physically, but commonly used organic solvents, such as acetone and ethanol, will be unable to separate the strong primary bonds holding these polymers together.

How differences between solution and reaction adhesives affect their final properties

Resolubility—The organic solvents commonly used by fossil preparators can easily redissolve solution adhesives as they are held together with weak secondary bonds, but are not effective on reaction adhesives which are held together by strong primary bonds. There are some instances when reaction adhesives can be softened with solvents and removed successfully, such as when they are used on a very small scale. However, in almost all cases removing or reducing reaction adhesives will require more time, effort, and far greater risk to the fossil.

Resolubility can be advantageous as field work often requires temporary application of consolidants or coatings, and lab work often involves multiple stages of applying, adjusting, removing, and reapplying adhesives to protect surfaces or support parts as matrix is removed. Resolubility is important in long-term as well as short-term or temporary applications. It is always preferable to use something reversible or reworkable if possible. Fossils are very commonly repaired, disassembled, stripped of coatings, and re-prepared for molding, display or for research; the future uses and requirements of the fossil are not always foreseeable and resolubility is therefore almost always an advantage.

There are some rare cases where resolubility may be undesirable, such as smaller, more delicate joins that could dissolve by accident if the surface was exposed to a solvent during cleaning or application of a coating in preparation for molding. More commonly, there can be instances where reversibility is sacrificed because reaction adhesives offer properties not available with solution adhesives, such as the ability to penetrate into hairline cracks or great strength.

Strength—Generally, the primary bonded, reaction adhesives are harder and more rigid than the secondary bonded solution adhesives: they have greater cohesive strength. This is why epoxies are often used when the joined parts are so large or heavy that more resoluble solution adhesives might fail due to the stresses of gravity over time. The hardness and

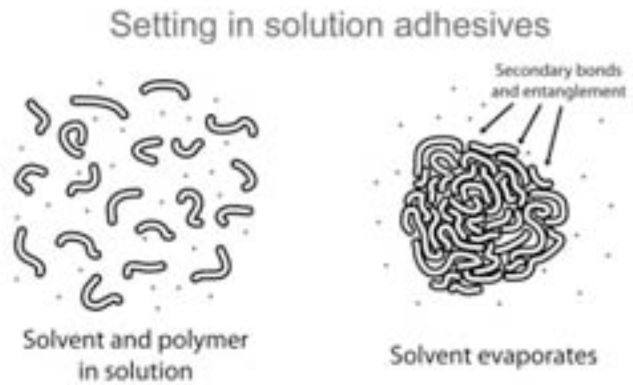

FIGURE 5: Solution adhesives remain a collection of individual molecules held together by secondary bonds and entanglement.

rigidity of reaction adhesives also makes them useful when specimens must withstand extreme stresses during preparation, such as the impact of a chisel or powerful air scribe.

It should be noted that it may be possible to exploit the strength of epoxies without sacrificing reversibility. Barrier layers of solution adhesives such as Paraloid B-72 can be applied prior to application of an epoxy in order to allow for greater reversibility of the join in the future. It has been shown that this technique, if executed properly, can be used without negatively impacting the strength of the join (Podany *et al*, 2001). Soluble barrier layers can also be used to increase reversibility when reaction adhesives, such as epoxy putties, are used to fill gaps.

It is also important to note that stronger is not always better. The relative "weakness" of solution adhesives can be advantageous in some cases. In addition to being resoluble, these adhesives require less force to remove mechanically without the aid of solvents. Thus solution adhesives often work better than reaction adhesives when preparation requires temporary consolidation of loose matrix or application of temporary coatings which will later be removed with needles or air scribes.

In addition, very hard and rigid adhesives like epoxies and cyanoacrylates generally lack elasticity or flexibility unless they are heavily modified with additives. The ability to give or stretch under strain can be an important quality in a successful adhesive, as it allows it to move and bounce back under certain forms of stress rather than breaking or transferring the stress to the object and potentially causing damage. Generally it is undesirable for an adhesive to be more rigid or harder than the substrate as this can lead to damage in the original material. If the adhesive used in a join has more cohesive strength than the fossil itself, applied stress may fracture the fossil rather than the adhesive, resulting in characteristic fresh breaks parallel to the original join. Similarly, consolidation of soft substrates with very hard adhesives can cause zones of weakness due to incomplete and uneven penetration. Flexibility is a particularly important consideration when selecting an adhesive for use on sub-fossil or other materials that may expand and contract in reaction to fluctuating environmental conditions, such as relative humidity.

One of the reasons Paraloid B-72 is often favored by conservators is that it exhibits a moderate hardness and a specific balance between flexibility and rigidity that renders it a successful general purpose adhesive for a variety of materials (Koob, 1986). It should be noted that not all solution adhesives possess this balance and some, like certain grades of polyvinyl acetate, can be soft and rubbery enough at room temperature to be problematic. If used in joins they can slowly creep or move over time and eventually fail, and as surface coatings they can be sticky and trap dust and grime (Horie, 1987: 92). These adhesives become even softer at elevated temperatures, which could be problematic in hot field or storage environments.

Aging—When adhesives are used for long-term applications it is preferable that their aging properties are well understood and proven to be good. Poor aging of an adhesive can lead to a variety of undesirable results including shrinkage, distortion, embrittlement, decreased solubility, and darkening or yellowing over time. Damage from poor aging of adhesives can be found in most fossil collections, often

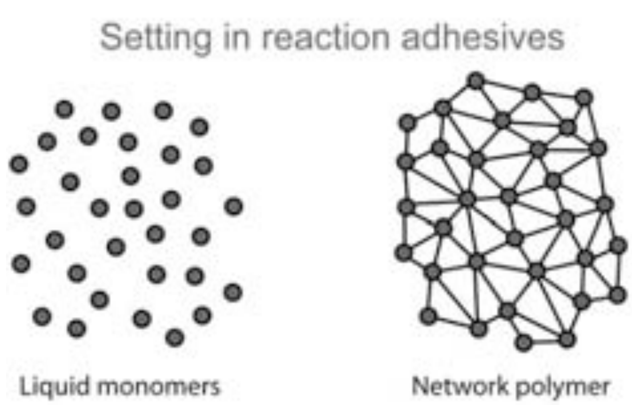

FIGURE 6: Reaction adhesives basically form one large molecule held together by primary bonds.

including join failures, and embrittled, lifting coatings that have damaged the surface of the bone.

When solution adhesives are purchased as powders or beads they are generally single ingredient products, containing only the pure polymeric material. This makes it easier to assess and predict their aging characteristics, and many solution adhesives are known to have excellent aging properties, especially Paraloid B-72 (Down *et al*, 1996; Feller and Curran, 1975; Lazzari and Chiantore, 2000; Chiantore and Lazzari, 2001). Polyvinyl acetates are reportedly somewhat less stable than Paraloid B-72 but are still generally considered to have very good aging properties (Feller and Curran, 1975; Horie, 1987: 92). The long-term aging of polyvinyl butyrals has been questioned in the past but recent studies indicate it is also a very stable material (Feller *et al,* 2007).

In contrast to the solution adhesives, reaction adhesives are often fairly complex formulations, with ingredients that can vary from one manufacturer to another. Formulas can change according to availability and cost of ingredients, and they often include additives that can affect aging. Even in formulations with fewer additives, it is difficult to know exactly what you are using: the terms "epoxy" and "cyanoacrylate" both denote a large and varied category of resins. The materials within these categories share some basic chemistry, but may differ significantly in their properties, which can make it more difficult to make general statements about many aspects of their behavior including aging.

The aging of epoxies has been studied in connection to the conservation of glass and many formulations have been found to yellow severely (Down, 2001). Yellowing is generally considered a sign of degradation and may be indicative of other changes in the material over time. The epoxies that have been shown to yellow the least are those with few additives that have been formulated for use in art conservation or for optical applications, such as Hxtal NYL-1 and Epo-Tek 301-2 (Down, 1986). While these epoxies have very long set times that make them impractical for many preparation tasks, others with more reasonable setting times have also been shown to be relatively stable and have found use in the conservation of stone, including Araldite AY103/HY991 (Down, 1984,1986 and 2001b; Podany *et al,* 2001).

All epoxies are subject to user error: imprecise measurement of the components and inadequate mixing can interfere with the chemical reaction, resulting in incomplete polymerization and poor aging. This is especially true of very fast-set epoxies such as 5-minute formulas that can harden before the components have a chance to fully react. These fast-set formulas may contain additives that make them quick, easy, and convenient for casual consumer use, but make them poor choices when the goal is producing the best possible bond with the most predictable behavior over time (Horie, 1987: 173). In addition, all epoxies have a very limited shelf-life, of about one year. Epoxies that are past their shelf-life may appear to set after mixing but may not have polymerized properly and might eventually deteriorate, so it is always preferable to discard old epoxies and to use freshly received material (Down, 2001b).

Cyanoacrylates have found increasingly wide use in fossil preparation since the late 1970's (Howie, 1984; Rixon, 1976). However, the aging behavior of cyanoacrylates has not been fully investigated. This is partially attributable to the fact that they have not been used widely in the field of art conservation, which has initiated many of the previous assessments of adhesive stability applicable to fossil preparation. One published study of cyanoacrylates has shown that there are still many unanswered questions regarding their stability and that contact with some fossils may accelerate degradation of cyanoacrylates (Down and Kaminska, 2006). The unique properties of cyanoacrylates, such as their superior ability to penetrate into hairline cracks and fast set time, may override questions about their aging in some instances, but care should be taken to avoid using them when more fully investigated adhesives could do the same job.

It should also be noted that not all solution adhesives have good aging properties. Cellulose nitrate, often found in household glues such as Duco Cement, becomes very brittle, shrinks, yellows, and weakens with age, often leading to bond failure (Horie, 1987: 133-134; Koob, 1982). Other solution adhesives can become harder and less soluble with time by cross-linking (forming primary bonds), like cross-linking reaction adhesives. This is true of some natural resins such as shellac and also some modern synthetic resins such as Paraloid B-67, which is sometimes used as a resistant coating for acid preparation (Horie, 1987: 108, 149-150; Lazzari and Chiantore, 2000; Chiantore and Lazzari, 2001).

Emulsions or "white glues" (such as Elmer's Glue-All) are a special class of water-born solution adhesives, many of which are known to deteriorate with age (Horie, 1987: 94-96,110-112). These adhesives consist of minute particles of non-water soluble polymers such as polyvinyl acetates or acrylics which are suspended in an aqueous solution. They set by evaporation of water, but are water soluble only before they are fully set. Once set, the resulting polymer film is only soluble in non-aqueous solvents such as acetone, toluene, and xylene. These adhesives are complex formulations as their suspended state is achieved and maintained through the addition of various materials such as emulsifiers, stabilizers and dispersing agents, and the compositions often include many other additives including plasticizers, thickening agents, and biocides. The quality of these adhesives varies greatly and the formulations commonly sold for home use (Elmer's, etc) can become hard, brittle, discolored, and insoluble over time (Down *et al*, 1996; Johnson, 1994:226). Other specialty formulations of emulsions or dispersions, particularly the acrylics, may fare better over time, including certain grades of adhesives with the trade names Acrysol, Primal, Rhoplex, Jade and others (Down *et al*, 1996; Johnson, 1994). However, even these "better quality" white glues are only recommended for use when a water based adhesive is required, such as in the consolidation of wet specimens in the field.

How differences between solution and reaction adhesives affect their working properties

Working and Setting Times—The working time and set time of solution adhesives are dependent on the volatility of the solvent used. The solution adhesives mentioned in this paper can be dissolved in a range of different organic solvents with diverse rates of evaporation. This property can be exploited to vary the working and setting time of an adhesive to meet the requirements of a specific task. Conveniently, acetone and ethanol, the two solvents most commonly found in the prep lab and field, present a range of volatility from fast (acetone) to moderate (ethanol), and almost all the solution adhesives listed in this paper are soluble in both of these solvents. Thus the working and setting times of a single resin, such as Paraloid B-72, can be adjusted by dissolving it in different solvents: mix it in acetone for quick setting, or with ethanol for slower evaporation and longer working time. Temperature and air-flow can also affect working times of adhesives that set by evaporation; evaporation can be slowed by covering the specimen to reduce air-flow, and these adhesives will set more quickly if used out in the hot sun in the field. Working time of solution adhesives can also be affected by volume; application of tiny drops for micropreparation can be difficult because they harden too quickly due to a high surface-to-volume ratio which speeds evaporation.

Most cyanoacrylates set relatively quickly and are thus sometimes preferred when clamping is not possible, although often a solution adhesive in acetone can set as fast. Because polymerization is initiated by surface moisture, cyanoacrylates do not usually harden until they make contact with the substrate, thus they can be applied as tiny drops. They also set more slowly in dry conditions and more rapidly in humid conditions, which is why some preparators speed setting with their breath. The use of cyanoacrylate accelerators such as sprays for an instant bond is not recommended because of their commonly observed tendency to turn fossils bright green, yellow or blue, reportedly in reaction to iron (Howie, 1984).

Epoxies naturally set slowly and the long working time of epoxy allows plenty of time to align and adjust fragments before setting. This can be useful for small, complex joins such as multiple broken cusps on small teeth. Epoxies can be used for consolidation of fine cracks; although viscous they can penetrate well because they have slow set times which allow them more time to flow. This is especially true of very slow setting epoxies (Epo-Tek 301-2, Hxtal NYL-1) which can take days to set. Epoxies with very fast set times, such as 5 minute formulas, have added accelerators and these additives can lead to an inferior product.

Viscosity—Viscosity is defined as the resistance of a liquid to flow. The more viscous the adhesive, the thicker it will be and the slower it will be to pour and spread. The viscosities of solution adhesives can be modified easily by adjusting the concentration of the polymer in the given solvent. Paraloid B-72 can be mixed in concentrations as low as 1-5% to produce a dilute low viscosity resin for consolidation, or in concentrations as high as 35-50% to produce a thick adhesive for joins. A high viscosity mixture of

Paraloid B-72 in acetone loaded into a tube, commonly used by conservators, is very useful and convenient for quick assembly of fragments, and can often be used in place of commercially packaged fast setting epoxies and cyanoacrylates, which while convenient, are not as resoluble and do not have as good aging properties as Paraloid B-72 (Koob, 1986).

One problem with solution adhesives is that their viscosity is directly linked to their concentration or polymer content. The only way to produce a low viscosity adhesive is to have a dilute or low concentration solution; one may get the adhesive solution into place but once the solvent evaporates relatively little actual adhesive polymer remains. This is not true of the reaction adhesives because they do not contain solvent. Therefore, it is possible to have low viscosity epoxies and cyanoacrylates with 100% monomer content, all of which reacts to form the polymer. This can be advantageous for very small joins and hairline cracks, where the need is to get a significant amount of adhesive into a very small space.

Penetration and Migration—The volatile solvent component of solution adhesives causes the polymer to migrate during solidification. The solvent is the carrier for the polymer: it carries it in, but also carries it back out as it evaporates and the polymer can often end up deposited on or close to the surface. The propensity of solution adhesives to migrate to the surface with the solvent can be problematic when one is trying to achieve deep consolidation. Migration of solution adhesives can be moderated by a variety of factors that have been discussed in the conservation literature, including solvent selection and control of drying conditions (Domaslowski, 1987-88; Hansen *et al,* 1993).

Reaction adhesives have no volatile solvent component and thus do not have a tendency to migrate out after penetration. They are applied as liquids composed of monomers, which are much smaller, more compact molecules than the linear or branched chain polymers of the solution adhesives. Thus they are more able to travel into the open spaces in the substrate, potentially achieving deeper penetration. This is especially true of cyanoacrylates which are not only composed of small monomer molecules but can also have very low viscosities without being dilute. However, low viscosity cyanoacrylates are also known to have poor gap filling properties (Down, 2001a: 36). Thus they may achieve deep penetration without successful consolidation in instances where there are large cracks or voids that need to be filled in order to stabilize the specimen effectively.

Reaction adhesives migrate less and have the potential to penetrate better than solution adhesives, but their insolubility, hardness, and questionable aging characteristics may outweigh these advantages. It should also be mentioned that in some cases deep penetration of the adhesive may not be necessary to achieve adequate consolidation, as superficial consolidation with more stable solution adhesives is often very effective at binding together difficult material in the field and the lab, and for many specimens this may be adequate or even preferable to using reaction adhesives.

Conclusion

The solution and reaction adhesives commonly used in fossil preparation are all polymers that are applied as flowing liquids, which solidify in place and become interlocked with the porous and irregular surfaces of fossils. However, they change from liquid to solid in fundamentally different ways resulting in significantly different products.

Many solution adhesives, including Paraloid B-72, McGean B-15, and the Butvar resins, solidify by evaporation of solvent and form masses of polymer chains held together by entanglement and secondary bonding. These adhesives can be custom mixed in different solvents and offer a versatile range of setting and working times, as well as viscosities. Because they set by solvent evaporation, they tend to migrate to the surface, which can be problematic for some applications, but this behavior can often be countered with various application and drying methods. The resulting adhesives are known to have very good aging properties, remain resoluble over time, and possess a range of cohesive strengths, which, although generally lower than those of reaction adhesives, are appropriate and sufficient for most preparation tasks.

Epoxies and cyanoacrylates set by chemical reaction to form large, primary-bonded polymers. They are not as versatile as solution adhesives: to obtain variations in setting time and viscosity they must be purchased in different commercial formulas, often containing additives that make it difficult to evaluate and predict their stability. Because they do not set by evaporation, they do not migrate toward the surface during setting, and it is possible to have low viscosities without dilution. These traits, as well as their great cohesive strength, make them very useful in some instances. However their questionable aging properties and the insolubility of their strongly-bonded structures means they should only be used when the more versatile and stable solution adhesives cannot be used successfully.

There is no universal adhesive that will fulfill every application, and it is usually necessary to compromise when selecting a practical adhesive system. The selection process is difficult because many factors only briefly mentioned here must be considered, including the need for a full initial assessment of the specimen and its required treatment, and an understanding of the more subtle differences between the different individual adhesives and how to manipulate them with different mixing and application techniques. However, understanding the basic differences between the solution and reaction adhesives should equip the preparator with some of the fundamental information necessary to make the most appropriate and successful choice.

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DIFFICULT EXCAVATION AND PREPARATION OF A LARGE *DASPLETOSAURUS* SPECIMEN

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Abstract

A difficult combination of soft matrix, soft fractured bone, low overburden, plant root damage, weathering and a high degree of specimen articulation posed special problems in the recovery of a *Daspletosaurus torusus* Russell skeleton, RMDRC 06-005. Traditional jacketing methods yielded unsatisfactory results, therefore the Pallet method was used to remove large numbers of inseparable elements. Mechanical preparation proved impossible without consolidation of both the fossil material and the surrounding matrix with low strength cyanoacrylate adhesives. Preparation was then accomplished mainly by air abrasion.

Keywords: **Pallet, jacket, consolidation, field methods, *Daspletosaurus***

Maltese, A. 2009. Difficult excavation and preparation of a large *Daspletosaurus* specimen. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 63-68. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

Discovered in 2005 and recovered in 2006, RMDRC 06-005 has been identified as a large (11 m) *Daspletosaurus torosus* Russell from the Campanian upper Judith River Formation, Fergus County, Montana. It was found with the dorsal, sacral and proximal caudal vertebrae, right ilium, dorsal ribs, and proximal chevrons articulated, along with a large mass of gastralia, scapulae and forelimbs concentrated in one area. Excavation was swift due to the softness of the matrix and total lack of concretion. The matrix consisted of a silty fine grained grey sandstone, with two distinct layers of shale chip clasts immediately above the bottom of the bone layer. Only light hand tools (brushes, trowels, shovels) were needed. The bone itself was heavily fractured on its surface, with a soft, punky interior. The matrix appeared to provide all of the support to the fossil, and special care was taken to ensure the material could be safely transported over 1300km from digsite to lab.
Institutional abbreviations: **RMDRC**, Rocky Mountain Dinosaur Resource Center; **UNO,** University of New Orleans; **LDP** Lance Dinosaur Project.

Materials and Methods

Excavation

The site is located on a gently sloping rise, with an average of 0.5m of overburden covering the skeleton. The sandstone matrix was poorly cemented and very soft. Bone quality had degraded and become problematic for two reasons. First, the low overburden allowed plant roots to invade and partially demineralize the fossil. Secondly, the increased exposure to subsurface weathering due to water infiltration and freeze/thaw cycles had shattered the weakened fossil material, though the fragments themselves had not moved relative to each other, with few resulting gaps. The surface bone is only marginally harder than surrounding matrix. Cancellous interior bone was not exposed except when field crew workers exposed it with hand tools. It was determined by the field crew that substantial hardening of the fossil and the matrix was required to safely recover the specimen. An absolute minimum amount of the bone was exposed in the field and much more matrix was taken in field jackets than normal.

FIGURE 1: Field photograph showing articulation of main jacket.

The initial field crew was not completely prepared for a dig of this magnitude, so a commercial water based urethane sealant was originally procured locally as an off-the-shelf consolidant, however results were unsatisfactory due to clouding, peeling and poor penetration of the bone and matrix. Later, a solution of Vinac B-15 in acetone, as well as Paleobond PB 4417 low strength cyanoacrylate were brought to the site by a supplemental field crew, and were utilized in consolidation before jacketing and removal, with more satisfactory results. The Paleobond PB 4417 was only applied on and immediately around exposed bone, with over one gallon used. Vinac was used as the bulk matrix consolidant because large amounts could be mixed at the site, and its penetration abilities could be controlled with adjustments to the solvent concentration. In rare cases, Paleobond PB 002 penetrant stabilizer was employed for severe damage,or when the interior cancellous bone was exposed, totaling less than 1 pint of adhesive. In total, 72 plaster and burlap field jackets

FIGURE 2: A. Main jacket capped with frame being installed **B.** Main jacket after installation of pallet.

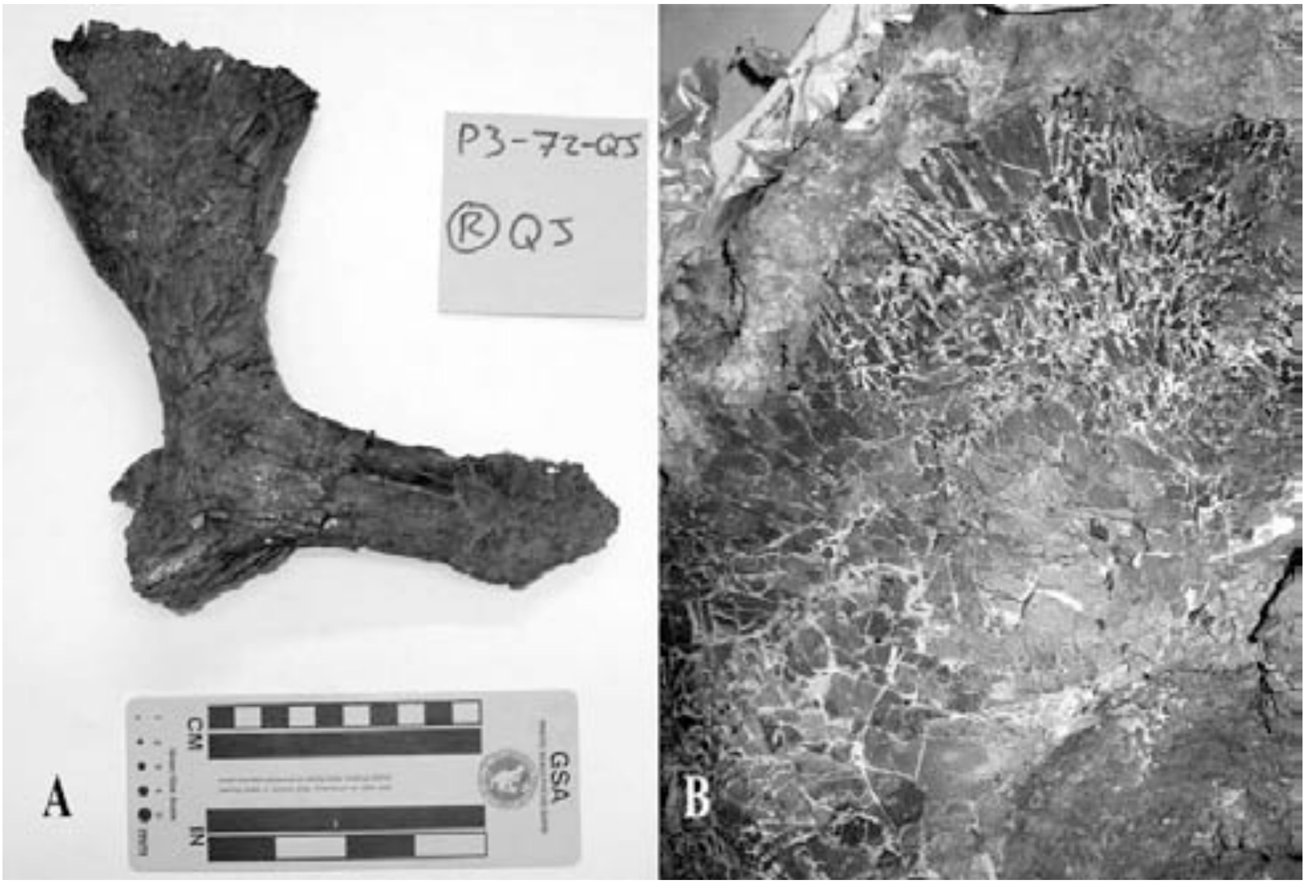

FIGURE 3: **A**. Right quadratojugal and **B.** left scapulocoracoid illustrating fragmentary nature of the bone.

with heavy duty aluminum foil separator were removed from the site. Due to the fragility of the specimen, even the smallest individual bones were recovered with plaster jackets, instead of traditional aluminum foil jackets. The smaller plaster jackets were prepared for removal as described by Converse (1984).

The largest and final jacket contained the main portion of the body as well as a significant number of gastral elements that were not separable in the field, well over 100 individual elements. The decision was made to recover the mass as one gigantic jacket. Because of the size, traditional jacketing and rolling techniques were impossible. The perimetered specimen and matrix were hardened with additional Vinac B 15, exposed bone covered with heavy duty aluminum foil, and a plaster and burlap cap jacket was applied.

A timber frame was constructed around and under the block using 4"x4" and 4"x6" posts fastened with 1/4" lag screws and washers. Tunnels were cut well under the specimen perpendicular to the long axis of the frame. Plaster (roughly equivalent to number 2 potting plaster) and burlap strips were then wrapped under the specimen through the tunnels, connecting to the cap jacket. 2"x4" cross beams were installed through the tunnels under the plaster strips and fastened to the frame using screws. Plaster and burlap wads were used to fill any space between the jacket and cross beams, and strips were wrapped under the cross beams and connected to the cap jacket for increased stability. These strips never went around the main frame rails in case the jacket is moved like a sled. The process was repeated until the jacket had totally encapsulated the specimen and was free of the underlying matrix. The jacket was then winched onto a trailer with come alongs and secured with heavy duty straps for transport. In total, over 500 pounds of plaster was used, with the jacket weighing approximately 4 tons. The UNO specimen LDP 987-1 "Rhonda" is an example of previous use of this method, on an articulated *Edmontosaurus annectens* mummy (Derstler pers. comm. 2008). Similarities between the specimens (large articulated animals) was the reason the pallet jacket method was used. This type of jacket differs from the RONDAN jacket in that the support structure is intended to be permanent, the underside of the jacket is constructed before moving, and the jacket is never rolled at any time (Peterson et al 1999).

Preparation

Daspletosaurus specimens are relatively uncommon. This specimen will be molded and the original bones mounted upon completion of preparation. Though the field consolidation enabled the jackets and their contents to be returned to the lab relatively damage free, extensive consolidation must be employed during preparation. Because of the extremely fragmentary nature of the bone, reversibility of the bonds is not a major concern. All consolidants are documented on preparation logs for future reference. The small jackets are prepared upside down relative to its position in the field through the extremely soft matrix. There are multiple reasons for this approach. First, all jackets were made covering the top and sides, with the matrix underside unjacketed. Secondly, it enables preparation to commence with the already consolidated side providing support and stability. Lastly, company field protocol calls for foil separator to be used only on exposed bone, with the matrix bonding to the plaster jacket for increased stability. This makes removal of the jacket as an initial step problematic, risking unnecessary damage to the specimen.

When bone is encountered, it is immediately saturated, along with the surrounding matrix, with Paleobond PB 4417 consolidant. This low strength adhesive is a very low viscosity liquid, and penetrates well, however does not harden matrix to bone like Paleobond PB 002. Vinac B-15 is too weak of an adhesive for this project's goals, however a coat is used as the last step in preparation to ensure all microfractures are stabilized. Thicker viscosity adhesives are rarely used, only to join two elements that may have been separated during excavation. The resulting mass can then be slowly prepared exclusively with air abrasion using Armex electronics formula sodium bicarbonate media at low to moderate pressures.

Air abrasion of consolidated bone is the only satisfactory method of removing matrix without damaging bone surface. Small jackets and individual bones are prepared inside “Blast box” workstations, whereas larger jackets require a temporary tent of plastic dropcloth material to control dust, both using dust collection systems. In many cases, individual bones in larger jackets are carefully isolated, jacketed, and separated before being worked on individually. Pneumatic impact tools such as Aro or Chicago Pneumatic air scribes cannot be utilized for matrix removal as the vibration created is too great, leading to damage of the specimen. Unconsolidated bone surface is too friable to allow use of hand tools, and consolidated matrix is generally too hard, transmitting vibrations through the specimen to unconsolidated portions.

Conclusions

The pallet method for jacket construction is an alternative to rolling large field jackets when heavy equipment is neither feasable or available, or if the specimen requires more delicate handling than usual. The wooden construction is cheap, light and strong, and easy to construct with basic hand and power tools. The frame provides an additional benefit in relieving much strain from the plaster jacket itself. The total amount of plaster and burlap material used is comparable to traditional jackets. This method was again used with great success in the recovery of RMDRC 07-020, a smaller, partially articulated *Lambeosaurus* specimen the following year, where the frame rails were used to slide the jacket 15m up a steep incline.

The shattered nature of this specimen required a specific method of preparation to ready the bones for display and molding. Field use of Paleobond PB 4417 and Vinac B-25 helped stabilize the fossil and matrix during transport from Montana to Colorado. Consolidation with a low-strength reversible low viscosity cyanoacrylate adhesive in the lab enables the very fragmentary bone material to be hardened in-situ before preparation. Higher strength penetrating cyanoacrylates such as Paleobond PB 002 harden the bone well, however overharden matrix and gypsum encrustation, requiring more time for matrix removal and increasing the risk of damage to the bone. Once stabilized, the most time effective and least damaging method of preparation is air abrasion.

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HISTOLOGICAL CORE DRILLING: A LESS DESTRUCTIVE METHOD FOR STUDYING BONE HISTOLOGY

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Abstract

This paper describes a new method for obtaining histological core samples. The Histological Coring Method (HCM) involves drilling a small core at a standardized location on the bone chosen for study. The core is collected using diamond studded drill bits mounted on a standard household power drill. The drill is stabilized in a drill press to control the vertical drilling speed. Long bones are preferably sampled because of their abundance and relatively simple growth pattern and morphology, but any vertebrate hard tissue can be sampled. Using an appropriately sized drill bit means any specimen ranging in size from small to extremely large can be sampled. After a core is obtained, it is processed into histological thin sections, and or polished sections with standard histological thin sectioning methods. Compared to classical histological techniques, the HCM is a much less destructive method for sampling vertebrate hard tissues. This new method will therefore allow continued conservation of rare and valuable specimens while simultaneously permitting access to unique biological information.

Keywords: Paleohistology, histological coring, less destructive, fossil hard tissues

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Introduction

Paleohistology is the science that studies the internal microscopic structure of fossilized vertebrate tissues like bone, ossified tendon, eggshell, teeth and dermal scutes. Bone paleo-histological studies have recently produced an array of information on extinct animals, more particularly on growth strategies (Horner et al., 2000; Sander, 2000; Erickson et al. 2001; McFadden, 2004; Sander and Klein 2005; Erickson, 2005; Klein and Sander 2008; Lehman and Woodward, 2008), reproduction (Schweitzer et al. 2005; Erickson et al. 2007; Lee and Werning, 2008), and evolution (Chinsamy and Elzanowski, 2001; Sander et al. 2004, 2006; Ricqlès et al. 2008).

Unfortunately, the usual practice of bone histological studies involves the destructive sectioning of complete bones, teeth, scutes or other preserved hard tissues (Wells 1989, Chinsamy and Raath, 1992, Wilson, 1994). Understandably, museum and collection curators are reluctant to give up rare or type specimens to these destructive methods. This has limited paleohistological studies in the last century mainly to isolated and or fragmented specimens and, with a few exceptions (e.g. Enlow and Brown 1956-58; Riqclès 1968, 1969, 1974, 1976, 1977, 1978, 1980, 1981), prevented substantial comparative analyses.

In repsonse, a less destructive method was developed by one of the authors (MS) to study long bones of sauropod dinosaurs (Sander, 1999, 2000). Instead of sectioning entire sauropod long bones, a small core sample was taken at a specified location on the long bone shaft, akin to a medical biopsy. This allowed a large number of bones to be sampled, expanding the study into a more quant-itative analysis instead of a mere qualitative des-cription, providing many insights into sauropod biology, and even allowing taxon discrimination based on their histology. Sander (2000) only gave a brief description of the method, which has since been developed further and will be explained in detail here.

Histological sampling is commonplace in archaeology and archaeozoology as well (e.g. Chan et al. 2007, Zedda et al. 2008) but this subject is beyond the scope of this paper.

Bone choice and sample location

Choosing the right bone for osteohistological studies requires knowledge about bone growth. Bones do not have mere appositional growth like the trunk of a tree, but they are formed in a process of constant primary bone deposition, resorption, and remodeling (Currey, 2002; Hall, 2005). This causes the bone to keep its original shape as it grows, but it also means that the earlier growth record is progressively being destroyed. When studying the primary growth record, it is therefore important to choose a bone with as little resorption and remodeling as possible.

Sander's initial study (Sander, 1999, 2000) and subsequent sauropod and prosauropod studies (e.g.

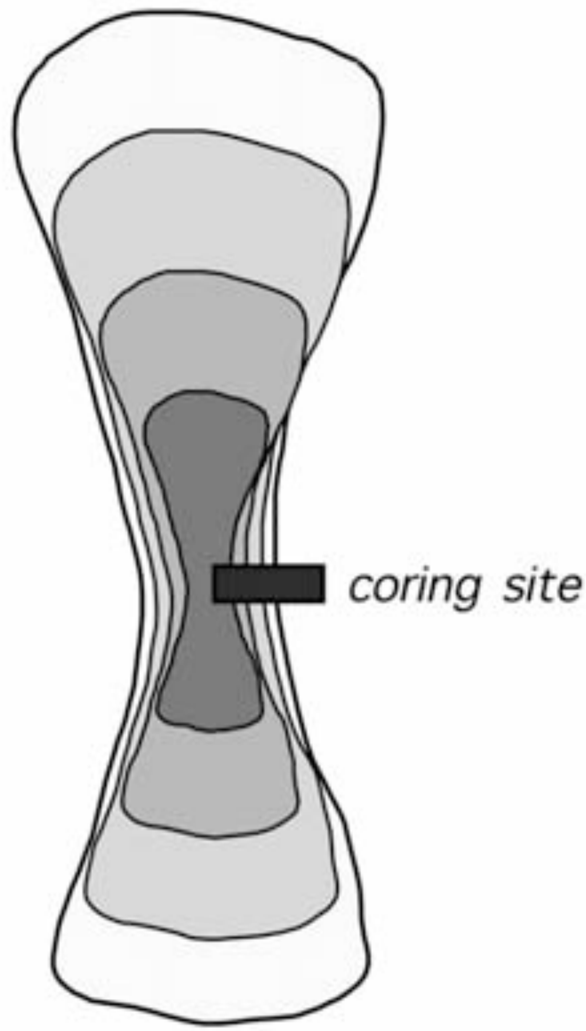

FIGURE 1: Idealized growth scheme of a long bone. Two epiphysial cones of endochondral bone are surrou-nded by a mantle of periosteal bone that is thickest at or near the middle of the diaphysis (shaft). The optimal sampling location is the narrowest part of the diaphysis, which is usually the middle of the bone shaft or slightly distal to it, as a core taken here will encounter the thickest as well as oldest periosteal bone and thus the most complete growth record.

Sander and Tückmantel 2003; Sander et al. 2004; Klein and Sander 2005; Sander et al. 2006) focused on long bones because of their simple morphology and relative abundance. Sauropod long bones do not have distinctive bends, crests, or trochanters that would require significant re-modeling during growth to maintain the shape of the bone. This means that they approximate the general growth scheme of two epiphysial cones of endochondral bone surrounded by a mantle of periosteal bone that is thickest at or near the middle of the diaphysis (shaft) (Sander, 1999, 2000; Sander et al. 2004), which makes them very suitable for histological studies (Fig 1).

On theoretical grounds, the optimal sample location is thus the narrowest part of the diaphysis, which is usually the middle of the bone shaft or slightly distal to it. A core taken here will encounter the thickest as well as oldest periosteal bone. To further minimize any effect of shape change of the long bones during growth, they are best drilled on the convex side. In anterior limb bones, this would be the posterior side, and in posterior limb bones the anterior side. However, when the surface of the bone is too damaged or unstable at these sites, it is best to choose an alternative drill location. Furthermore, Werning et al. (2008) describe a statistical method for determining which transects or coring locations best represent mean radial growth across the entire cross section. The specific histological sample location on long bones stresses the need for complete to near complete specimens. Isolated epiphyses or diaphyses provide little to no control on sample location, and are thus unsuited for comparative studies.

Apart from these theoretical considerations and general experience, the optimal location for drilling is best determined in a cross section of a medium-sized specimen of the taxon to be sampled. The cross section will reveal the location of the best growth record which is influenced by both the local apposition rate of primary bone and the patterns of remodeling and medullary cavity expansion.

Description of the coring device

The coring method involves a portable histological coring device. Setting up the coring device is straightforward. The three most crucial tools in the drill setup (Fig. 2) will be discussed in more detail. Most important are the drill bits (Fig. 2A), but also needed are a portable drill press (Fig. 2B) and a normal household electric drill. All the equipment required for the coring method is listed in Table 1.

Equipment
drill bits
extension piece and allen key
electric drill
drill press
large flower pot dish or tray
water spray bottle
tape measure
empty cloth bags or equivalent
small screwdriver (to break the core from its base)
tweezers

TABLE 1: Equipment required for tool kit.

Drill bits—The drill bits are available from different companies and in different sizes (Fig. 2A). We have mainly used 5/8 inch (15.9 mm) and ½ inch(12.7mm) diameter bits. The bits should be covered with fine to very fine diamonds, as medium diamonds are too rough and cut away too much bone. We cannot provide exact data on diamond grit size because this information is usually not released by the manufacturers. However, diamonds the size of 80 to 100 grit sand paper are best. High-quality bits have the diamonds sintered to the crown while in cheaper ones have the diamonds galvanized to the crown. Custom ordering of drill bits from lapidary companies is also an option, as well as resurfacing worn-down drill bits. Alternatively to buying finished drill bits, many university or museum machine shops should be able to turn out bits, and the diamond cover could then be added by a lapidary company. The coring bits should have a thin wall, less than 0.3 mm in thickness. This maximizes the size of the sample compared to the size of the hole. The length of the crown should exceed its diameter by several times because otherwise the recovered core will be too short. We use mostly bits with a crown length of about 45 mm, but other sizes exist. Most mid-range household electrical drills have a chuck size of 3/8 inch (9.5 mm) in the US and up to 13 mm in Europe, so the shank of the drill bit should also fit these requirements. Miniature drills (see next section), of course, require a smaller shank size.

The 5/8 inch bits are good for bones roughly over 60 cm in length (Fig. 2C); the ½ inch ones are good for bones from 30 to 60 cm long (Fig. 2D). Smaller bones can be sampled with smaller drill bits, but then the thickness of the wall becomes critical,


A
B
C
D
E

and the diamond cover may become too coarse and cut away too much bone during the drilling process. Therefore, it is best to make a complete cross section when dealing with very small bones. When dealing with very large bones, the length of the drill bit may not sufficient to drill all the way through the bone wall into the medullary cavity. In this case, an extension piece can be used (Fig 2A). This extension piece allows drilling to greater depths within the same hole. The extension piece has to be custom-made by a metal workshop and should consist of a short rod of brass or aluminum with a whole drilled into the center to receive the shank of the drill bit. To fasten the shank, a small sunken bolt with an Allen wrench head is added.

Electric drill—The drill should be a common household electrical drill. It should be able to run very slowly and with little torque, with torque decreasing at lower speeds. This means the drill should be of medium quality; the high-quality drills tend to be too powerful with torque being more constant at different speeds. For bones smaller than 30 cm, a low voltage miniature drill such as those made by Dremel® or Proxxon® may be used. These run with less power and fewer vibrations.

Drill press—A small and portable drill press is optimal (Fig. 2B). Manufacturers of the miniature drills discussed above also provide smaller presses for their tools. When visiting collections, the coring device can be set up on a table in a preparation lab or collections room. The press is then set in a bed of sand, or stabilized with bags of sand in a photo tray, or large flowerpot dish. Sand is available in most preparation laboratories, but on occasion we have also used rice to stabilise the drill press and the specimens. In a domestic laboratory, the drill press can be mounted on a table top for added stability. When dealing with extremely large and heavy specimens, like sauropod long bones, the specimen will extend over the edges of the tray, but the large weight of the specimen will add stability to the entire setup. If the diameter of the specimen is too large, a vertical extension of the drill press may be needed. In this case, the setup can be placed on a table top, with the drill on the opposite side of the drill press platform, hanging over the edge of the table top. The specimen can then be placed under the drill, on a lower table top.It is important when attaching the drill to the press to make sure that the axis of rotation of the drill bit is exactly parallel to the direction of the up and down motion of the press. If this is not the case, the core will break off prematurely. The drill press should also be well lubricated to allow smooth movement.

Traveling abroad—When traveling to foreign countries, be sure to take along the appropriate power adapter for the drill. We have usually checked-in the drilling device in a small suitcase as regular baggage when flying. The suitcase may be searched by customs or airport security, so always carry any freshly drilled specimens in your hand luggage, along with a letter of consent from the specimens' repository institution and perhaps any governmental permits. So far we have not had any major problems, but if you are visiting multiple countries on your trip, it is probably best to use a reliable international package delivery service. Taking specimens across a border of country that is not your homeland may lead to unfounded suspicion from security personnel. Practical problems may rise when flying. Some airlines have a limited baggage allowance, and will charge exorbitantly for any excess kilos. Therefore it is important to know that a disassembled drill kit will easily weigh around 10 kg when setting a budget for traveling.

The drilling process

A list of supplies needed during the drilling process can be found in Table 2. Lubrication of the drill bit is an essential part of the drilling process. Water or light oil are good lubricants. Water is usually less messy, cheaper and directly available, but some bones are damaged by water such as the *Plateosaurus* material

FIGURE 2: Histological coring set-up. **A:** Drill bits. From left to right, 6 mm drill bit, 5/8 inch (15.9 mm) diameter bit, custom-made extension piece for 5/8 inch (15.9 mm) drill bit, and a 1/2 inch (12.7 mm) diameter bit. **B:** Drill press for normal sized power drill. **C:** Complete drill set-up. Here a large sauropod humerus is being sampled. Notice the plasticine dam and water being added to cool the drilling site. **D:** Close-up of the drilling process. Notice that incomplete bones also qualify for sampling, as long as the standard location can be sampled. **E:** Retrieving the core, after it has been broken from its base with a small screwdriver. Note the mark of the bone long axis on the core, which is important for the correct orientation of the thin section.

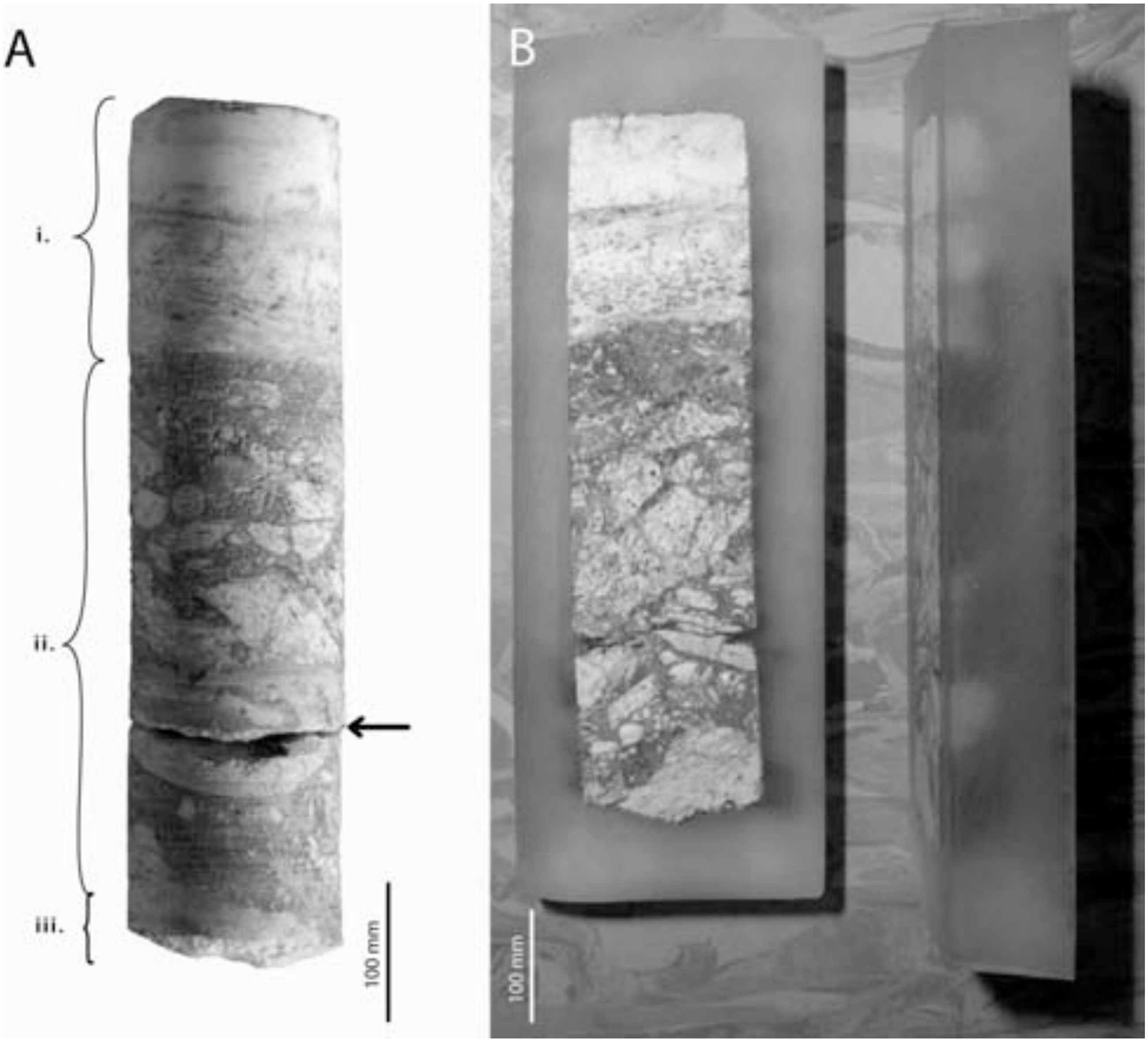

FIGURE 3: A. Core taken with a 5/8 (15.9 mm) drill bit. i. Cortex posterior side. Drilling commenced on this side; ii. Medullary cavity with matrix infill and crushed trabeculae; iii. Part of the cortex of the anterior side. This is where the core was broken off its base. Note that the lower part of the core had broken off in the drilling process (arrow). This is usually easily glued back together. **B.** The same core as in A embedded in epoxy resin and cut perpendicular to the long axis of the bone. These sections are further processed into a polished section and thin sections.

from Trossingen (Germany) and Frick (Switzerland),because they are clay cemented and disintegrate in water. Under such circumstances, oil is a more appropriate lubricant. See Sander and Klein (2005) and Klein and Sander (2007) for a histological description of the *Plateosaurus engelhardti* material, and more details of the methods used for sampling. A practical way of keeping the drill site permanently lubricated consists of building a circular plasticine or clay dam around it and filling it with 20 to 30 ml of lubricant. It is wise to change the lubricant periodically, or each time a core segment is taken out. This will avoid build up of mud in the drill hole and on the coring site, providing optimal lubrication. Once the core is finished, the reservoir can be drained with paper towels or a suction device. The bone can then be cleaned, and the dam removed and applied on the next specimen.

For further processing, thin-sectioning, and describing the bone histology, it is necessary to orient the sample. For comparative reasons, sections in long bones are usually cut perpendicular to the bones length

Supplies
sample boxes
adhesive tape (to seal sample boxes)
lubricants (water for cooling the drill bit oil for lubricating the drill press, and the drill bit in some cases)
plasticine or clay
cyanoacrylate glue (e.g. Paleobond®)
tissue paper
permanent marker

TABLE 2: List of supplies needed for the core drilling method.

axis. Therefore, the long axis of the bone is marked on the drill site on the bone before the core is drilled. Be sure to use a permanent marker that will not dissolve in the lubricant and the epoxy resin used to embed the samples.

The drilling process begins with the drill and drill bit in place above the drill site, with the drill bit in the basin filled with lubricant. The drill is then started and lowered onto the specimen. If the drill bit is placed on the specimen and then switched on, the outer part of the cortex may be damaged by shearing forces. Slow and careful drilling is in order until the bit has cut a complete circular groove. The electric drills used in this method do not have an accurate rpm-setting, but the initial drilling is usually done at the lowest speed, with only gentle pressure applied on the drill press. The speed dial may be increased one step once the drill bit has sunk about 5 mm into the specimen. After that, drill speed and pressure is adjusted, depending on how well-mineralised the specimen is, so that good progress is made but without overloading the drill motor or damaging the sample.

The drilling process continues until the medullary cavity is reached. The sedimentary fill of the medullary cavity usually differs in hardness and color from the cortical bone, and the color of the drill mud as well as the pressure necessary for drilling may change upon reaching the medullary cavity. If the thickness of the cortex is greater than the length of the crown of the bit, the core may have to be broken off prematurely. However, commonly, the core shears off earlier, anyway. If the cortex is thicker than the length of the crown of the drill bit, the already drilled core is retrieved, and the drilling is continued with the extension piece in place. Our 5/8” bit recovers a core of maximally 40 mm in length, and the extension adds another 30 mm. This takes care of the cortex of even the largest sauropod long bones, such as a 1.8 m femur of *Apatosaurus* (OMNH 4020) with a cortex thickness of 60 mm, and an ulna of *Supersaurus* (BYU 725-13744) with a cortex thickness of 70 mm.

It is possible to automate the drill feed by putting weights on the handle (e.g. sand bags), but the power necessary to depress the handle increases gradually, mainly because of the increasing compression of the spring holding the handle up, but also because of the changing geometry of the mechanism. It is thus best to drill by manually pressing down the lever of the drill press, to keep a constant coring rate.

The cores shear of frequently and in most cases are not recovered in one piece. When a core segment has sheared off in the drilling process, it is important to stop drilling and retrieve it, or it may be damaged. However, core segments that have broken off are usually easily glued back together (Fig.3A). We usually apply a cyanoacrylate glue such as Paleobond ™. Cyanoacrylate has the advantage of fast curing and a refraction index close to 1, and it will not interact with the epoxy resin used for embedding the cores. However, other glues that will not obscure the thin sections or interact with the resin may also be used. Retrieved cores should immediately be stored in secure sample boxes with the information of the particular specimen, and preferably sealed with adhesive tape. Retrieving cores, or core segments that have not sheared off prematurely, may require a thin screwdriver, a pair of tweezers and some skillful fingers (Fig. 2E). The screwdriver is inserted in the drilled cavity and used as a lever to break the core off its base. Then the tweezers are used to retrieve the core from the hole. It is almost impossible to avoid occasional core segments getting stuck in the drill bit. If this happens, the bit needs to be removed from the drill, so the core segment can carefully be pushed out with a thin rod or a blunt nail through the hole in the shank of the drill bit. Poorly mineralized specimens can be and have been destroyed in this action, so rinse with plenty of water to avoid any friction caused by buildup of mud in the bit.

If further drilling is required (e.g. when the medullary cavity has not been reached), the process may be continued within the same hole with the same core bit, or with an extension piece if the maximum drill depth of the core bit has been reached.

Timing

The time required per core is strongly dependant on the specimen that is being sampled. On one hand, silicified bones, such as some specimens from the Carnegie Quarry at Dinosaur National Monument, may take a long time and are best drilled with a drill bit studded with medium grained diamonds to speed up the process. On the other hand, subrecent specimens, such as Pleistocene mammals, have to be drilled slower (lowest setting on the drill speed dial) and more careful than usual, as they have not yet (completely) undergone the mineralization process, but have already begun degrading, and are generally more fragile than fossil and recent bones. Recent bone is relatively tough and can be drilled faster, providing there is no overheating. On average, about an hour per core sample is needed.

When desired, the small hole left at the drill site can be filled up with plaster, putty or other materials, so the original shape of the bone is restored. However, we prefer to leave the hole open for several reasons: the sampling site is immediately obvious and preserved for later workers, the existing hole can be use to obtain additional bone tissue samples, e.g. for isotope geochemistry, and the core sample can be extended by deeper drilling, e.g. to study the medullary region and the cortex of the other side of the bone.

Thin sectioning and polished sections

Histological cores are ultimately processed into petrographic thin sections (Fig.3B), following standard methods (Enlow and Brown, 1956; Wells, 1989; Chinsamy and Raath, 1992; Wilson, 1994; Lamm, 2007). The cores are usually embedded in polyester resin that cures water-clear (e.g. Araldite® or Silmar 41®) and then cut along the long axis of the core, perpendicular to the surface mark indicating the long axis of the long bone. The freshly cut surfaces are impregnated with resin in a vacuum chamber to reduce the risk of air bubbles that may obscure the slide. The sectioned surfaces are then ground with grinding powder until smooth and all saw marks having been obliterated. In our lab, we use a sequence of 400, 600 and 800 grit sizes for grinding, but depending on availability, other grit sizes may be used. Specimens should be thoroughly rinsed when changing grit size. Once the embedded core is smooth enough, it is glued with resin onto a frosted glass slide of desired size, and left to dry. Other glues or epoxies may also be used, providing they have a refraction index that is near that of water and are strong enough to withstand the forces of sectioning and grinding. The use of polyester resins is not recommended, as they are not very stable and may desintegrate after a number of years. It is also best to avoid the use of dessicators or glue presses, as this increase the risk of bubbles. It usually takes 24 hours for the sample to cure. Then, it is cut to a thickness of a few millimeters, using an automatic rock saw, and further manually ground to a thickness of about 120 to 150 μm. The desired thickness can be approximated by repeated control with a polarizing microscope. Finally, a cover slip is put on the section to increase the contrast and protect the sample. We usually apply a UV light curing adhesive to glue the cover slip. Two initial thin sections are made, one from each core half. The residual core part can then be used for polished sections, microprobe or isotope analysis and/or further thin sectioning. Alternatively, one of the core sections can be polished into a polished section *sensu* Sander (2000). Polished sections are polished to a high gloss, similar to polished ore or coal samples, to facilitate study in incident light. This allows observing polish lines, a growth line in fibrolamellar bone, which are only visible under bright field illumination, and not in thin sections (Sander 2000). When making polished sections, one should aim for a 'decorative polish'. Advanced polishing machines create an overpolish, making the polish lines invisible. In the process, a simple polisher, aluminiumoxide, and a synthetic polishing cloth are used. Polish lines will appear where differences in hardness exist in the bone matrix, as softer regions will be ground away faster. For a detailed description of polish lines in sauropod bones, see Sander (1999, 2000).

Literature on making geological and histological thin sections is extensive, but expertise in preparing fossil bone thin sections can only be acquired by experience. In general, thin sections from fossil bone are more difficult to cut than regular rock thin sections because the brittle nature of fossil bone. Examples of more detailed descriptions of the thin sectioning process for paleontological specimens can be found in Enlow and Brown (1956), Wells (1989), Chinsamy and Raath (1992), Wilson (1994), or Lamm (2007).

Advantages and limitations of the coring method

The most important advantage of the histological coring method described here is its less destructive nature compared to the cross-sectioning of whole bones. Comparable to a biopsy on living tissue, only a small fragment of the tissue is taken, and the morphology of the specimen is preserved. The coring method may also be used as an alternative to serially sectioning bones, taking cores at designated places along the long axis of the bone. Although the specimen would then have to be reinforced by filling up the drilled holes with putty or plaster, it is not entirely lost for morphological studies. When performing growth studies, incomplete specimens also qualify for core sampling, as long as the standard mid-shaft location can be sampled, and the full size of the specimen can be estimated.

The less destructive aspect of this method is more appealing to most museum curators and collections managers than traditional sectioning methods, and thus sampling is more easily approved. As more and more samples become available, the way for comprehensive comparative, skeletonchronological and other quantitative studies is being paved.

In addition to long bones, other bones may also qualify for the coring method. Sauropod ribs usually tend to show extensive remodeling and few to no growth lines. However, serial sectioning in our lab of complete *Camarasaurus* ribs from the Morisson Formation showed the proximal region and the rib neck preserve the original growth record. Other species may also preserve their growth record in this region, and so in further investigations rib specimens can be sampled using a coring device as well. Other researchers have already succesfully studied histology in a variety of bone types, which may also qualify for histological coring. Curry (1999) found growth marks in scapulae of *Apatosaurus* sp., which was grossly different from what could be observed in *Apatosaurus* long bones, where no growth marks were observed in the typical primary fibrolamellar cortex. Erickson et al. (2004) and Horner and Padian (2004) performed multi-element histological analyses on tyrannosaurid bones. These studies revealed that non-weight bearing bones (e.g. pubis, fibula, ribs, gastralia and some post-orbital skull bones) usually exhibit a better growth mark record than weight bearing bones, which tend to have more extensive remodeling.

The coring method also has some practical advantages. The drill press, drill, and other components will fit together in a small travel case, with a total weight of around 10 kg, which makes it possible to take the drilling equipment along and sample bones directly in the collection rooms, transport to preparation lab being not necessary. This is a major advantage in the case of large sauropod long bones that may weigh several hundred pounds. The samples obtained by core drilling are small enough to carry a large number in a small backpack or travel case. Additionally, the method works equally well for extremely large as well as for small bones, only requiring the mounting of a smaller drill bit when drilling smaller specimens.

The most important limitation of the method is the restricted view of the cortex. The core is a sample taken at a controlled location on the bone shaft, but it is only a narrow segment of the cortex in a large bone. Any localized variation in cortical histology (e.g. pathologies, cortical drift, medullary bone, differential remodeling) along the circumference of the bone will not be observed, which could seriously affect any histological interpretations. This emphasizes again the importance of a standard sampling location when comparing histologies of different individuals and taxa.

Other problems may arise when sampling subrecent or other poorly preserved specimens. If there has been no infilling or cristallization of the medullary cavity, coring can destroy the trabecular bone. Therefore, it is necessary to decide which features should be studied, before starting the drilling, and evaluate the risk of destroying those features or the entire core in the process. Extremely fragile bones are best embedded in resin to stabilize them, and subsequently completely sectioned instead of core drilled. Nevertheless, if the coring method is chosen because the bone is too large, or because complete sectioning is not allowed, slow drilling is in order. Additionally, if the bone has not been consolidated already, it may help to locally impregnate the drill site with an appropriate product (e.g. polyvinyl alcohol or polyvinyl acetate). Finally, it should be mentioned that this is a general description of the coring method, and that this description is not a definite working procedure. Many aspects described here can be modified to workers’ and technicians’ preferences and wishes, and most difficulties will probably surface finding adequate drill bits.

Acknowledgments

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CREATING A MULTI-USE POLYURETHANE MOLD WITH A REPLACEABLE POUR SPOUT

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Abstract

Typically, the molds made at the University of Michigan Exhibit Museum of Natural History (UMEMNH) and Museum of Paleontology (UMMP) are created with one type of casting in mind. We recently had the unique opportunity of knowing before the project began that we would be creating molds of a 60 foot fossil whale skeleton that would be used to produce two very different types of castings. UMMP wanted to create research casts using the museum's standard fiberglass hollow-casting method, while UMEMNH wanted to create lightweight foam casts that would facilitate mounting the skeleton suspended from the gallery ceiling. To address this challenge, we modified our standard multi-piece semi-flexible molding method by adding a removable/replaceable plug that would enable the molds to be used for both types of castings.
Keywords: molding, casting, polyurethane mold, foam cast, plug, pour spout

Cherney, M. 2009. Creating a multi-use polyurethane mold with a replaceable pour spout. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 81-86. Brown, M.A., Kane, J. F., and Parker, W.G. Eds.

Introduction

Dr. Philip Gingerich, University of Michigan Museum of Paleontology (UMMP), had secured a one year loan of a large fossil whale specimen that he had excavated in Egypt. All preparation of the bones (including extracting, consolidating, reconstructing, and molding) was to take place during the loan period. At the end of the year, the prepared bones would then be returned to Egypt for display. The molds would be used both by UMMP to create a set of research casts and by the University of Michigan Exhibit Museum of Natural History (UMEMNH) to create a set casts for display. For creating research casts, UMMP had previously adopted a standardized method of hollow casting using polyester resin and fiberglass that reproduces much of the microscopic detail of the bone while holding up to the abuse of frequent handling. For display purposes, UMEMNH wanted lightweight casts that could be suspended from the ceiling of the exhibit hall without expensive structural modifications to the building. Although hollow casts produced by the UMMP prep lab would be lightweight compared to the original fossil material, we (the exhibit staff of UMEMNH) wanted to make casts that were even lighter but still retained the necessary detail and structural stability required for the display. So, in anticipation of creating a skeletal mount, we started looking into other casting methods. Our research and initial experimentation led to the idea of using expanding polyurethane foam to make the exhibit casts. We first looked into self-skinning foams in the hopes of simplifying the casting process to one step, but found that only the more dense foams (8 lb/ft3 and above) produced the level of surface detail that we desired for the casts. Such casts would be heavier than the fiberglass hollow casts currently produced by UMMP. We decided that we would apply a thin layer of polyester resin to the mold to pick up the surface detail before filling the inside of the cast solid with low density polyurethane foam (2 lb/ft3). This casting method would require each mold to have a pour spout.

Figure 1: The polyurethane plug (foreground) is cup-shaped with walls about 1 centimeter thick. Two ridges and a vertical "key" position and secure the plug in the mold. I initially sculpted the form out of clay and then produced a silicone mold (two pieces in the background) from which we could produce numerous polyurethane plugs.

Although it was easy to determine a location for such a spout that would be hidden on the exhibit casts, UMMP was unwilling to sacrifice specimen surface area in their research casts. Our solution was to develop a molding method incorporating a plug that when removed would provide a pour spout and when reinserted (possibly even mid-casting to cap off the opening) would key into the mold in order to create casts that retained the complete surface area of the bone.

Methods

After determining the objective, to devise a process that would produce molds with a secure but removable plug, we had to work out the details of the method. We had limitations. To the extent that we could, we wanted to use materials and tools familiar to us and since we were on a limited budget and tight schedule we could not afford to alter the existing methods in such a way that significantly increased the amount of time required to produce the molds. Also, because we would be relying heavily on student help to complete the project on schedule, we had to

Figure 2: I attached the plug to the bone using the same polyurethane from which the plug was created. A plaster cylinder inserted inside the plug supports its flexible walls.

keep it simple enough that it could be quickly mastered by those with no previous molding experience. In the end, we decided that the material that best fit the objectives and budget was a system of polyurethane molding rubber supplied by Polytek Development Corporation. The process would likely work similarly using other rubber molding materials such as silicone.

We first designed the plug element (Fig. 1). The plug needed to key into the rest of the mold so that it could be easily replaced to its original orientation. It also needed to lock into the mold securely so that pressure from the expanding foam inside the mold would not force it out. Finally, we wanted to be able to replace the plug after pouring the liquid foam to seal off the opening. Such a plug would require too much attention to be something an inexperienced student would be able to construct for each bone being molded. So, we created one master that we could mold and reproduce as needed. We cast the plug using Polytek Polygel 40 © (a polyurethane molding rubber) both because it provided the desirable balance between stiffness and flexibility without additives and because we would already using it in the molding process. This helped keep the process simple, avoided any adverse reactions between materials and any differential shrinkage of mold pieces, and allowed us to use a single parting agent throughout the process. We attached the plug to the bone with a thin layer of Polygel 40 to add surface detail to the initially featureless end of the prefabricated plug (Fig. 2). After attaching the plug to the bone, we applied a layer of Polytek Pol-Ease 2300 © mold release as a parting agent and the completed the section of the mold surrounding the plug. This involved applying two layers of Polygel 40 to pick up the surface detail of the mold followed by two layers of a more viscous polyurethane (Polytek Polygel 50 ©) to strengthen the mold. For our purposes, it made the most sense to completely enclose the plug inside of one of the mold pieces (Fig. 3). This would simplify the hollow casting process by treating the plug and its encompassing mold piece as one part, but required that the fiberglass reinforced polyester mother-mold be made of two c-shaped pieces so that it could be removed from around the plug. In preparation for casting, the two mother-mold pieces would be bolted together to provide a rigid backing for the mold section.

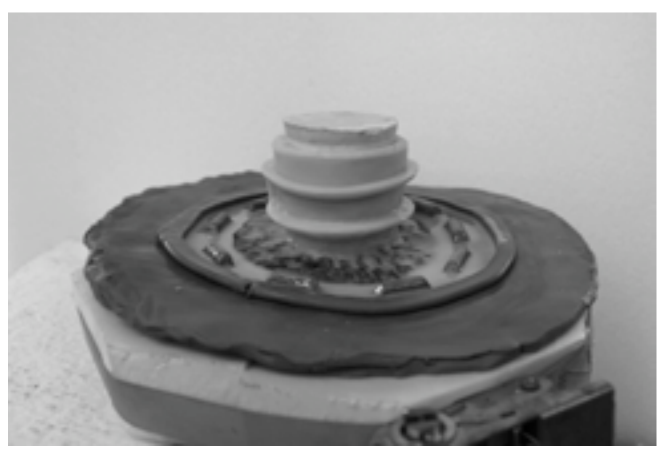

Figure 3: Because the plug is collapsible once the plaster support is removed, it is easily pulled out of the surrounding mold piece.

Casts	Weight
Test 1: Rigid polyurethane foam (2 lb/ft3) with an outer layer of polyester thickened with talc	405 g
Test 2: polyester and fiberglass hollow cast	770 g
Test 3: Foam cast using fumed silica in place of talc as a thickening agent for the polyester	365 g
Polyester and fiberglass hollow cast filled with 2 lb./ft3 rigid foam for mounting purposes *	1045 g *

Table 1: The recorded weights of the first two test casts are listed. A second foam test cast (Test 3) was produced using fumed silica in place of talc as a thickening agent in the polyester used for the outer layer of the cast. The actual weight is recorded here.
* In the mounting process we would likely fill any hollow casts with 2-lb. density polyurethane foam in order to secure them to the metal armature. We estimated that it would take 275 g of polyurethane foam to fill the cast produced by Test 2. The projected final weight of the mounted hollow cast is listed here. In contrast any of the solid foam casts would not require any additional foam.

After the plug and surrounding mold piece were complete, the rest of the bone was addressed as normal to createa multiple piece semi-flexible mold, dividing the bone into the necessary amount of sections to facilitate demolding with minimal risk of damage to the specimen.

Tests

After creating the first test mold of a bone of somewhat average size for the project, we ran several tests. First, we used the mold without the plug to produce a foam filled cast. We painted a thin layer of catalyzed polyester resin onto the surface of the mold. Testing determined that the uncured polyester reacted negatively with the polyurethane foam, so we waited overnight for the polyester to cure. The next day, we estimated the volume of the mold and poured the associated amount of polyurethane foam liquid into the mold. The foam expanded out of the pour spout of the mold, leaving a large sprue in the cast that we removed. Overall, the test was a success. We produced a lightweight cast that had all the detail from the mold. It was not as rigid as the fiberglass reinforced hollow casts that we were used to handling (we could dent the surface by firmly pressing our thumbs into it) but was overall far more durable and resilient than required for a museum skeletal mount not intended for frequent handling. As an added bonus, each cast took just over a half hour of labor to produce, compared with the three to four hours that we usually spend creating a hollow cast of similar size. After we felt satisfied with the performance of the mold for the purpose of creating exhibit casts, we passed the mold to the UMMP fossil preparators to test it for creating a research quality hollow cast. They created one cast using polyester resin (talc for a thickening agent) and fiberglass mat. That one test was enough to convince them that the method would not introduce any complications to the method. The cast, with the exception of one additional minor seam line around the plug, turned out no different than if the mold had been made without the plug. We then compared the two test casts. With the exception of the remains of the pour spout in the foam cast, the details in the casts were identical both having talc filled polyester as the outermost layer (fig. 4). The research cast was harder and would likely hold up better to extended handling. However, at only 53% of the weight of the hollow cast, the foam cast would be significantly easier to mount to the ceiling. In a subsequent experiment we were able to produce a foam cast using fumed silica in place of talc as a thickening agent for the polyester that weighed only 35% of the projected final weight of a mounted polyester-fiberglass hollow cast (Table 1).

Conclusion

By engineering a secure, removable, replaceable plug for use in semi-rigid polyurethane molds using familiar materials and simple procedures, we successfully

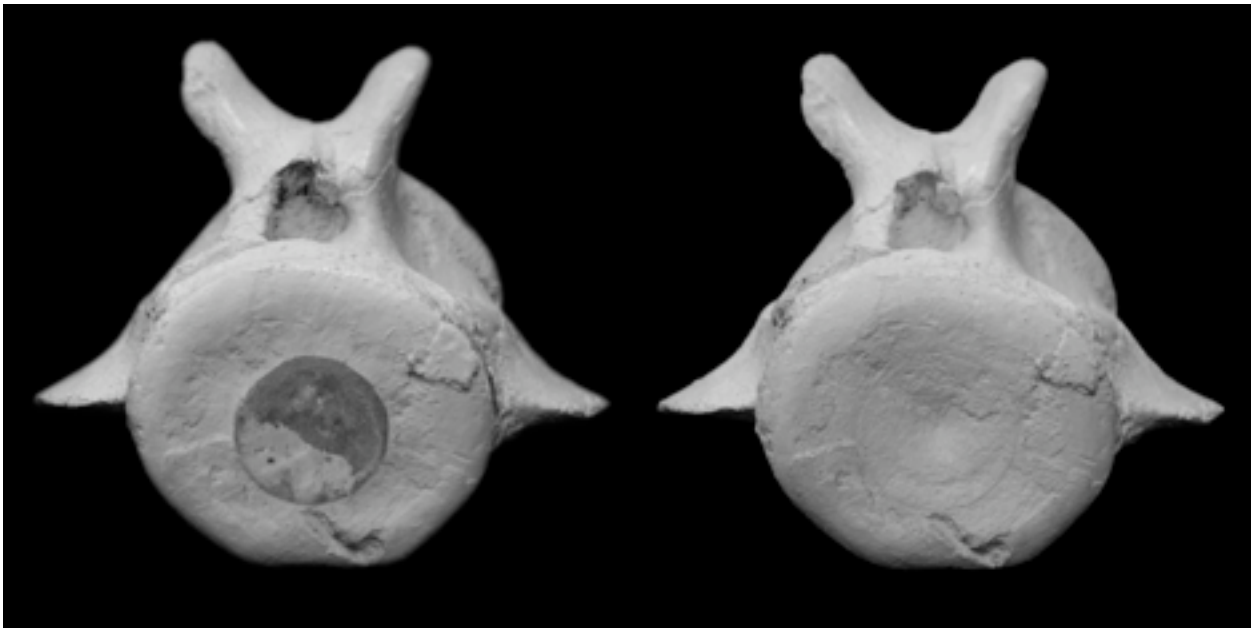

Figure 4. The first test cast (left) made from and expanding rigid polyurethane foam. The location of the pour spout is shown. The second test (right) was made as a fiberglass hollow cast with the plug secured in the mold. The directional ridges (see fig. 2) on the plug will allow insertion of the plug into the mold during casting but prevent internal pressure from ejecting the plug. Future tests will involve replacing the plug after pouring the liquid foam into the mold to retain the surface detail in the location of the pour spout.

modified our incumbent methods to accommodate multiple modes of casting and thus enabled ourselves to use the same molds to produce both durable research casts and lightweight exhibit casts. Although it will add a short amount of time to the molding process of each bone, the process of making a foam cast (or any other pour casting method), which potentially could be modified slightly to satisfy the requirements for research specimens, takes only a fraction of the time required to make a traditional hollow cast. So, the time added to the molding should be easy to make up in casting.

However, most significant is the multi-use nature of the molds, which we are confident will enable the quality and durability required by UMMP and will simultaneously allow UMEMNH to pursue other casting methods more tailored to the various requirements of museum exhibits.

Acknowledgments

Special thanks to Daniel A. Erickson (UMEMNH) for his assistance engineering the removable plug, and to William J. Sanders (UMMP) and Tyler Keillor for reviewing this paper. Thanks also to editor Matthew Brown for making this publication possible.

Materials

Polytek PolyGel 40 © polyurethane molding rubber – for removable plug and first layers of the mold
Polytek PolyGel 50 © polyurethane molding rubber – for final layers of the mold
Polytek Pol-Ease 2300 © mold release agent – used as a parting agent between mold pieces
Polyester resin – to create casts and mother-molds
Rigid polyurethane foam – provided the solid internal core of the lightweight casts
Fiberglass mat – to create research hollow casts and mother-molds
Talc – thickening agent for polyester
Fumed silica – lightweight alternative to talc for thickening polyester

THE USE OF LINEAR COLLAPSIBLE FOAM FOR MOLDING ICHNOFOSSILS IN THE FIELD

Thomas C. Nolan[1]; Rob Atkinson[2]; and Bryan J. Small[3]

Abstract

Time is a valuable commodity and any method that shortens the time making an impression in the field or copy in the lab translates to more time available for other tasks. Additionally, transportation of the materials to a site can be difficult and burdensome. Current methods of creating impressions of ichnofossils entails the use of liquid latex, Plaster of Paris, or silicon rubber that is poured or brushed into the impression, allowed to harden, then removed. This often leads to residual material left at the site, damage to the fossil and expenditure of long periods of time. The use of linear collapsible foam (the same foam used to take impressions of body parts for orthotics) eliminates the residue, does no damage, is inexpensive, and produces a high quality impression of the fossil within minutes. The foam has a density from .7 to 2.8 pounds per square inch and can be ordered in various thickness and sizes. The cost of the foam is competitive with other molding materials (~$.65/board-ft). The lighter density foam was deemed too friable to use, however, the denser foams proved ideal for taking impressions. There are limitations using this method. Objects that have undercuts, even slight ones, will not copy and the foam will be damaged when removed; transportation of the material must be made in a single lid cardboard box to prevent damage to the impression; and large area footprints requiring large sheets of the foam may require multiple people to compress the foam into the object. Once taken a master cast of the impression is made using Plaster of Paris or Water Putty. At this point the foam impression is destroyed removing it from the hardened cast. Organic based casting materials can not be used because of adsorption of the liquid into the foam and possible reactions with the foam. Once made, the master copy retains the details and sharpness of the original fossil. This method produces a copy of the subject within a few minutes in the field and the materials are easier to transport into the field and back. This foam can also be used to make one-time plaster casts of simple fossil bones in the lab producing a medium-fidelity copy of the bone in a few hours.

Keywords: Ichnofossils, Footprints, Molding, Silicon Rubber, Rapid Curing Latex, Linear Collapsible Foam

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Nolan, T. et al. 2009. The use of linear collapsible foam for molding ichnofossils in the field. In: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 87-92. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

Often while surveying an area for fossils one will come across ichnofossils that would be of interest but would be too difficult and time consuming to remove. These are generally footprints but also include plant impressions, trace tracks and burrows. Current methods for copying these trace fossils involve layering latex over the impression, allowing it to dry, then pouring a plaster mother mold. Once hardened the mother mold and latex is removed (Baird 1951; Goodwin and Chaney, 1994). Another method involves the use of silicon rubber to create a mold of the object. Both methods involve the expenditure of time and the carting of heavy materials and/or equipment to and from the site. Removal of the latex or silicon rubber can damage the fossil by inadvertently pulling up loose pieces. Cleanup of the area is also problematic as often plaster or latex is left behind. Even using the rapid curing latex method (Hamley and Thulborn 1993) is still time consuming. Linear collapsible foam is an ideal alternative for making molds of trace fossils in the field. It reduces the time required and eliminates the disadvantages of current methods.

Material and Methods

The linear collapsible foam used is a less dense version of the foam that florists use to create arrangements and is used in molding body parts for creating orthodics (Fig. 1). The density ranges from .7 to 2.8 pounds per square inch and can be custom ordered in various sizes and thicknesses. The lighter density foams were found to be too friable to be used breaking off into small pieces of foam on the edges that made a mess to clean up. Foams in the range of 1.5 to 2.0 were ideal as they were easily collapsed but did not break up into pieces. The cost of the foam (~$.65/board foot) is competitive with other molding materials.

Directions to make a mold of an ichnofossil in the field are:
Step 1: Clean any debris out of the fossil.
Step 2: Measure the fossil and cut the foam to size. We recommend the block of foam be cut 2 inches wider and longer and 1/2 inch deeper than the fossil (Fig. 2).

Figure 1: A 20" X 20" X 3" block of the linear collapsible foam.

Step 3: Place the foam over the fossil centering the fossil on the foam.
Step 4: Place the press board over the foam and evenly press the foam firmly into the fossil (Fig. 3) .
Step 5: Remove the foam by carefully lifting the foam straight out of the fossil. Any side movement of the foam could damage the foam when removed.
Step 6: Place the foam carefully back into the carrying box.
You now have an impression of the original fossil (Fig. 4).

These steps work regardless of the pitch of the ichnofossil including upside down.

Once back in the lab a dam is created around the foam impression and plaster of Paris or water putty is poured over the foam to make a permanent copy. The foam is removed from the hardened casting material, destroying the foam. A soft brush or air gun can be used to clean the remaining foam from the cast. Organic based casting resins or coatings can not be used on the foam as they are absorbed into the foam and react with it rendering the foam useless. Silicone mold release is also absorbed into the foam and does not aid in the removal of the foam from the casting material (Fig. 5).

This material can also be used to make medium fidelity one time casts of fossils in the lab. Fossils such as leg bones, ribs, and foot bones are ideal candidates since they rarely have undercuts. In this application two pieces of the foam are used. Again, the foam should be two or more inches wider and longer than the fossil. A pouring spur and vents

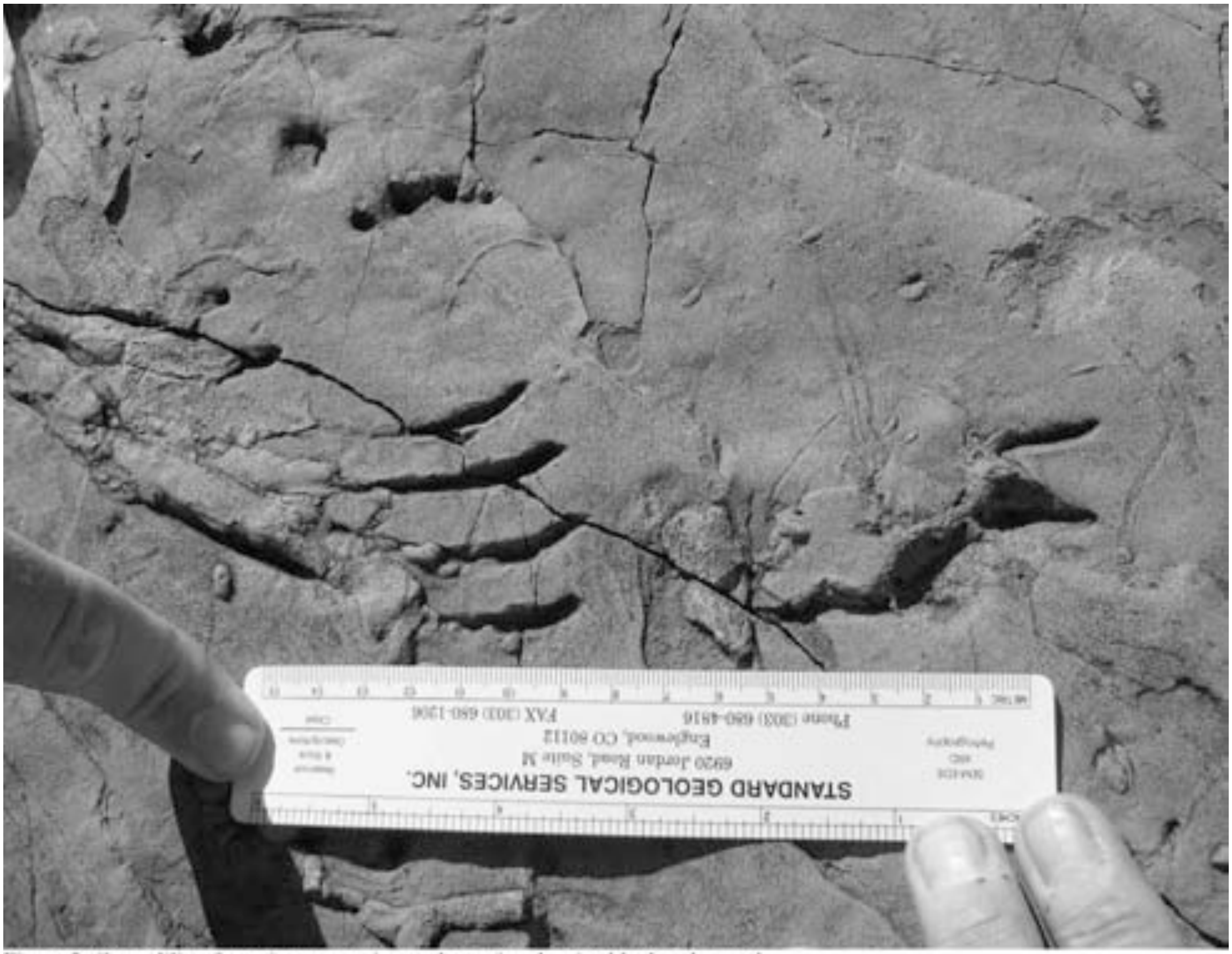

Figure 2: Crocodilian footprint, measuring to determine the size block to be used.

Figure 3: Pressing the linear collapsible foam into crocodilian footprint. Comanche National Grasslands.

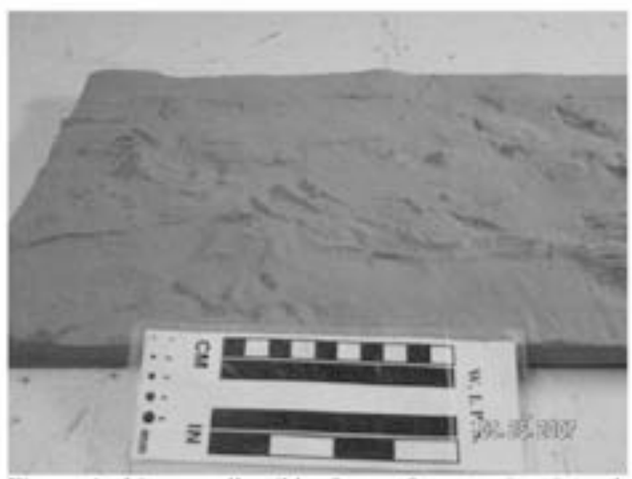

Figure 4: Linear collapsible foam after pressing into the footprint.

Figure 5: A dry brushed plaster cast of crocodilian footprint taken from linear collapsible foam mold.

will need to be attached to the fossil and square key blocks made to realign the foam for casting. The fossil is laid on the foam with pouring spur and vents extending to the edge of the foam. Alignment keys are pressed slightly into the foam and the second block placed on the top. Press the top block down until it touches the bottom block then press ¼ to 3/8 inch more. Lift the top block off and remove the fossil, pouring spur and vents making sure they are clear to the fossil and the edge of the blocks. Place both blocks back together and hold them together with boards and clamps making sure not to further compress the foam. Pour the casting Plaster of Paris or Water Putty into the mold and allow it to set. Remove the cast using a soft brush or air gun to clean the cast.

Advantages and disadvantages

There are several advantages to using this material. The light weight of the material and minimal equipment to use it makes it easier to carry it to the site than heavy bags of plaster, buckets of latex, mixing trays and materials to create dams to hold the latex and plaster in place. Operational time is considerably less as this method requires less than10 minutes to create the mold verses several hours to make latex molds. Cleanup after the fact is also easier as the foam leaves no residue. There are several disadvantages. The foam must be carried in a single lid box that will not damage the impression while being transported. This method can not be used on ichnofossils that have undercuts as the foam will not flow into these undercuts and will be damaged when removed. Large area impressions may require more than one person to crush the foam into the impression

The only equipment required is a brush or other cleaning tool, a long sharp knife to cut the foam to size, and a board to press the foam into the ichnofossil. A satisfactory "press" may be fabricated from a sheet of plywood or other suitable material, cut to size, and fitted with a handle.

Conclusion

Although not applicable to every situation, these processes, offer a simpler, faster, and cost effective way of copying ichnofossils and fossil bones than do the current methods. The material may be obtained from manufactures of linear collapsible foam for orthopedic use.

Acknowledgments

We thank Joe Temple, Executive Director, Dinosaur Ridge, Morrison Colorado for allowing the initial testing of the process at his facility; Bruce Schumacher, Rocky Mountain Region East Zone Paleontologist, USDA, U.S. Forest Service, for allowing field testing at Comanche National Grassland and his encouragement to produce this paper; Lou Taylor, WIPS, for his photographs and encouragement; Mark Ludwig, President, Ludwig Inc., Waldo Arkansas, for the data on the foam and for his generosity in supplying various foams for testing; and Steve Miller, WIPS, for allowing the testing during the 2007 CNG survey project. Thanks to David Slauf for providing a review of this paper.

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INEXPENSIVE AND SIMPLE CONSTRUCTION OF A MANUAL CENTRIFUGE FOR RESIN CASTING

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Abstract

A manually operated casting centrifuge was made to replace an older commercial model for the University of Michigan Museum of Paleontology. The intended use was for casting small fossils using a variety of resins in silicone molds to reduce the occurrence of air bubbles in the cast. The design was based on size criteria specified by the head preparator. This particular device was constructed mostly with scrap materials to keep costs low, and works very efficiently.

Erickson, D. 2008. Inexpensive and simple construction of a manual centrifuge for resin casting. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 93-96. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

The University of Michigan Exhibits Museum of Paleontology produces casts of fossils in a wide range of sizes. The preparation lab often casts small fossils, such as mammalian tooth rows, using silicone molds and tinted epoxy resin for casts. A common problem encountered in the casting process is that small air pockets become trapped in the molds when resin is poured into them, resulting in voids in the extremities of the casts. To mitigate this problem, a centrifuge is used to force the resin into the molds, thus displacing the trapped air.

Materials and Methods

Most of the materials used in the construction of this centrifuge came from scrap pieces left over from other museum exhibit projects. Other parts such as the spindle shaft, ball bearings, chain, pulleys, belt, etc. were purchased from a local hardware store, with the hopes that any replacement and repair parts could be easily obtained by future operators. Since most materials used for this project are sold using standard inch measurements, I will describe them as they are most commonly found, with metric equivalents in parenthesis. For sake of simplicity all nuts, bolts and tapped holes utilize 1/4-20 threads (.25 inch diameter with 20 threads per inch). Metric nuts and bolts would be equally suitable.

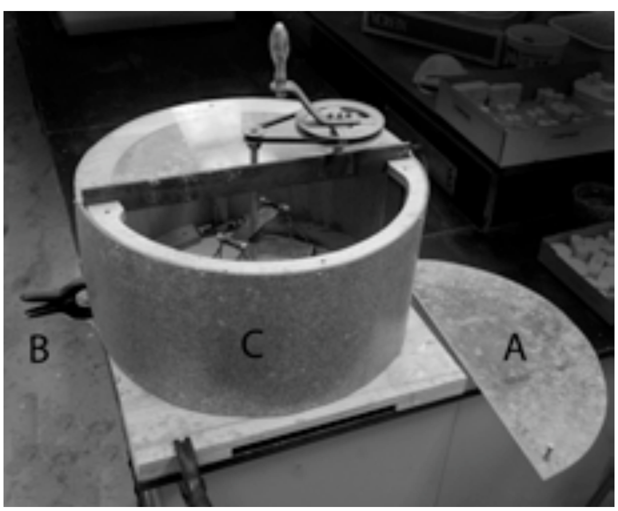

FIGURE 1. A. Centrifuge with acrylic lid removed, **B.** spring clamps used to secure centrifuge to lab table, **C.** sheet metal reinforcing plywood wall.

The size of this centrifuge is based around a standard specimen box size of 9cm x 13cm x 5cm (4"wide x 5"long x 2" high). These cardboard containers are used as disposable liners for the metal baskets.

Excess epoxy often runs out of the spinning molds and collects in the boxes. A proportionally larger, or smaller centrifuge could be constructed based on this design.

Since our facility has certain basic fabrication equipment such as a welder, milling machine, drill press, and hand-held power tools we took advantage of those. Mechanical fasteners, nuts and bolts, could be used in place of welding if welding is not available.

Discussion

Balancing weights

These are important to reduce vibration or shaking of the centrifuge. Weights can consist of most any available relatively dense objects. Pieces of scrap brass were used in this casting lab. The molds filled with casting material are weighed and appropriate counterweights are then added to the opposing centrifuge basket.

Baskets and related parts

The metal centrifuge baskets were made from scrap sheet metal. Heavy construction paper was folded loosely around the cardboard specimen boxes. This folded paper then becomes the template used to mark the sheet metal. If other sizes of specimen boxes are used the same procedure can be used for making metal baskets as needed. It is important to allow sufficient clearance between the swinging baskets and all other parts. No attempt was made to calculate the potential g-forces needed for the resin casts, so the length of the basket support arms was simply determined by what seemed convenient for the size and proportions of the centrifuge. The baskets are attached to the support arm via two lengths of chain. The chain is attached at each end and the middle using 1/2 inch diameter key rings. The chain and rings need to be sufficiently strong to resist the centrifugal forces.

Base

This was constructed with 3/4 inch (19mm) thick plywood, measuring 24 inches square (61 cm x 61 cm). An extra thickness of scrap 3/4 inch plywood was placed under each corner of the base simply to allow extra clearance space for the spindle shaft and supporting bearing to protrude through the bottom of the base.

Crank handle

After considerable use the inferior shop made handle was discarded and an industrial grade polished chrome plated revolving steel crank handle was installed (part number B6-50, from Reid Tool Supply Company). The handle needs to be comfortable to the hand and very durable. The polished chrome finish is easily cleaned of resin.

Drive train

The v-belt pulleys were determined by trial an error, testing different diameters. It was found a 4:1 ratio worked well for operator cranking speed and resulting spindle speed. Other combinations may be more suitable for other operators. The crank handle was attached to a bent metal bar. The crank pulley was mounted on the end of a 3/4 inch diameter steel rod which was turned down to a smaller diameter which accommodated a bronze bearing. This steel shaft was welded to a 1/4 inch thick steel plate. A slot was milled near one end of this plate allowing it to be positioned and fastened to another metal plate which was welded to the frame of the centrifuge. The sliding plate provides a means for tensioning the v-belt. A cover for the v-belt and pulley drive train was not made for this centrifuge, but would be a good addition since students may also be operating the device. As with most tools with moving parts, any long hair and loose clothing should be tied back. Practice common sense when using a centrifuge.

Frame

The main metal framework for the device can be either three or four legged. I found three supports to be sufficient, with the idea that greater access to the baskets could be achieved if the surrounding wall is removable.

Operation, speed and time

It has been found through experience that this centrifuge produces the best casts at baskets speeds close to 300 rpm for a duration of 1 to 1.5 minutes. Due to the 4:1 ratio of crank handle pulley to spindle shaft pulley the operator needs to crank the handle about one revolution per second. The centrifugal force

FIGURE 2: Centrifuge drive train assembly. The large drive pulley turns on a slotted belt tensioning mount.

required to displace the trapped air is not necessarily great. Too much force, from high rpm, or excessive time may in effect separate any additives in the resin, such as tinting pigments. Experience is valuable in this case. Note, significant undercuts in the mold will trap and retain air pockets in the cast if the air has no escape route.

Spindle and bearings

The central spindle is held in place by two inexpensive flanged ball bearing units, centrally located in the metal frame and the plywood base. A variety of bearing types are available, so feel free to experiment. An appropriate sized hole is drilled into the frame and plywood base. In this case the top bearing was fitted in place first and an oversized hole was drilled in the plywood base. Doing this allows easier alignment of the lower bearing support, which is a metal plate bolted to the plywood base. A plastic

FIGURE 3: Centrifuge baskets.

shield was made to fit over the lower bearing so to keep any stray resin from entering the bearing.

Wall and lid

The purpose of the wall and lid is to contain any excess resin that may be slung out of the molds and to protect the operator and surrounding area in case of accidental breakage of other parts. Initially this centrifuge was surrounded by 1/8 inch flexible plywood, scrap from the museum woodshop. This was later reinforced with galvanized sheet metal after one of the baskets broke loose and punched a hole in the plywood. It is wise not to underestimate the force that can be generated within the system! Quarter-inch thick acrylic (or polycarbonate may be used) was cut to cover the centrifuge to permit observation of operation, retain flying resin, and prevent anything from falling into the centrifuge. The wall is attached to the plywood base using plywood cleats cut to match the curvature of the wall. A similar piece is cut to fit the top of the wall, to which the acrylic lid is attached.

Conclusions

Due to the experimental design for this centrifuge it was constructed from mostly scrap materials to save on expenses. It was found that this design has been quite functional and durable and so would probably justify purchasing new materials for construction.

Acknowledgements

Thanks go to Dr. William J. Sanders, who continually harassed me in the first place to make this contraption, and now wants a bigger one. Dr. Sanders has used this centrifuge for several years and has provided helpful input into its design and feedback on its success. Tyler Keillor provided a helpful review of this manuscript.

PACKING METHODS FOR DOMESTIC AND INTERNATIONAL FOSSIL SHIPPING

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Abstract

During the summer of 2006 and the spring of 2008, Augustana College shipped fossils to three separate destinations. Remains of the holotype specimen *Cryolophosaurus*, a prosauropod, and capitosaur, along with plant material, were shipped to Tokyo, Japan. This fauna was the focus of an Antarctic exposition at the National Science Museum in Tokyo. Therefore, the safe packing of these vertebrate fossils for overseas transport was vital for the future study of these remains and for the success of the exhibit. Vertebrae belonging to the holotype specimen of *Cryolophosaurus* from the Lower Jurassic Hanson Formation of Antarctica were later sent to Research Casting International in Trenton, Ontario (Canada) in March of 2008. Casting of a new vertebral column based on specimens recently prepared since its original casting in 2002 was the goal of this shipment. Several of the twenty-one vertebrae sent have very thin and delicate post- and prezygapophyses preserved, and the safe arrival of these specimens was critical. A labyrinthodont skull from the Triassic Fremouw Formation of Antarctica was also shipped (domestically) during April of 2008 to Washington State for collaborative research purposes. This amphibian skull is extremely thin in areas and required extra attention in packing to insure no damage would occur during the shipping process. The safe packing of these vertebrate fossils for international and domestic transport was vital for the future study of these remains.

The fossils were packed in boxes constructed of ½ inch foamcore board with an interior of G-60 foam to help contour to the shapes of the individual fossils. The delicate and less robust vertebrae of *Cryolophosaurus* along with the labyrinthodont skull were enclosed within individual clam-shell cradles constructed of a/c foam, Ethafoam and plaster. The remaining fossils were wrapped in a protective soft sheet of Tyvek to act as an inert moisture barrier and placed within the box, to be followed by custom cut G-60 foam supports. The boxes were then placed within the interior of custom built plywood crates for shipment. These crates were transported to their individual destinations by shipping companies.

Hunt-Foster. 2009. Packing methods for domestic and international fossil shipping. In: Methods in Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 97-102. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

In the winter of 2006 Bill Hammer of Augustana College was approached to loan fossils from the Transantarctic Mountains to the National Science Museum of Tokyo for an exhibit focusing on research efforts in Antarctica. The fossils needed to be appropriately packed and crates had to be constructed for the journey to Japan and back. The investigation into the crate building process revealed much that we were unaware of regarding the guidelines and standards that one must meet to have wood crates certified for exportation. Ultimately, the decision was made to have the crates fabricated by an outside agency. The crates were fabricated by Icon Group, Inc. and packed by the author and the group. The fossils arrived at their destinations unscathed with no incidents. These same methods were again followed in 2008 to send two separate shipments of fossils successfully to their individual destinations, making the packing methods described here a success.

Methods & Materials

Crating—During the initial investigation of shipping wood crates overseas, our attention was brought to a set of guidelines that the crates must meet for wood packaging material (WPM). The fabrication of wood crates for overseas importation must adhere to set guidelines by the United States Department of Agriculture's National Plant Protection and Quarantine (PPQ) Organization a program within the Animal and Plant Health Inspection Service (APHIS). Regulations set by APHIS for WPM that are imported into the United States of America (through 7 CFR 319.40) include logs, lumber, and other unmanufactured wood articles. There are two official export treatment and marking programs used to meet the standards of countries with import requirements based on the International Standards for Phytosanitary Measures —Guidelines for Regulating Wood Packaging Materials in International Trade (ISPM15). Phytosanitary measures are defined as "Any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests" (FAO, 2002). The implementation date for enforcement of the ISPM15 regulations began September 16, 2005. Heat Treatment (HT) and the Methyl Bromide (MB) Fumigation Programs must be applied to untreated wood if it is intended for international travel and must be marked by a certified inspection agency. This can be both a costly and time consuming venture.

It was discovered during the course of this investigation that most of the wood one can purchase at your average chain home improvement store already has been appropriately treated, unless otherwise stated. This obviously should be checked before acquisition. Due the added cost of self-fabrication of the crates, we chose to have the crates for the trip to Japan constructed by a certified shipping agency, Icon Group, Inc. We were introduced to this shipping company by our associates in Japan, as they had past experience working with them. A quick internet search of "fine art shipping/museum shipping/ custom packing & crating/ crate construction/crate shipping" with your specific location will often yield results in your area.

The crates were constructed from a double-sided medium density overlay wood panels with plywood facing, full batten construction, bolt plates, with silicone caulk seals on the interior seams to prevent moisture entering the cavity, as well as a gasket to seal the lids, handles, tray-packs and forklift skids. The crate interior has custom 2¼ inch thick Ethafoam padding to secure the internal foam boxes that contain the fossils and absorb any shock from transit (Fig. 1). The wood used to build the crates was pretreated and therefore did not require the certification mark.

There are several other ways to avert issues that may arise for using non-treated wood, including fabricating your containers from a non-wood product. Past methods employed have included the use of aluminum, styrofoam, plastic and prefabricated shipping containers (K. Carpenter, personal comm., 2006; P. Viegas, personal comm., 2006). It has also been suggested that "plastic wood" made from 100 post-consumer HDPE (high-density polyethylene) could be used for crate building (B. Amaral, personal comm., 2006). At the current time this can only be purchased as lumber and not in sheets. HDPE is also susceptible to warping and bowing with heat, bringing the structural stability of a heavy load into question (J. Mason, personal comm., 2006). Hopefully advances in technology will help to make this

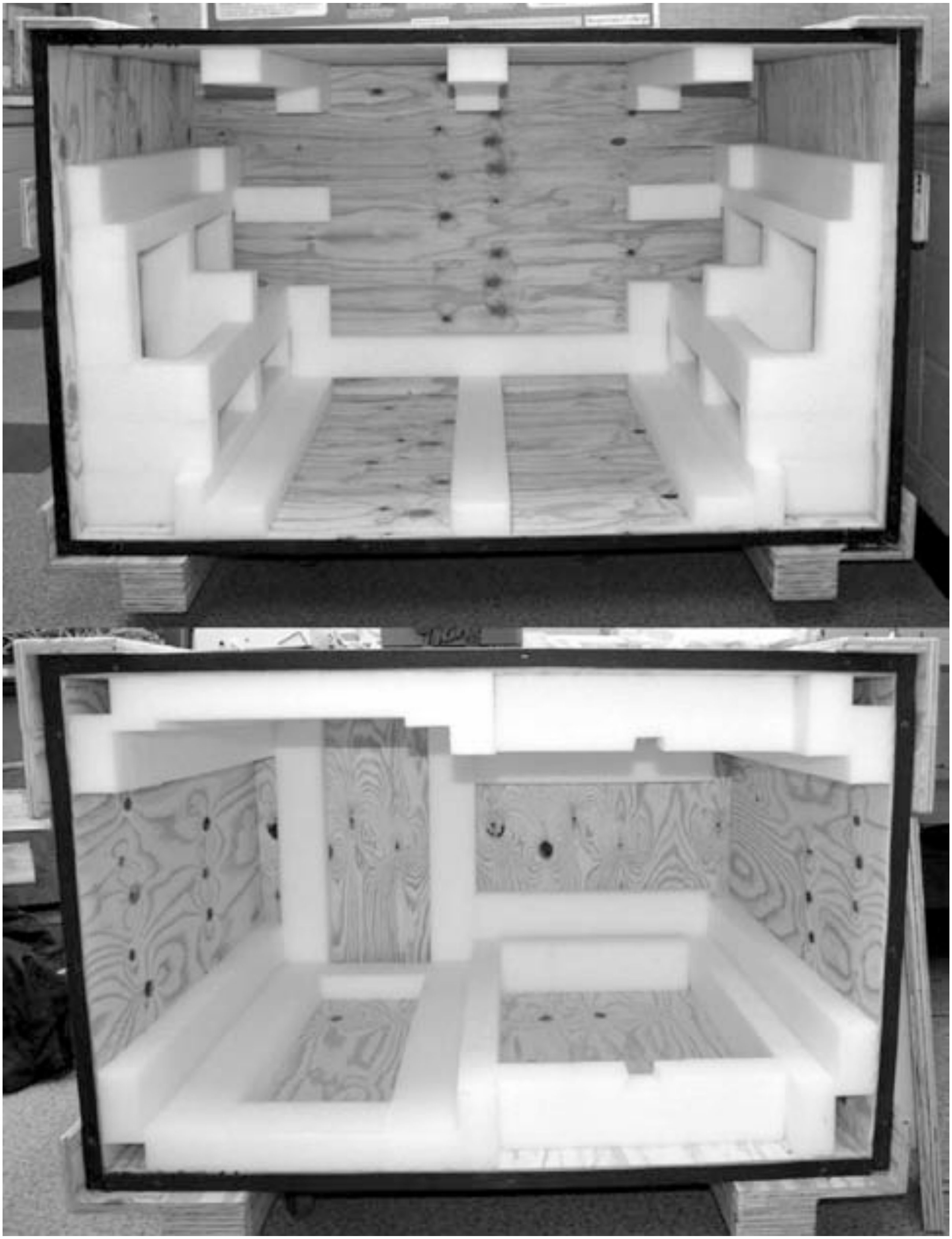

Figure 1: The two crates fabricated by Icon Group, Inc. Internal view shows lid gasket and ethafoam padding used to secure the foam boxes.

Figure 2: Fossils packed in a foamcore box, surrounded by G-60 foam separators and bedding. Fossils are then wrapped in a protective sheep of Tyvek to act as a moisture barrier and then surrounded with additional G-60 foam to keep movement to a minimum and to protect the fossils from breakage.

environmentally friendly alternative more structurally stable for use in a high range of products.

Crates assembled for the 2008 shipments were modeled after the crates used in the 2006 shipment. ¾ inch plywood was used for the crate sides, top and bottom, while crossbeams of 2x2 lumber were used to give added support. During the construction of these crates it was discovered that the 2x2 lumber purchased was warped and not adding the extra strength required. The substitution of 1x2 in place would be sufficient and less bulky, although not necessary in our case. In the end we chose to construct our 2008 crates strictly from plywood. Metal handles were affixed to the outside of the crate for easy carrying. The tops were affixed using screws only. No hinges were added to the lid in these cases, although repeated use of crates could benefit from their presence.

Packing

The fossils were all packed in boxes constructed of ½ inch foamcore board with glued and taped seams, and a hinged lid that is secured with velcro tabs (Fig. 2). The interiors of the foamcore boxes were lined with softer charcoal colored G-60 foam to help contour to the shapes of the individual fossils. The fossils were then wrapped in a protective soft sheet of Tyvek to act as an inert moisture barrier and placed within the box, to be followed by custom cut G-60 foam supports. The boxes were placed within the interior Ethafoam padding of the crate (Fig. 3). Another method considered for this project consisted of wrapping the small to medium sized fossil material in foil to insure that any breakage would be held in place during shipping. The use of styrofoam peanuts (contained in separate bags), bubble wrap, clamshell jackets and sturdy boxes to ensure stability during the shipment were also considered as possible alternatives, along with expanding liquid foam that sets up rigidly and contours to the individual fossils. All of these methods have been used successfully in the past by various other parties (J. Cavigelli, personal commun., 2006; M. Fox, personal commun., 2006; J. Mason, personal commun., 2006; B. Woodward, personal commun., 2006). Including information that include photos and step-by-step instructions for packing and unpacking of crates is strongly encouraged. This practice was not used for the 2006 shipment to Japan, since the author was present for the packing and unpacking of the crates. Photography is also greatly encouraged for specimens are they are being packed and unpacked to document the condition of the fossils prior to shipping and upon arrival to their destination.

Results

The crates received very good attention during the shipping process and no damage was done to the fossils or the crates themselves during the Japan and Washington shipments. This method of packing has proved to be successful for the transportation of multiple types of fossils. The shipment to Canada experienced some breakage to the delicate pre-zygapophyses to the

Figure 6: Foamcore boxes secured within the crates.

Cryolophosaurus vertebrae, although no damage had occurred to these same specimens during the 2006 shipment to Japan. Packing methods may be reconsidered if these specific delicate fossils were shipped again, with one of the possible alternatives such as clamshell jackets considered to preserve these delicate remains.

Acknowledgements

The entire paleontology preplist for their continued support and assistance – particularly Jane Mason, JP Cavigelli, Matt Brown, Brett Woodward, Greg Brown, Scott Madsen, Don DeBlieux, Pete Reser, Bill Mueller, Marilyn Fox, Bill Amaral, Jim McCabe, Ken Carpenter, and Pedro Viegas. I would also like to thank Bill Hammer for allowing me to accompany the fossils to and from Japan; Icon Group, Inc.; Patrick La Quaglia at Masterpiece International, Chicago office; Chisako Sakata, Shin-ichi Fujiwara, Makoto Manabe, Reiko Horikoshi and the The Asahi Shimbun; Christian Sidor and Bruce Crowley of the University of Washington and the Burke Museum of Natural History; and Peter May and Norman Markland of Research Casting International Ltd. A review by Pete Reser greatly improved this manuscript.

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RAPID IN-HOUSE DESIGN, CONSTRUCTION, AND INSTALLATION OF A TRIASSIC PALEONOTOLOGY EXHIBIT HALL AT PETRIFIED FOREST NATIONAL PARK, ARIZONA

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Abstract

Petrified Forest National Park preserves an amazing assemblage of Late Triassic Chinle Formation vertebrates, invertebrates, and plants. Recent iterations of exhibited material in museums and visitors centers included elements of text and graphics last updated in the 1950's and 60's, some of which had become grossly inaccurate. Modernization of the exhibits space was therefore critical to expand the park visitor's education and entertainment experience, and to fulfill our responsibility to communicate the scientific resources of the park.

Utilizing primarily existing resources, we endeavored to complete this project as quickly and at as low a cost as possible, while maintaining professional output and a high standard of accessible scientific content. Design work was accomplished with popular computer software packages, while text, graphics, printing, mount fabrication, and landform construction were all done in-house. Installation took place in phases, so that the museum could remain open with limited disruption to visitors.

Keywords: Exhibits, In-house, Interpretation,

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Introduction

Petrified Forest National Park (PEFO) was established in 1906 to preserve fossils from the Late Triassic Period. Over the last century, more than 700 academic papers have been published describing and analyzing a diverse terrestrial paleoecosystem. Over that same period, visitors have been exposed to a wide range of information explaining with varying accuracy the breadth of both research and resources within the park boundary.

Methods of information dissemination have included signs, waysides, ranger presentations and guided tours, site bulletins, virtual tour kiosks, museum exhibits, websites, videos and filmstrips, and the sale of books by the park's cooperating association. At times, that information has variably supported current scientific thought, or has not reflected the modern research of the time. As generations of staff turned over, incorrect elements have lingered, contradicting modern views of the resources. An egregious example of this was the display at the Rainbow Forest Museum located near the southern end of the park. Exhibits contained inconsistent presentations of key information from five decades of revisions. Some were correct; some misrepresented the science; and some presented a fossil specimen with no identifying labels or associated data (Fig. 1). Results of a recent social science study interviewing 60 visitors at the Blue Mesa portion of the park demonstrated that visitors have little to no understanding of the geological history of the park especially regarding the depositional and erosional processes that formed the present park landscape (Bueno-Watts, 2007). Informal conversations between park staff and visitors indicated similar confusion about the paleoecology as well.

In 2003, park staff decided to renovate the exhibits to eliminate the inconsistencies and enhance visitors' appreciation of the park's paleontologic significance by presenting accurate technical information and a wider variety of better preserved paleontological specimens from park collections. This project quickly evolved into a redesign of much of the building interior. Implementation of design plans was to be phased, beginning with the construction of a small theater (completed in 2005), establishment of a 525 square foot exhibit hall featuring vertebrate paleontology (completed in 2007), followed by a paleoecology hall and a geology hall (both in progress).

Museum exhibit development is often an extremely costly, time consuming process involving numerous staff and contractors. Costs of even small exhibits sometimes run into the millions of dollars and are completed after several years of planning and implementation. When planning and construction of the second phase of the Rainbow Forest Museum exhibit project, the vertebrate paleontology hall, began in December of 2006, a budget and timetable for completion had not yet been established, despite three years of discussion for exhibit spaces. At the outset of the project the authors established a deadline of February 9th for installation of wall mounted cases, and planned to complete the landform the following month. We estimated supply costs totaling below $3000 USD. The park Superintendent set an absolute deadline for completion at April 16, 2007. This paper discusses our methods in producing a professional, informative exhibit in-house, in under three months, for minimal cost.

Methods and Materials

Interpretation in the National Park Service

The philosophy of communication called Interpretation, as espoused by the National Park Service (NPS,) differentiates itself from traditional education, as having the mission to communicate ideas and themes rather than facts (Ham 1992). As defined by Tilden (1957:8), interpretation is "an educational activity which aims to reveal meanings and relationships through the use of original objects, by firsthand experience, and by illustrative media, rather than simply to communicate factual information". Therefore, in developing an exhibit for an NPS unit, careful consideration is taken to present scientific data in an accessible, interpretive manner. While the vertebrate paleontology of the Petrified Forest is indeed complex, and may seem imposing at first, we felt that the subject matter remains eminently explicable and wished to reflect that in exhibit content. The goal is to provide layers of information so that every visitor regardless of their familiarity with Late Triassic vertebrate paleontology (or lack of) gains information about the park's paleontological resources. This may appear to be at odds with accepted Interpretive practice, which calls for presenting a minimum of facts, and only when

FIGURE 1: Exhibit hall prior to renovation.

necessary to explain the resource themes (Tilden, 1957). However, a topic as rich as 10 million years of Late Triassic ecological change requires very well organized and thorough fact based information to interpret it effectively.

Creating Themes

Fossil Vertebrate Hall—The first step in design was choosing prominent and essential themes that represent the vertebrate paleontology of PEFO. Discussions with visitors and staff show that they commonly misidentify all of the Triassic vertebrates as dinosaurs (or crocodiles in the case of phytosaurs), even though dinosaurs are rare components of most North American Triassic faunas (Nesbitt et al. 2007). In fact, only two genera of dinosaurs are known from the park (Parker et al. 2006). The majority of taxa represent dozens of species of pseudosuchian archosaurs, therapsids, temnospondyl amphibians, and fish. Also, while phytosaurs superficially look crocodilian, they are only distantly related and possess key characters of the skeleton which effectively separate them from crocodylians (Camp, 1930). Therefore explaining the differences between these groups became one primary theme.

In order to reflect modern scientific research within the park, we chose to present the vertebrate fossils within the motif of phylogenetic systematics, as used successfully in both the Evolving Planet exhibit at The Field Museum in Chicago and the Hall of Fossil Vertebrates at the American Museum of Natural History. Explaining how one group of animals was related to another, helped by the analog of a genealogical family tree, became a second theme. Accordingly, it is also important to explain that the visitor is related distantly to all of these Late Triassic vertebrates.

Finally, explaining the process of science itself became a third thematic element, illustrated by the discovery of new material from the pseudosuchian *Revueltosaurus callenderi*. Recognized prior to 2004 only from isolated teeth, *R. callenderi* was identified as an ornithiscian dinosaur, but reclassified after the 2004 discovery of a quarry containing numerous individuals (Parker, 2005). Demonstrating ready acceptance of changing lines of evidence and resulting conclusions is an important component in explaining the scientific process to a lay public.

Text and Case Layout

The final plan for the hall called for seven wall mounted cases containing specimens, graphics, and text. One small freestanding case contained a partially prepared, incomplete phytosaur skull, as a demonstration of fossil preparation methods. Another large freestanding case contained a 1.4 meter long cast skull of the phytosaur *Smilosuchus gregorii*, and mounted cast skeletons of the rauisuchian *Postosuchus kirkpatricki*, the aetosaur *Desmatosuchus spurensis*, and the dicynodont *Placerias hesternus*, which were mounted on a sculpted landform.

The dynamic nature of paleontology requires constant updating of exhibit information to maintain continued relevance, and using an easily replaceable paper backdrop allows for inexpensively keeping the exhibit current and professional in appearance. All case backgrounds, which included text and graphics, were composed using the Adobe software packages Photoshop 7 and Illustrator 10. The backgrounds were then printed with a Hewlett Packard 48” plotter, on heavy matte paper rolls. Cases were outfitted with UV resistant acrylic vitrines, to protect both the specimens and lengthen the life of the backgrounds (Pretzel, 2003).

The first wall mounted case presents the two genera of dinosaurs, and the second illustrates and explains the morphological differences between the dinosaurs and the other vertebrates in the exhibit hall. The following five taxon-specific cases demonstrate the relationships between the rest of the vertebrates in the exhibit. A cladogram is used to figuratively illustrate that not only are abstract groups of animals connected through evolutionary descent, but also that the actual specimens representative of those animals are evolutionarily tied to one another.

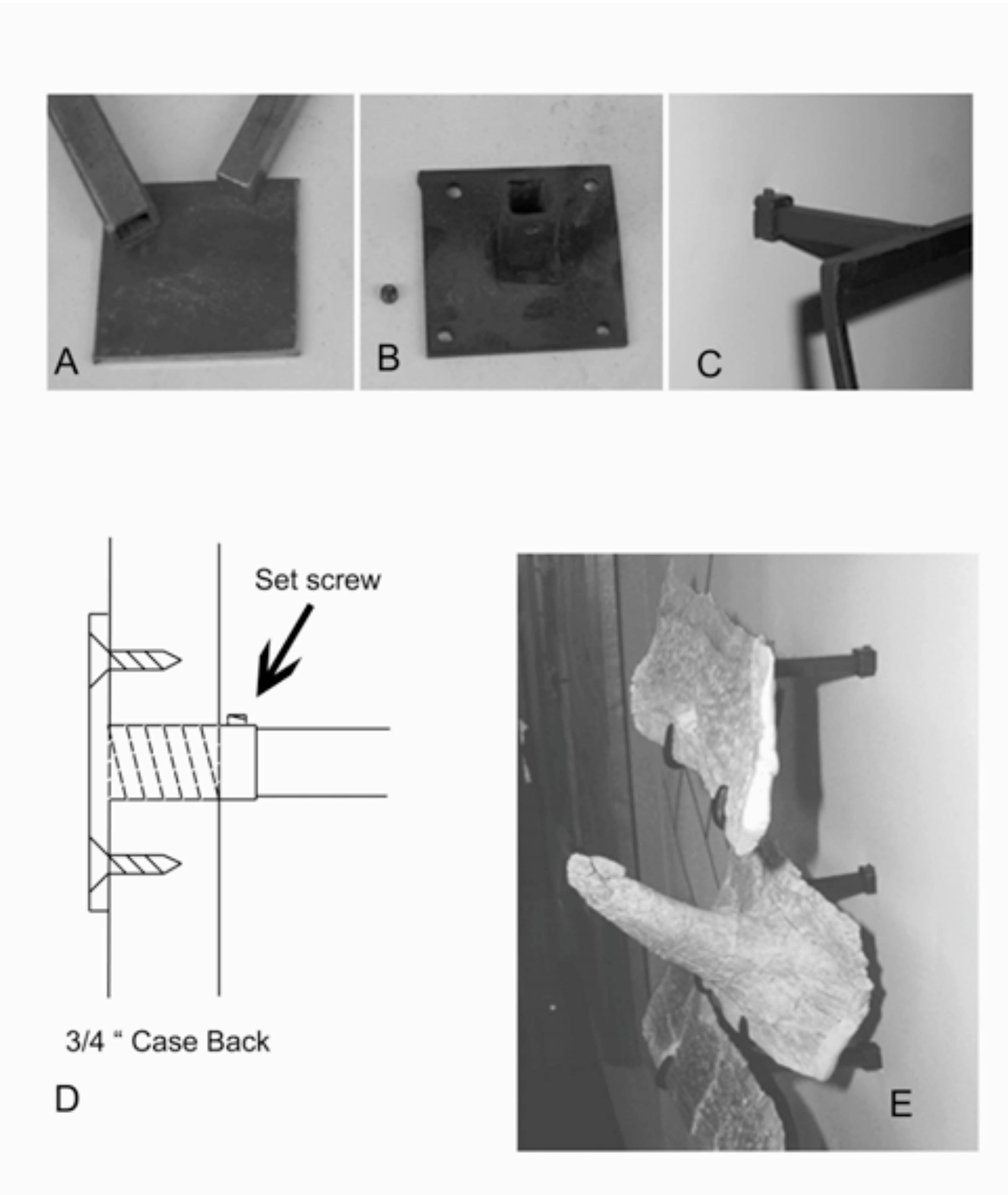

FIGURE 2: Creating mount for specimen armature system. **A.** Components for mount- 1in long square tube stock, 2x2 in backing plate, armature post **B.** Tube stock welded to backing plate, mounting holes drilled, and set screw threaded **C.** Socket mount protruding from case back with armature mounted **D.** Cutaway illustration showing backing plate mounted to case back, set screw holding armature in place **E.** Detail of aetosaur plates suspended in armature.

Construction and Installation

Wall mounted cases— Fossil specimens are displayed by means of an armature mount projecting through the case back, suspending the element in space (Fig. 2). Cast specimens are similarly supported with a single steel rod threaded into the cast, and friction fit into a hole drilled in the case back. Armatures were hand forged and welded together, and all metal work was painted with 100% acrylic paint, to conform with NPS museum and collections standards. (NPS *Museum Handbook*, Part III, 2001:38) The paper case backgrounds are razor cut to accept armatures passing through them, and the paper is actually held in place by the lid when closed. Updating of exhibit content due to changes in the science, or changes in the goal of the exhibits can take place quite rapidly. Case background files are stored on the PEFO intranet server, and can be modified and reprinted by exhibits staff. Backgrounds can then be changed out in an average of 20 minutes per case. Specimens can also be rotated out of cases easily, both by reusing existing armature socket locations, an instant solution, or removing the entire case from the wall, which might take two hours start to finish. All specimens are inspected for damage on a regular basis (Pretzel, 2003).

Reading rails—Informational text was included outside of the main cases supplementing the main concepts with in-depth information about cladistics, historical geology, and geologic time. For those text panels, 48"w x 18"h angled "reading rails" were constructed out of plywood and oak veneer. The text panel was printed, installed on the angled face, and then a sheet of antiglare acrylic was secured over it, fastened with brass screws.

Landforms—Landforms were constructed using 2"x12" lumber as joists, and ½" OSB plywood for decking. Expanded polystyrene (EPS) foam sheets were affixed to the deck, and then carved to simulate a rocky substrate. The EPS was then covered with synthetic stucco sold under the brand name Dryvit™. Dryvit™ can be ordered pre-pigmented and in a variety of textures. Dryvit was applied with a trowel. First, a thick, chunky, white basecoat was put down to create the appearance of a weathered clay rock outcrop. Next, a thinner mixture of pigmented sandy brown Dryvit was applied as a durable finish coat, to attain the desired texture and color. The finished product is resistant to light traffic, enabling easy dusting or repair of cast specimens, yet is still enclosed behind a railing to keep all but the most determined visitors from damaging the landform or casts. The railing was constructed of 1¼" gas pipe line recycled from a demolished park structure. Contours were measured and formed using a standard manual pipe bender, angled upright supports were welded to the pipe, and each upright was bolted to the 2" x 12" landform joists.

Conclusion

All project goals were met, and our expectations for the quality of the final product were exceeded. Most materials costs and time commitment on this project were very low, supplies did not exceed $2000 USD, and cumulative employee time was approximately 1040 hours, equivalent to six months of one employee, including the efforts of all Resources Management, Interpretation, Maintenance and Administrative staff. Planning and implementation began in earnest in December of 2006, and final installation of the wall mounted display cases was completed on schedule in February of 2006. The landform was completed the following month (Fig. 3). Exceptions to the low costs were the exhibit cases, which were purchased for $76,000. However, equivalent cases could easily be built in-house for a small fraction of that price. The three mounted specimens were created and purchased in the 1980s, so the only cost to this project was the time and materials in reassembling one cast that had fallen apart. Some materials were recycled from other park projects, such as landform barriers, which were segments of natural gas pipeline salvaged from demolished park buildings. The Dryvit synthetic stucco was excess material from a PEFO housing exterior project. Many of the tools used in the process were already present in the PEFO fossil preparation lab and Maintenance workshops.

The exhibit hall is now used by science and educational staff to help visitors, volunteers, students, and staff understand the breadth and importance of PEFO paleontology. Educators bring primary and secondary education classes through the exhibit, park paleontologists use the information as an introduction

FIGURE 3: Exhibit hall after installation of wall mounted cases, landform, and mounted skeletons.

to new staff and volunteers, and existing staff members have expressed a more thorough understanding of park resources. A formal survey of visitor experience has not yet been implemented, and is strongly recommended. The majority response during informal discussions with visitors indicates that the exhibit content is informative and interesting, and that visitors understand more about the themes than they did prior to visiting the exhibit.

Some variation of these techniques can be used very effectively in the future at PEFO, and easily apply to any other institution with access to limited resources, or adopted to further stretch a large budget.

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A REPORT ON A MINI-SEMINAR ON ADHESIVES FOR FOSSIL PREPARATION

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Abstract

The Fossil Preparation and Collections Symposium held at Petrified Forest National Park, Arizona on April 10-12, 2008 afforded an opportunity to develop and test a "Mini-Seminar on Adhesives for Fossil Preparation." This report describes the evolution from a short talk to the Mini-Seminar format and then a later day-long workshop. 16 preparators responded to a pre-symposium quiz designed to tailor the Mini-Seminar. Two main "take-home" points were focused on: 1) the importance of knowing the difference between solution and reaction adhesives. 2) the importance of using accurate names for adhesives. The goal of the Mini-Seminar was to communicate these in a reasonable amount of time. Limiting the subject matter and length of the Mini-Seminar proved to be a challenge. Basic points were conveyed but the amount of information that could be absorbed and retained by the participants from this verbal format was limited. The need for hard-copy reference materials tailored for fossil preparation is discussed. Appendices include quiz questions and responses, a list of Mini-Seminar reference materials and a description of the subsequent one-day workshop.

Davidson, A. 2009. A mini-seminar on adhesives for fossil preparation. In: Methods In Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium, pp 111-122. Brown, M.A., Kane, J.F., and Parker, W.G. Eds.

Introduction

Vertebrate Paleontology, more than any other biological science, depends on adhesives. While much information is available about adhesives, very little is tailored specifically to vertebrate fossil preparation. The resources available to conservators through the literature, courses and workshops include much that is not directly relevant to fossil preparation and at the same time tend to skim over important basic details that are assumed to be already understood.

Over the last 13 years I have worked individually and in collaboration with conservators at the American Museum of Natural History to develop an informed approach to adhesives for fossil preparation. This has resulted in a number of 15 minute talks and also posters presented at the annual meetings of the Society of Vertebrate Paleontology (hereafter SVP) (Davidson 2002, 2003, 2004, 2006; Kronthal, 2005, Levinson 1996 and 1996), the Society for the Preservation of Natural History Collections, the American Institute for the Conservation of Historic and Artistic Works (Bisulca 2008, Davidson 2003) and other venues. Talks at the SVP 2003 and 2004 meetings in particular were intended to be a three part series on adhesives as liquids, through phase change and as solids.

While the 2003 SVP talk did not engender much interest, the 2004 talk was well received, with multiple requests for copies and repeated presentations. The Fossil Preparation and Collections Symposium held at Petrified Forest National Park, Arizona (hereafter PEFO), on April 10-12, 2008, afforded an opportunity to expand this into a one-hour "Mini-Seminar on Adhesives for Fossil Preparation." In the end this ran overtime, to 90 minutes, a problem discussed later. Subsequent to the PEFO Symposium, a presentation at the Royal Tyrrell Museum, Canada, provided an opportunity to expand it further into a one-day format. In the following the evolution of the presentation is described.

Expanding a 15 minute presentation

The 2004 talk was entitled "From Liquid to Solid and Back: Phase Change in Adhesives." It compared solution adhesives (e.g. Butvar B76 and Paraloid (Acryloid) B72), which set by the evaporation of a solvent, with reaction adhesives (i.e., epoxies and cyanoacrylates) which set by chemical reaction. This talk used hand-drawn illustrations of behavior on a molecular level (basic chemistry) to explain the following:

1) Why solution adhesives are weaker, soluble and easier to remove.
2) Why reaction adhesives have great adhesive and cohesive strength, are insoluble and are more difficult to remove.
3) Why, when employed as consolidants, solution adhesives tend to set near the surface whereas reaction adhesive have a greater ability to penetrate and set deeper.

In addition it used specific examples of porous, weak fossils from the Gobi Desert (Cretaceous) and hard, dense fossils from Greenland (Triassic) to illustrate the importance of choosing between solution and reaction adhesives.

The greatest challenge in expanding this talk was limiting the scope of the subject matter. The most frequently asked question in fossil preparation is "what glue should I use on this specimen?" The answer is "it depends." All adhesives have appropriate and inappropriate uses in fossil preparation but the assessment of individual specimens and specific applications is a topic too complex to be addressed in one hour.

It is my opinion that making educated choices between solution and reaction adhesives and also using accurate names are fundamental first steps in selecting the right adhesive for the job at hand. Therefore, a choice was made to focus the Mini-Seminar on two "take-home" points:

1) the importance of knowing the difference between solution and reaction adhesives.
2) the importance of using accurate names for adhesives.

The goal of the Mini-Seminar was to communicate this effectively and the greatest obstacle to achieving this goal was the difficulty of "sticking to the point" (and avoiding glue jokes!).

Pre-Symposium Reference Materials— Some reference materials were provided in advance of the Symposium (Appendix 1). This included a recommendation to purchase the excellent self-teaching series "Science for Conservators" which was the primary source of information for the 15 minute Powerpoint© presentation.

A Pre- Symposium Quiz— A request for a voluntary response to a short quiz (Appendix 2) was sent to participants in advance of the PEFO Symposium. The request was later posted on the PREPLIST preparators' e-mail discussion list to include non-participants. This quiz was designed to:

1) find out what adhesives the participants are using.
2) identify any particular confusion about setting mechanisms.
3) coach the respondents to use accurate names.

Sixteen preparators responded to the quiz. A compilation of their adhesives is shown in Appendix 3.

Of the 16 preparators, 12 use both solution and reaction adhesives, two use only solution adhesives, and two use only reaction adhesives.

Regarding setting mechanisms, most of the questions were answered correctly but there was significant confusion about how cyanoacrylates (CAs) set, and some confusion about other adhesives in the following responses:

CAs do not set by the evaporation of a solvent or by chemical reaction. They set by exposure to water molecules in the air, according to one response.

CAs bond by chemical reaction but not sure of the mechanism - one response.

CAs bond by a combination of chemical reaction and solvent evaporation - one response.

CAs set by the evaporation of a solvent - two responses.

CAs air dry on their own (set by the evaporation of a solvent), but when an accelerator is used it sets by chemical reaction - two responses.

Epoxies bond by solvent evaporation - one response.

Not sure how Elmer's Glue© sets - evaporation of water? - two responses.

Durham's Rock-Hard Water Putty© sets by the evaporation of a solvent - one response.

Duco© cement may set by chemical reaction and solvent evaporation - one response.

Regarding names, it is obvious from the responses compiled in Appendix 3 that, while most of the adhesives are accurately identified, quite a few answers are vague and confusing despite the coaching in the quiz instructions. This confirmed my view that these respondents would have difficulty discussing the adhesives they and others are using.

In retrospect, it would have been better to include instructions to identify each adhesive by chemical family in addition to the commercial brand names, etc., since chemical family names are very useful for accurately identifying adhesives, especially in combination with the commercial name and grade (e.g. PVAC Vinac B15).

The 90 minute PEFO adhesives mini-seminar

The Mini-Seminar was attended by 42 people, half of them professional fossil preparators and half highly motivated volunteers. It was organized into four parts:

Part one: Powerpoint presentation - "Liquid to Solid and Back: Phase Change in Adhesives "(as previously described).

Part two: Questions for the Participants.

a) Naming Adhesives. The group was asked to make a collective list of what adhesives they use and taught to use complete and accurate names to identify products. The problems of confusing industrial grading systems (e.g. the various "B" grades), shifting manufacturers and changes in formulas were discussed using Powerpoint diagrams.
b) Classifying Adhesives by How They Set. The group was asked to classify the adhesives on the collective list as either solution or reaction adhesives. Powerpoint diagrams were used to explain polymerization and how cyanoacrylates and epoxies set.
c) A Long Group Quiz. The group was asked to respond to a list of questions about adhesives terminology, setting mechanisms, working properties and aging (physical and chemical changes over time) (see Appendix 4). About an hour had elapsed at this point which was too long without a break for many participants.

Part three: A Group Discussion of Adhesive Choice and Paraloid (Acryloid) B72. There was not enough time to cover the topic of adhesive choice adequately, but the intention of this section was twofold:

a) briefly touch on the many factors taken into consideration when choosing an adhesive, using a Powerpoint diagram.
b) discuss particularly the advantages of Paraloid (Acryloid) B72, especially its long-term stability. Paraloid (Acryloid) B72 was recommended as a "default" adhesive (i.e. if it can do the job, use it), which should be in stock in every lab and available for experimentation, along with acetone, ethanol and self-loading

tubes for applying thick solutions ("Koob Tubes" as described in Koob, 1986). A broken flowerpot was used to demonstrate the rapid bonding possible with thick Paraloid (Acryloid) B72 in acetone. This was an effective demonstration and breaking a flowerpot could be used to spark renewed interest for those with lagging attention.

Part four: Case Studies. A series of slides was shown of examples of adhesive failures. This required lowering the lights again and was the least effective part of the Mini-Seminar which was approaching 90 minutes at this stage. In retrospect this should have been cut out and the time limited to one hour, beyond which it is difficult to speak and for the participants to listen.

A subsequent one day adhesives workshop

The Mini-Seminar was effective at least in part, because directly afterwards I was invited by two participants, Jim McCabe, Senior Technician, and Brandon Strilisky, Acting Head, Collections Management Program, to teach a workshop on adhesives at the Royal Tyrrell Museum, Drumheller, Canada. In subsequent conversations it was decided that, in addition to repeating what was covered in the PEFO Mini-Seminar, the workshop should include archival marking (since labels depend on adhesion to the specimen) and archival housings (since these are an important alternative to gluing specimens back together). A day-long workshop entitled "Materials for Fossil Preparation (Adhesives, Archival Marking and Archival Housings)" was held on May 21, 2008, at the Royal Tyrrell Museum. Approximately 20 people participated, mostly professional fossil preparators and paleontological collections workers. The schedule is outlined in Appendix 5.

Conclusion

As previously stated, the goal of the Mini-Seminar was to communicate the important differences between solution and reaction adhesives effectively and also the need to use accurate names. I believe this goal was achieved although much could be streamlined and improved, especially in regard to amount of time necessary.

Participants seemed reluctant to criticize directly and an anonymous follow-up questionnaire would have been useful. It is my assessment that the participants "got" the take-home points enough to seek out additional information when needed. Months after the Mini-Seminar an exchange with one of the participants regarding a suspected mistaken purchase of Butvar B72 instead of Paraloid (Acryloid) B72 supports this assessment. The Mini-Seminar did not communicate the specific information necessary to answer the participant's question, but it did raise their awareness of problems stemming from inaccurate names.

The strong point of the Mini-Seminar was probably the 15 minute Powerpoint presentation, especially the hand-drawn illustrations, which received numerous favorable comments. In retrospect the following important topics should have been moved from Part 2b and incorporated into the Powerpoint:

a) polymerization.

b) a detailed description of the setting mechanisms of cyanoacrylates and emulsions (e.g. Elmer's Glue).

c) an explanation of undesirable crosslinking in solution adhesives over time.

Regarding time, in retrospect it is clear that expanding a quarter-hour talk to one hour is not the same as presenting four consecutive fifteen minute talks. There is a limit to what the participants can absorb and pushing that yields diminishing returns. Part three should have been abbreviated and part four should have been omitted. The group quiz (Part 2b) was too long and repetitive. One person suggested it be cut by one third. Perhaps some of the questions could be incorporated into other parts of the presentation.

One person commented that the results of the Pre-Symposium Quiz should be shared with the group, and several expressed particular interest in knowing what other people are using.

Two people said they would have preferred to be presented with a case study to discuss and then decide which adhesive to use. The idea of case studies is attractive but I believe they would be more useful for advanced audiences well schooled in adhesives. It is hard to have a useful discussion if the participants are not speaking the same language.

One person wanted a wall chart of useful adhesive properties (specifically not including glass transition temperature) as a quick reference for selecting an adhesive. I have often heard similar comments from frustrated preparators who just want to know what adhesive they should use. Selecting the right adhesive is not straightforward. It depends in part on an ability to evaluate the specimen and the job at hand. Using an adhesive successfully also depends on the skill of the preparator, something that requires a feel for materials that some people have and some do not, despite years of experience. This might be something that cannot be taught.

An understanding of adhesives can however be taught. Two participants wanted hard- copy handouts of the following Powerpoint diagrams used during the presentations:

Diagram 1. Summary of solution and reaction adhesive properties from liquid to solid.

Diagram 2. List of the many grades sold within four adhesive product lines.

Diagram 3. Outline of many factors which must be considered when selecting an adhesive: properties as a liquid, through phase change and as a solid over time, the job at hand and other practical considerations.

Hard-copy reference material would greatly improve the effectiveness of any presentation on adhesives. Ideally a workshop or course on adhesives for fossil preparation would be based on a reference text or a series of reference papers which cover the material in detail. With this in hand, the verbal, visual and interactive format of a speaker in front of a group could serve as a vivid introduction and the texts as the ultimate source of information.

It is my hope that this report will serve to aid and encourage anyone charged with teaching adhesives for fossil preparation.

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Appendix 1

Reference materials sent to participants in advance of the Mini-Seminar.

1) A PDF of "Adhesives and Adhesion" by Jonathan Thornton, professor of Objects Conservation at Buffalo State. Professor Thornton was on the advisory group of an American Institute for the Conservation of Historic and Artistic Works "Adhesives for Conservation" workshop held in September 2005 in Nebraska. As a participant I received his paper in advance of the workshop. It is written for conservators, with an emphasis on adhesives for use on wood. Fossil preparators use relatively few of the adhesives listed but this paper provides a good general overview on the use and classification of adhesives and could also be useful in identifying old adhesives used on fossils in the past.

2) A link to SPNHC Leaflet #2, Spring 1997
Adhesives and Consolidants in Geological and Paleontological Applications
Part One: Introduction, Guide, Health and Safety, Definitions
Part Two: Wall chart
This is available from the website for the Society for the Preservation of
Natural History Collections (SPNHC)
`<http://www.spnhc.org/?q=publications/leaflets.html>`

3) A recommendation to purchase all three volumes of Science for Conservators
Conservation Science Teaching Series, The Conservation Unit
Vol.1. Introduction to Materials
Vol.2. Cleaning
Vol.3. Adhesives and Coatings

These three volumes are an invaluable resource for the conservator and fossil preparator who want to teach themselves basic materials science. The books are clearly and simply written and must be read slowly in sequence from volume 1 to 3. Do not be fooled by the titles. Vol. 2 (Cleaning) includes important concepts such as solubility and Vol. 3 (Adhesives and Coatings) is of little use without the first two.

Appendix 2

A Short Quiz on Adhesives for Fossil Preparation sent to participants in advance of the Mini-Seminar.

What adhesives do you use on fossils in your lab and how do they set (solidify)?

Note: the term "adhesive" is used here to include all "glues", "sealants", "hardeners", "stabilizers", "fillers", and "consolidants".

List each one by name and be as specific as possible, using the commercial brand name and including any commercial grades, types, numbers or formulations in the name. Also include all components of any mixtures you have made.

You may choose from one of the following to explain how they set:

a) a chemical reaction.
b) the evaporation of a solvent.
c) other (explain).

For example:
Butvar B76 in acetone sets by the evaporation of a solvent
Devcon 2 Ton epoxy sets by a chemical reaction

Appendix 3

Adhesives Used on Fossils as Reported by 16 Preparators in Response to a Short Quiz (Appendix 2).

Solution Adhesives:

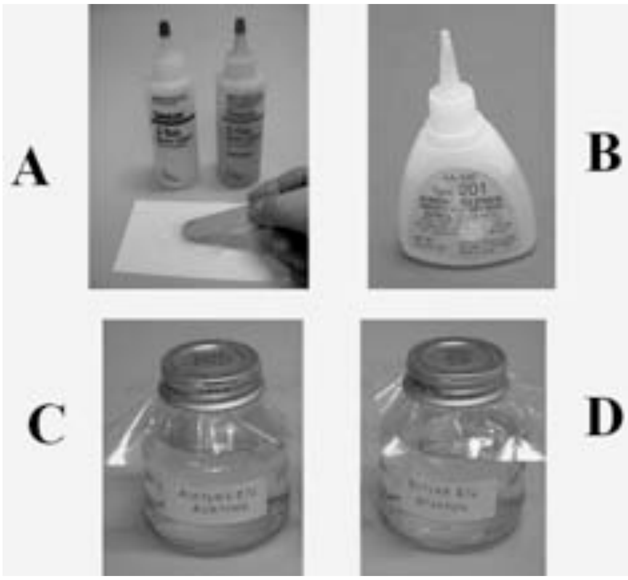
Adhesive	Report	Adhesive	Report	Adhesive	Report
Butvar B76	7	B67 (trade name unknown)	1	UHU All-Purpose Adhesive	1
B76 (trade name unknown)	2	Vinac B15	1	Elmer's Glue or School Glue	2
Butvar B98	1	Vinac B-25	1	Elmer's Wood Glue	1
B98 (trade name unknown)	1	Vinac (grade unknown)	2	White Glue (trade name unknown)	1
Butvar (grade unknown)	1	Poly n-butyl methacrylate	1	Archival Herbarium Glue (trade name unknown)	1
Paraloid (Acryloid) B72	5	Duco Cement	1	Sahara Brand Acrylic Masonry Sealer	1
B72 (trade name unknown)	1	Krylon Workable Matte Fixative	1	Acryl 60 (liquid admixture for cement)	1

Reaction Adhesives

Adhesive	Report	Adhesive	Report	Adhesive	Report	Adhesive	Report
Devcon 2 Ton Epoxy	5	Magic Sculpt Epoxy Putty	1	Paleobond 750	1	Super Glues (unknown trade names or grades)	1
Devcon 5 minute Epoxy	3	All Game Epoxy Putty	1	Paleobond 4540	1	Cyanoacrylate Glue (unknown trade names or grades)	1
West System Inc. Epoxy 105-B resin with 205-B hardener	1	Epoxy Paste (taxidermist putty) (unknown trade name)	1	Paleobond (thick gel) (grade?)	2	Zap Pink (grade?)	1
G5 Five Minute Epoxy	1	Wood Putty (unknown trade name)	1	Paleobond Cyanoacrylate (unknown grades)	4	Zap Green (grade?)	1
Epoxy 330 (trade name?)	1	Paleobond Penetrant/ Stabilizer	4	Starbrand Cyanoacrylate EM-02	1	Durham's Rock Hard Water Putty	2
Lamination Epoxy 110 (trade name?)	1	Paleobond 40	3	Starbrand Cyanoacrylate EM-2000	1	Hydrocal Plaster	1
Epoxy Resins (slow cure) (unknown trade names or grades)	1	Paleobond 100	3	3M Scotchweld Cyanoacrylate CA40	1	Gypsum cement	1
Keypoxy Putty 2 part EA1161 Resin and Hardener	1	Paleobond Paleosculpt	1	3M Scotchweld Cyanoacrylate CA8	1		

Appendix 4

A Long Quiz on Terminology, Setting Mechanisms, Working Properties and Aging.



A photograph of the following adhesives in their labeled jars/dispensers is shown:

A) Devcon 2-ton epoxy
B) Aron Alpha 201 cyanoacrylate (low viscosity)
C) Paraloid (Acryloid) B72 in acetone
D) Butvar B76 in ethanol

Terminology

1. C has two trade names- Acryloid /Paraloid. Explain why. Is it necessary to use both names?

2. C and D both have a "B" number after their trade name. Does this mean they are similar chemically? Why is it important to use both the trade name and the "B" number? Explain.

3. Which ones can be referred to as "glue"

4. Which ones can be referred to as solution adhesives?

5. Which ones can be referred to as reaction adhesives?

6. Which ones can be referred to in solid form as a polymer?

7. Which ones are solvent release polymers?

8. Which ones have a solvent carrier?

9. Which ones can be referred to in solid form as a resin?

10. Which one, in solid form, is a synthetic resin?

11. Which one, in solid form, is an organic resin?

Setting Mechanisms

12. Which ones are polymers in their solid state after they set?

13. Which ones contain polymers in their liquid state?

14. Are there any monomers in this picture?

15. Which ones set by crosslinking?

16. C and D each have two components. List them.

17. Could you switch solvents and make C with ethanol and D with acetone instead?

18. Which one will set faster- C or D and why?

19. Which ones shrink the most upon setting and why?

20. Which ones shrink the least upon setting?

Working Properties

21. Which ones could be used as an adhesive to join pieces together if appropriate?

22. Which ones could be used as a consolident if appropriate?

23. Which ones could be used as a coating if appropriate?

24. Which ones could be mixed with a filler (such as crushed matrix or another bulking agent) to fill gaps if appropriate?

25. Which one has the longest set time?

26. Name two ways to make D set faster.

27. Name two ways you could make C set slower.

28. Name two ways to increase the viscosity of D.

29. Name two ways you could increase the viscosity of A.

30. Some of these are difficult to apply as tiny drops because they set so fast. Which ones and why?

31. Which one has the longest working time as tiny drops and why?

32. How might very high or very low relative humidity affect the set time of B and why?

33. Is A soluble after it is set?

34. Is B soluble after it is set?

35. Are C and D soluble after they are set?

Aging (Physical or Chemical Change)

36. Which of these could be past its shelf life as a liquid? Can you tell by looking?

37. A is five years old but still sets when mixed. Is there a reason why you might want to discard it anyways?

38. Could D crosslink over time? How might you know?

39. Is it possible for a reaction adhesive to continue changing chemically after it is set?

40. Is it possible for a solution adhesive to change chemically after it is set?

41. Which one is most likely to remain unchanged over time and why do we think that?

42. Which one is most commonly used by conservators and why?

43. Name two adhesives which have been used on fossils in the past which often change physically and/or chemically with age.

44. Name four observable properties that indicate the adhesive used on a specimen has changed physically and/or chemically over time.

45. Which of these is particularly prone to yellow over time? Name three ways to minimize the chances of this happening.

46. Which of these is associated with the development of yellow or green staining shortly after use, and why?

Bonus Million Dollar Question:
What is the best adhesive to use on fossils?
(the answer is “it depends”)

Appendix 5

A Day-Long Workshop on Materials for Fossil Preparation (Adhesives, Archival Marking and Archival Housings)
held on May 21, 2008, at the Royal Tyrrell Museum, Drumheller, Canada.

10:00-10:45 am (in the classroom)
Participants introduced themselves.
Powerpoint presentation "Liquid to Solid and Back: Phase Change in Adhesives"

Break

11:15-12:15 pm (in the classroom)
Group quiz and discussion:

Naming Adhesives. The group was asked to make a collective list of what adhesives they use and taught to use complete and accurate names to identify products. The problems of confusing industrial grading systems (e.g. the various "B" grades), shifting manufacturers and changes in formulas were discussed using Powerpoint diagrams.

Classifying Adhesives by How They Set. The group was asked to classify the adhesives on the collective list as either solution or reaction adhesives. Powerpoint diagrams were used to explain polymerization and how cyanoacrylates and epoxies set. There was an extended discussion about 5 minute epoxy; how it sets, potential problems and why it is not recommended.

Additional Group Quiz. The group was asked to respond to a list of questions about adhesives terminology, setting mechanisms, working properties and aging (physical and chemical changes over time).

Choosing Adhesives. Powerpoint diagrams were used to discuss Paraloid (Acryloid) B72 as a recommended "default" adhesive. Exceptional cases were discussed.

Archival Housings. Examples were shown using Powerpoint as an introduction to the afternoon demonstration.

Recommended books on adhesives and other literature were available for perusal.

Lunch

1:15- 4:00 pm (in the lab)
Hands-on demonstration with samples:

Using Adhesives. Paraloid (Acryloid) B72 joins were demonstrated by me and Jim McCabe to compare methods for large and tiny joins. Also covered were techniques for making a good join in general. Methods for mixing, dispensing and storing B72 were demonstrated. The bulking of B72 and other adhesives with various fillers was discussed and demonstrated. Problematic specimens and the removal of adhesives were discussed.

Archival Marking. An archival marking kit and a reference poster on materials and techniques were introduced and marking was demonstrated, after which participants practiced making archival marks on sample material.

Archival Housings. The group was asked to consider archival supports as a possible alternative to adhering specimens together in some cases. A special technique using cut ethafoam, polyester batting, Tyvek© and thumbnail reference photos was demonstrated and participants had the opportunity to try this technique and keep samples for future reference.

ABSTRACTS

FIRST ANNUAL FOSSIL PREPARATION AND
COLLECTIONS SYMPOSIUM

Petrified Forest National Park
April 10, 11, 12 2008
Petrified Forest, Arizona

Platform

FOSSIL PREPARATION TEST: AN INDICATION OF MANUAL SKILLS

Bergwall, Lisa
Field Museum of Natural History

When interviewing candidates for preparation positions, Field Museum preparators issue a skills test to evaluate basic levels of manual dexterity. The test requires the candidate to prepare the tail fin of a Priscacara fish specimen. Preparation proceeds one ray at a time, from the relatively large base to the more delicate tip. While an inexperienced individual is not expected to be perfect immediately, the preparation test allows evaluators to gauge ability to adapt to new equipment, techniques, or specimens. Monitoring progress and, hopefully, improvement, over the duration of the test is informative, regardless of whether the interview is for a volunteer or staff position. After several years of testing, a comparative "library" of specimens can be amassed, allowing evaluators to compare early test results with the abilities of an individual after development, and establish a baseline for minimum acceptance.

Bergwall, L. 2008. Fossil preparation test: an indication of manual skills. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:5

Platform

MODERNIZING AMERICAN FOSSIL PREPARATION AT THE TURN OF THE 20TH CENTURY

Brinkman, Paul
North Carolina Museum of Natural Sciences

By the turn of the 20th century, the institutional setting for American vertebrate paleontology had shifted from private collections into large, well-funded, urban museums, including the American Museum in New York, Pittsburgh's Carnegie Museum, and the Field Columbian Museum in Chicago. This shift ignited a fierce competition among museum paleontologists to display fossil vertebrates – especially gigantic Jurassic sauropods from the American West. Museums launched ambitious expeditions aimed at collecting exhibit-quality dinosaurs. The net result was an enormous influx of unprepared fossils. Getting these fossils into shape for study and display posed a number of novel challenges for fossil preparators. New material arriving from the field required room for temporary storage and dedicated laboratory space in which to prepare it. Adapting a basic fossil preparation lab to the needs of dinosaur paleontology often involved considerable extra investment in equipment and space. Finding, training and retaining skilled fossil preparators could be very expensive, also. The sheer volume of work, and its unique demands, led to increased specialization and professionalization among the science support staff. This, in turn, drove higher standards for the work, leading to important lab innovations. Preparators developed new techniques to handle the workload, some of which required expensive new machinery, entirely new systems (e.g., electricity, or pneumatic apparatus) or new spaces in which to operate the equipment, some of which produced particularly noxious dust, noise, or smells. The essential task of fossil preparation, usually performed in backroom or basement labs by low-paid minions working in relative obscurity, was a vital prerequisite for the higher profile work of publishing original research and putting fossils on display.

Brinkman, P. 2008. Modernizing American fossil preparation at the turn of the 20th century. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:6

Platform

LESSONS FROM THE LAGERSTÄTTE: AN ASHFALL FOSSIL BEDS RETRSPECTIVE AND UPDATE

Brown, Gregory
University of Nebraska State Museum

Ashfall Fossil Beds in northeast Nebraska is a Miocene (Clarendonian) waterhole death assemblage containing fully articulated and associated skeletons of rhinoceroses, horses, camels, musk deer, birds and turtles preserved in death positions in volcanic ash. Subsequent to Ashfall's discovery in 1972, some of the fossils were excavated and removed to the Museum collections (1977-1979), some partially excavated and reburied (1988-1990), and others exposed, prepared in-situ and left in place under the protection of the "Rhino Barn", a structure providing limited control of environmental agents of deterioration (1991-2008). This thirty-year "experiment" has allowed us to observe differing modes and rates of deterioration and compare the efficacy of preservation strategies under various conditions. Collections made during the 1977-1979 field seasons, now housed in the University of Nebraska State Museum, present their own unique challenges. Approximately three thousand field jackets containing the remains of hundreds of individual skeletons were collected during this period. Each jacket was separately numbered and mapped and each contained perhaps only a part of a single articulated skeleton, or, more typically, parts of multiple skeletons of multiple taxa, associated elements and isolated elements, many of which were revealed only after preparation and thus not referenced in the field notes. Traditional collection databases such as Specify are incapable of tracking such complex associations of specimens or facilitating their full curation. Prior to a recent move and reorganization of these collections, we designed an inventory-based relational database capable of tracking all "objects" within the collection, regardless of their curatorial status, location or known associations. This database relates field notes, inventory observations, curator's notes and catalogue records and is an essential tool in re-uniting individuals that had become dissociated during collection, preparation and years of research. In addition, newly designed, stable support systems were constructed for skulls and other heavy, fragile elements to improve storage and assure safe handling. Construction of a new, much larger "Rhino Barn" will begin in 2008, allowing excavation, in-situ preservation and research to continue for many years to come.

Brown, G. 2008. Lessons from the Lagerstatte: an Ashfall Fossil Beds retrospective and update. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:7

Platform

EVALUATION AND CERTIFICATION OF FOSSIL PREPARATORS: IDEAS FOR THE FUTURE

Brown, Matthew
Petrified Forest National Park
and
John Kane
University of Heidelberg

Increased levels of specialization in the field of paleontology along with new methods of collecting and analyzing data from fossil specimens require a large body of knowledge and breadth of skill from fossil preparators. In order to advance the science of vertebrate paleontology, preparators must hold themselves personally and as a community to high standards of quality, safety, and ethics. Currently there is no widely accepted curriculum of training or standard of best practice for the prep lab, but many other professions demonstrate effective models. Evaluating and adopting these models while incorporating elements of successful existing institutional programs allows us to create a plan for professional development. This presentation examines the roles of educational institutions, professional associations, and the individual lab in training and evaluation of fossil preparators.

Brown, M.A., J. F. Kane. 2008. Evaluation and certification of fossil preparators: ideas for the future. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:8

Platform

ONE SAND GRAIN AT A TIME: FOSSIL PREPARATION UNDER THE MICROSCOPE

Cavigelli, J.P.
Casper College, WY

Despite the popularity of charismatic megafauna fossils, many vertebrate (and invertebrate) fossils are actually quite small and need to be prepared with the aid of a microscope. Many of the techniques used for both field collecting and preparation of large fossils can be modified to be used under the microscope, but there are also many tools and techniques that are useful for microscope work. This talk will outline some tools, techniques and products found to be useful in microprep of fossils. From the microscope to needles, glues, air-abrasives and carbowax, and more.

Cavigelli, J.P. 2008. One sand grain at a time: fossil preparation under the microscope. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:9

Platform

ADHESIVES FOR FOSSIL PREPARATION: A MINI-SEMINAR

Davidson, Amy
American Museum of Natural History

This one hour seminar will cover basic information about how adhesives work and will have three components:

1) An Adhesives Quiz will be distributed to participants in advance of the Symposium and the answers will be distributed prior to the mini-seminar. This quiz will focus on four adhesives and two solvents commonly used in fossil preparation: Aron Alpha 201 Cyanoacrylate (Krazy Glue), Devcon 2 Ton Epoxy, Acryloid/Paraloid B72, Butvar B76, acetone and ethanol. Participants will be encouraged to return their completed quiz in advance, as this will help tailor the discussion.

2) Two 15 minute PowerPoint presentations:

ADHESIVES AS LIQUIDS
Adhesives work because they can flow as liquids that then solidify in extremely close contact with the surface to which they are applied. Adhesion of the two solids is due to secondary attractive forces and mechanical interlocking. In their liquid phase and in their setting mechanism, adhesives vary widely but all must be able to flow. Factors that affect flow such as viscosity, wetting and interaction of liquid adhesives with surface contaminants and entrapped air will be discussed, along with techniques to manipulate adhesive flow for the preparation of fossil vertebrates.

FROM LIQUID TO SOLID AND BACK: PHASE CHANGE IN ADHESIVES
All adhesives used in fossil preparation are applied as flowing liquids which set into solids, but through different setting mechanisms. Some solid adhesives can be made to flow again. A basic understanding of phase-change behavior on a molecular level enables the preparator to define the behavior they want for a particular specimen, and to choose the most appropriate adhesive.
This talk will present a basic introduction to solution and reaction setting mechanisms. Gross behavior during phase change such as set time, solvent retention, shrinkage, migration, resolubility and swelling, and the relationship between adhesion and cohesion will be linked to inter and intra-molecular bonding. Specific specimens with different phase-change behavior requirements will be presented as illustrations of the adhesive selection process.

3) Case Studies: The group will look at images of specimens which illustrate common problems. This will be a guided group discussion. Participants will be encouraged in advance of the Symposium to submit images of problem specimens for consideration by the group.

Davidson, A. 2008. Adhesives for fossil preparation: a mini-seminar. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:10

Platform

PLEASE DON'T DROP MY BOX OF ROCKS!: PACKING METHODS FOR DOMESTIC AND INTERNATIONAL FOSSIL SHIPPING

Hunt, ReBecca
Augustana College

In March and April of 2006, Augustana College shipped fossils to two separate destinations, on either side of the North American Continent. The holotype specimen of *Cryolophosaurus* from the Lower Jurassic Hanson Formation of Antarctica was sent to Research Casting International in Trenton, Ontario (Canada). Casting of a new vertebral column based on specimens recently prepared since its original casting in 2002 was the goal of this shipment. Several of the twenty-one vertebrae sent have very thin and delicate post- and prezygapophyses preserved, and the safe arrival of these specimens was critical. A labrynthodont skull from the Triassic Fremouw Formation of Antarctica was also shipped (domestically) during this time to Washington State for collaborative research purposes. This amphibian skull is extremely thin in areas and required extra attention in packing to insure no damage would occur during the shipping process. The safe packing of these vertebrate fossils for international and domestic transport was vital for the future study of these remains.

The fossils were packed in boxes constructed of 1⁄2 inch foamcore board with an interior of G-60 foam to help contour to the shapes of the individual fossils. The delicate and less robust vertebra of *Cryolophosaurus* along with the labrynthodont skull were enclosed within individual clam-shell cradles constructed of a/c foam, ethafoam and plaster. The remaining fossils were wrapped in a protective soft sheet of Tyvek to act as an inert moisture barrier and placed within the box, to be followed by custom cut G-60 foam supports. The boxes were then placed within the interior of custom built crates for shipment. These crates were transported to their individual destinations by a chain shipping company. This process and the products used will be explained in this talk.

Hunt, R. 2008. Please don't drop my box of rocks!: Packing methods for domestic and international fossil shipping. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:11

Platform

A CLOSER LOOK AT THE PREPARATION TECHNIQUES OF FOSSILS FROM THE FOSSIL BUTTE MEMBER OF THE GREEN RIVER FORMATION

Holstein, James L.
The Field Museum of Natural History

The Fossil Butte Member of the Green River Formation in southwest Wyoming contains some of the world's most diverse and complete fossils. This 50 million year old locality represents a brief snapshot of a lake system that survived for 15 million years. There are two main fossil bearing deposits, the F-1 and F-2 layers, each posing unique challenges of excavation and preparation. Containing primarily fish, the locality has also yielded birds, reptiles, mammals, insects and plants. Preparation of these fossils require an understanding of the idiosyncrasies of the various fossil bearing layers and the subtleties of individual specimens. Application of proper preparation and conservation techniques will yield the best results and preserve the maximum amount of information.

Holstein, J. 2008. A closer look at the preparation techniques of fossil from the Fossil Butte Member of the Green River Formation. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:12

Platform

EVALUATION AND CERTIFICATION OF FOSSIL PREPARATORS: AN OUTSIDERS VIEW

Kane, John
University of Heidelberg
and
Matthew Brown
Petrified Forest National Park

Experience during the 1970s in pediatric psychology demonstrated that training, evaluation, certification and periodic re-certification are absolutely essential in providing quality treatment and service delivery to children with severe behavior disorders. However, resistance to certification was intense and was resolved only after a series scandals and litigation. Resistance was a product of an antiquated model of treatment. This model was replaced by a more flexible paradigm accompanied by intensive efforts to train, certify and supervise “front line child behavior analysts and change agents”. In many respects the current discussion and model of doing science in paleontology appear to be similar to the discussions encountered in the 1970s. The presentation will briefly describe the development and will draw parallels relevant to the practice of preparation. The brief experience of the presenter as a novice preparator strongly suggests the need for specific training and supervision. Finally the author will point out why the current preparator “role model” needs to be rethought and perhaps revised. The model of preparator as the guarantor of quality data perhaps needs greater exposition.

Kane, J., and M. Brown. 2008. Evaluation and certification of fossil preparators: an outsiders view. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:13

Platform

THE PREPARATOR: A SURVIVOR'S GUIDE

Madsen, Scott
(Retired)

Working as a professional preparator can be a joyous, fulfilling and rewarding occupation, but it is not without its hazards to life, limb and psyche. This talk will examine some of those hazards and suggest practical tips on how to achieve a safe and happy work environment. Information from past talks and preparator surveys regarding occupational health will be presented with updates and case studies. Topics will include: dust and fume evacuation systems; radon hazards; common injuries sustained in the field and lab. Preventative measures to combat these hazards will be addressed including a discussion of the "Safety Culture" in the work place, the need for baseline physicals and suggestions on how to get what you need to mitigate safety issues- a safe workplace should be seen as a right, not a luxury. Additional topics will include a discussion of means to achieve a more prosperous and fulfilling career through the use of formal and informal mentoring programs, moonlighting and employee development opportunities. The reality of achieving these goals for all may be greatly facilitated by preparators taking it upon themselves to create a professional society or organization to represent our common interests.

Madsen, S. 2008. The Preparator: a survivor's guide. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:14

Poster

FROM THE CRADLE TO THE WATERBOARD: HANDLING LARGE BONES WITH LIMITED RESOURCES

Madsen, Scott (Retired)
Dale Gray
Tom Nelsen

The closure of the Quarry Visitor Center at Dinosaur National Monument in 2006 due to safety concerns meant that dozens of awkward and fragile specimens had to be prepared for removal to temporary storage "facilities" (2 garages and a trailer). Rugged and functional storage and transportation systems needed to be made quickly. Numerous experiments were conducted using AC filter foam, different weaves of fiberglass and various types of plaster to create stable, clean and light-weight beds for bones, but most of these techniques and materials were found to be too cumbersome for mass production and inadequate for the intended purpose. The 2-piece fiberglass and hydrocal cradles as described by Jabo, Kroehler, and Grady in 2005 provided the best model for a practical solution; however, we modified their technique by eliminating the use of clay. This poster will illustrate how we rapidly produced many custom form-fitted cradles using 1/16th inch foam, a single layer of double-bias fiberglass and hydrocal.

Some specimens, particularly complicated vertebra, are best stored upright for better viewing by researchers as well as the structural integrity of the specimen. A low-profile hydrocal base was constructed for a large vertebra as it lay on its side in a sand table by building a wood frame, (the "Waterboard") placed inches from the centrum and lined with a plastic bag; this was then filled with hydrocal and removed to create a perfectly form-fitted base. Additionally, a partially jacketed 2000 lb sacrum that could not be lifted off the table was given a base by rocking the specimen fore and aft and gradually adding layers of hydrocal to the underside. The end result is a sturdy stand that could be lifted onto a wheeled pallet that allows for easy viewing and transport. These and other storage techniques and materials will be illustrated in this poster.

Madsen, S., D. Gray, and T. Nelsen. 2008. From the cradle to the waterboard: handling large bones with limited resources. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1:15

Poster

ROTTEN WOOD IN SAND: DIFFICULT PREPARATION OF A LARGE THEROPOD SPECIMEN

Maltese, Anthony
Rocky Mountain Dinosaur Resource Center

A difficult combination of soft matrix, low overburden, and a high degree of specimen articulation posed special problems in the recovery of a *Daspletosaurus torusus* skeleton. Traditional jacketing and mechanical preparation yielded unsatisfactory results. Mechanical preparation proved impossible without consolidation of both the fossil material and the surrounding matrix. Techniques were developed for the stabilization, transportation, and preparation of the original fossil material.

Maltese, A. 2008. Rotten wood in sand: difficult preparation of a large theropod specimen. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 16

Platform

A PALEONTOLOGY LABORATORY APPROACH TO RADON HAZARDS, DETECTION, AND MITIGATION

McCullough, Gavin
Arizona Museum of Natural History

Radon is a colorless, odorless radioactive gas that occurs as a product of radium or uranium decay. In recent years, radon has been identified as a serious health hazard in residential and industrial environments, the EPA estimating that about 20,000 lung cancer deaths are radon-related. Radon poses a risk of lung cancer to non-smokers, and a far greater risk of lung cancer to smokers. Recently the AZNMH tested its paleontology laboratory and storage vaults for radon, based on observations that the parent sediments contain uranium. After testing with store-bought radon detectors followed up by testing by an environmental/industrial safety company, we discovered that Pliocene fossils collected from southeastern Arizona are sources of elevated radon levels (above 4 pCi/L, the EPA "action level"). Immediate action included 24-hour active ventilation, simple dust control measures, and increased passive ventilation during work hours. The results of our action are that paleontology lab radon levels have steadily decreased at a rate of 0.10 pCi/L per week. In addition, we are scheduled to receive an industrial-grade ventilation system as part of a safety upgrade allowance. Radon detection is inexpensive and mitigation is not complicated, but health risks due to radon exposure can be severe. Radon testing should be emphasized as part of environmental safety regimes in laboratory and industrial situations that work with fossils, rocks, or create mineral dust as part of their work.

McCullough, G. 2008. A paleontology laboratory approach to radon hazards, detection, and mitigation. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 17

Poster

THE USE OF LINEAR COLLAPSIBLE FOAM FOR MOLDING FOSSIL FOOTPRINTS IN THE FIELD

Nolan ,Thomas C. - WIPS / Denver Museum of Nature and Science
Rob Atkinson - WIPS
Bryan Small - Denver Museum of Nature and Science

Time in the field is a valuable commodity and any method that shortens the time making an impression in the field translates to more time available for exploration. Additionally, transportation of the materials can be difficult and a burden. Current methods of copying fossil footprints entail the use of liquid latex, Plaster of Paris, or silicon rubber that is poured or brushed into the footprint, allowed to harden, then removed. This often leads to residue material left at the site, damage to the fossil and expenditure of long periods of time. The use of linear collapsible foam (the same foam used to take impressions of body parts for orthotics) eliminates the residue, does no damage, is inexpensive, and produces a high quality impression of the footprint within minutes. The foam has a density of from .7 to 2.8 pounds per square inch and can be ordered in various thickness and size. The cost of the foam is competitive with other molding materials. The lighter density foam was deemed too friable to use, however, the denser foams proved ideal for taking impressions. There are limitations using this method. Objects that have undercuts, even slight ones, will not copy and the foam will be damaged when removed; transportation of the material must be made in a single lid cardboard box to prevent damage to the impression; and large area footprints requiring large sheets of the foam may require multiple people to compress the foam into the object. Once taken a master cast of the impression is made using Plaster of Paris or Water Putty, at this point the foam impression is destroyed removing it from the hardened cast. Organic based casting materials can not be used because of adsorption of the liquid into the foam and possible reactions with the foam. Once made the master copy retains the details and sharpness of the original fossil. This method produces a copy of the subject within a few minutes in the field and it is easier to transport the materials into the field and back. Finally, the master cast can be used to make a latex mold to produce additional copies if required.

Nolan, T. et al. 2008. The use of linear collapsible foam for molding fossil footprints in the field. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 18

Platform

ANALYSIS OF MISTAKES CORRECTED AND PERPETUATED IN MULTIPLE MOUNTS OF PLACERIAS GIGAS AND RESIN CAST CONSERVATION PROBLEMS.

(Original presentation at SVP in 1996, re-presented at this meeting because of immediate relevance)

Reser, P.K., Retired
and
Geiser, R.M., Retired

Late in 1987 our museum delivered a mount of Placerias to Petrified Forest National Park Arizona. It was then moved several times and altered by third parties. It also suffered from ultraviolet degradation and temperature extremes because it was placed behind unfiltered windows. These factors exacerbated the original fabrication, anatomical, and materials flaws. Mounts are composites of materials but also of real and restored bone parts from different individuals, and current scientific opinion. Anomalies are certain and only resolved by the process of fitting together the whole three-dimensional animal.

In September of 1991 we completed another mount for the New Mexico Museum Of Natural History And Science articulated at one extreme of the range of movement of the vertebral column. This configuration changed our concept of Dicynodont posture but also repeated distortions of the pectoral girdle originally introduced by ribs restored in an arc too wide to allow the sternum to articulate with the scapula-coracoids.

In 1996 a corrective overhaul of the first mount (existing mount at Petrified Forest) was undertaken. We found serious delamination between the W.E.P. cast material and adhesives, fillers, and paint except where filled polyester resin (Bondo) was used. We found that rib restorations had to be re-contoured, the the restoration of the proximal humeri prevents assumption of the posture seen in the standard published figure, the feet are probably mis-interpreted, and no fossil mount is 100% accurate.

Reser, P. and R. Geiser. 2008. Analysis of mistakes corrected and perpetuated in multiple mounts of Placerias gigas and resin cast conservation problems. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 19

Platform

THREE-DIMENSIONAL PREPARATION OF A LATE CRETACEOUS STURGEON FROM MONTANA

Vanbeek, Constance
Field Museum of Natural History

The Cretaceous fossil record of sturgeons (Acipenseridae), while plentiful, has not been known for well-preserved or complete sturgeons. The poor quality and fragmentary nature of the known material have made them of limited value to studies on the comparative anatomy and phylogenetic significance of fossil sturgeons. When an unusually well preserved specimen of a new, undescribed taxon arrived at the Field Museum on loan from the Museum of the Rockies, it presented an opportunity to fully prepare the most complete fossil sturgeon yet known.

Because the specimen was so unique in its completeness, it was necessary to fully expose and then disarticulate all elements for research. This entailed removing previous consolidants that had been applied for stabilization of the fossil; and preparing elements in such a way that high-resolution images, both photographic and illustrative, would reveal the fine details. An important consideration was strengthening the fragile bones yet still being able to disarticulate them while undergoing this very thorough and detailed preparation. That dichotomy proved to be a persistent theme throughout the preparation of this remarkable specimen.

Van Beek, C. 2008. Three dimensional preparation of a Late Cretaceous sturgeon from Montana. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 20

Platform

PETRIFIED FOREST NATIONAL PARK REPHOTOGRAPHY: PHOTOGRAPHY AND DIGITAL IMAGING PROJECT, 120 YEARS OF PHOTOGRAPHIC HISOTRY

Williams, T. Scott
Petrified Forest National Park

This project focuses on several objectives relative to the park: 175 photographic images were re-photographed in this survey to utilize photography from the park's collection that could provide a basis of data to answer specific questions about the effects of erosion over time and to measure the extent of erosion that has occurred over the past 120 years. This project will provide a visual history of the park that traces human exploration and impact on the land and resources before Petrified Forest was a monument and beyond. Utilization of rephotography for interpretation of the park resources will educate visitors and to attempt to record resource loss (e.g., petrified wood).

Williams, T.S. 2008. Petrified Forest National Park rephotography: photography and digital imaging project, 120 years of photographic history. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 21

Platform

REDISCOVERY: MANAGING THE VERTEBRATE FOSSIL COLLECTION AT PETRIFIED FOREST NATIONAL PARK

Williams, T. Scott
Petrified Forest National Park

This talk will discuss the development and management of museum collection at Petrified Forest National Park since 2002. A selection of vertebrate fossils that were rediscovered in the collection and conserved will be highlighted emphasizing the importance of museum collections for preserving the heritage of the fossil resources at the park and for furthering scientific endeavors.

Williams, T.S. 2008. Rediscovery:managing the vertebrate fossil collection at Petrified Forest National Park.. First Annual Fossil Preparation and Collections Symposium, Abstracts of Papers 1: 22