DOI: TBC
Published: 26 January 2019

Cyclododecane and fossil vertebrates: some applications for matrix removal, moulding and shipping

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Over the past decade, cyclododecane (CDD) has been increasingly adopted by vertebrate fossil preparators as a more effective and advantageous material for several standard treatments and for new applications borrowed from art and artefact conservation. Many techniques in palaeontology utilise CDD's special properties, including its use as a temporary embedding and support material to protect fragile specimens during removal of rock matrix; as a barrier layer during consolidation; as a temporary consolidant; as a temporary filler during airscribe preparation; as acid-resistant protection for fossil bone during dissolution of the limestone matrix; as a gap-filler, sealant and separator during silicone rubber moulding; and as a protective coating for specimens that are otherwise too delicate to ship. In several of these techniques, CDD replaces materials traditionally used in preparation – such as polyethylene glycol (PEG), microcrystalline wax or oil-based clay – that must subsequently be laboriously melted, dissolved or mechanically removed. CDD is not used in some fossil preparation laboratories due to health and safety concerns. It is hoped that continued exchange of information with art and artefact conservators will promote safe handling practices, encourage experimentation and spark new ideas.

1 Introduction

The volatile binding medium cyclododecane (CDD), a solid waxy hydrocarbon that sublimes at room temperature, was first introduced into vertebrate fossil preparation through interactions with object conservators in the late 1990s. Amy Davidson first learned about CDD at the 1999 Studio Tips session of the New York Regional Association for Conservation when conservator Gary McGowan presented his work using CDD to stabilise and detach dried mud reliefs from a wall (McGowan 1999). The potential uses for this material in vertebrate palaeontology were obvious and exciting. In 2003 Davidson briefly described CDD to a group of preparators during the annual meeting of the Society of Vertebrate Paleontology. The response was immediate and by the next meeting in 2004 there were four presentations, all on different uses for CDD (Arenstein *et al.* 2004; Brown 2004; Maywin *et al.* 2004; Williamson *et al.* 2004).

This paper presents a composite of work done by the authors since 2003, using case studies of various applications of CDD for temporary stabilisation, matrix removal, moulding and shipping.

CDD has proven to be a very versatile material for fossil preparation and its use is undoubtedly spreading among professional as well as amateur fossil preparators; however, lack of definitive health and safety studies remains a concern.

2 Fossil vertebrates as materials

The material nature of fossil vertebrates varies depending on the local geology and preservation conditions. In vertebrate palaeontology the term 'matrix' is used for any sediment around the bone. These matrices are highly variable and can range from extremely hard, dense volcaniclastics to very soft and loose sandstones, silts and ash.

Fossil bones themselves are usually composed of the original bone mineral hydroxyapatite with varying degrees of replacement and infilling of pore spaces by minerals dissolved in the local groundwater. Usually, the original collagen content of the bone vanishes over millions of years, but it can persist in more recent fossils. One almost universal physical property of fossil bone is inflexibility. Bones may become dense and heavy during fossilisation, but they are always brittle and easily broken by preparation tools, handling or even gravity.

In-situ fossils are typically found in various stages of displacement and deterioration with many cracks and voids running through the bone. How can such fragile material survive for millions of years? The answer is that Nature does a great job 'packing' the fossils. With the tight support of the surrounding matrix there is no room for the specimen to fall apart. The difficulty comes with the 'unpacking', either through the natural forces of erosion and weathering or during preparation.

Most fossils are collected still encased in the matrix, either as nodules, or as chunks of hard sediment, or as specimens inside excavated blocks encased in plaster field jackets (Rixon 1976; Camp and Hanna 1937: pg. 1–27). The challenge of fossil preparation is to remove the matrix and expose the bones in a controlled manner, unlike natural erosion. In the laboratory, a variety of tools and techniques is used to expose the bones and sometimes extract them completely, depending on the requirements of the researcher. Generally, specimens are prepared on one side, stabilised with consolidant, then inverted and prepared and stabilised on the other side (Leiggi and May 1994: pg. 121–127). This intermediate 'flip' requires support and protection of the previously exposed side of the specimen. When done well, preparation is an artful process of removing the matrix and adding reinforcement in the form of consolidants and fillers.

Some of the more challenging tasks for fossil preparators include: 1) removing matrix from very small or comminuted (badly fragmented) specimens; 2) reproducing specimens by moulding, even if the bones are very brittle and the matrix is extremely porous; and 3) shipping fragile specimens without damage. CDD has proven to be very useful in accomplishing these difficult tasks.

3 Modes of use

In most palaeontology preparation techniques, CDD is applied as a pure melt prepared by heating CDD to its melting point of 60 °C over a temperature-controlled hot plate, in a wax pot or under a heat lamp. Keynan and Eyb-Green (2000) reported preparing the melt in a double boiler on a hot plate. Care must be taken to avoid high temperatures while heating. Rowe and Rozeik (2008) found that technical information on the flashpoint and ignition temperature of CDD varies widely according to the source but may be as low as 89 °C and 175 °C respectively. They recommend heating in a water bath no higher than 80 °C. CDD vapour production is accelerated during heating, so this must be done within a properly equipped fume hood or efficient local exhaust. Applied as a pure melt to a fossil or matrix that is at or below room temperature, CDD acts as a temporary surface coating with little or no penetration. If a porous object is heated to or above the melting point of CDD before the melt is applied, CDD readily penetrates and acts as a temporary consolidant (Brown 2013).

In some instances, unheated CDD in solution with an appropriate solvent is useful. CDD is soluble in many low-polar and aromatic solvents (Watters 2007). G. Brown 2005 has used VM&P Naphtha (petroleum ether) successfully to produce a temporary film/surface sealant in some moulding applications in order to prevent moulding compounds from mechanically adhering to porous substrates. All CDD solvents present serious health risks, so follow all MSDS safety recommendations and use good chemical hygiene practices at all times.

4 Applications for matrix removal

Removal of matrix is an essential step in the preparation of fossils for study. This is often a straightforward task utilising simple hand tools such as chisels, needles, dental picks and brushes, or small pneumatic or electrical tools such as airscribes, air abrasives and rotary grinders. Regardless of the tools used, however, specimens must always be properly supported to prevent tool pressure and gravity from collapsing the specimen during preparation. For small or delicate specimens, providing firm, form-fitting but easily removable support is critical. CDD provides ideal support for a number of matrix removal techniques.

4.1 Temporary embedding

Probably the most common way that preparators use CDD is as a substitute for Carbowax polyethylene glycol (PEG) for temporarily embedding small specimens or nodules onto working mounts. The Carbowax method was developed by A.E. Rixon at the British Museum in the 1960s (Rixon 1965). Carbowax is a colorless waxy substance that can be melted and also dissolved in warm water. When mounted in a medium such as Carbowax, small specimens can be handled safely during preparation. In addition, as delicate elements are exposed, Carbowax can provide support and protection. An easily removable material is required for these purposes. One of the limitations of Carbowax is that the removal process requires picking, melting, wiping with ethanol or, to ensure complete removal, dissolving by submersion in hot water. Not every specimen can withstand this process without damage.

CDD is an ideal substitute for Carbowax for temporary embedding of small specimens onto working mounts. Davidson prefers an embedding technique devised by William Amaral using a small block of plaster with a carved depression which acts as a reservoir for molten CDD and the specimen (Amaral 1994) (Figure 1 (a)). When the CDD solidifies, the plaster block allows safe handling and manipulation of the specimen during preparation. After preparation, the entire mount may be placed in a fume hood and sublimation accelerated with a heat lamp, hairdryer or increased air movement.

A variation on this embedding technique was designed by G. Brown. This uses a more elaborate work holder created from a small cardboard tray mounted on a heavy steel ball that can be easily held and rotated in any direction during preparation (Figure 1 (b)), thus providing an infinite number of preparation angles while maintaining optimum hand and tool position (Brown 2011, 2012). A pure melt of CDD is poured into the tray and allowed to cool. Using an electric wax pen, a small pool of melted CDD is created in the centre of the tray into which the specimen is placed. This method allows more control of the embedding level and position than just dropping the specimen into a large pool. For localised control of melting and sublimation, Brown uses a modified desoldering iron with a heated nozzle to direct a small stream of hot air wherever needed Brown (2012). When combined with a dental air pedal, very fine control is possible, which is especially useful for the manipulation of CDD under the microscope.

For most small specimens the melting, embedding and post-preparation sublimation processes can be done in the fume hood. The actual specimen preparation, however, must be done at the work station under a microscope and may take several weeks or months to complete. Preparators must be aware that CDD sublimes continuously during preparation and ensure that local exhaust equipment is available that can be placed within several inches of the specimen while under the microscope.

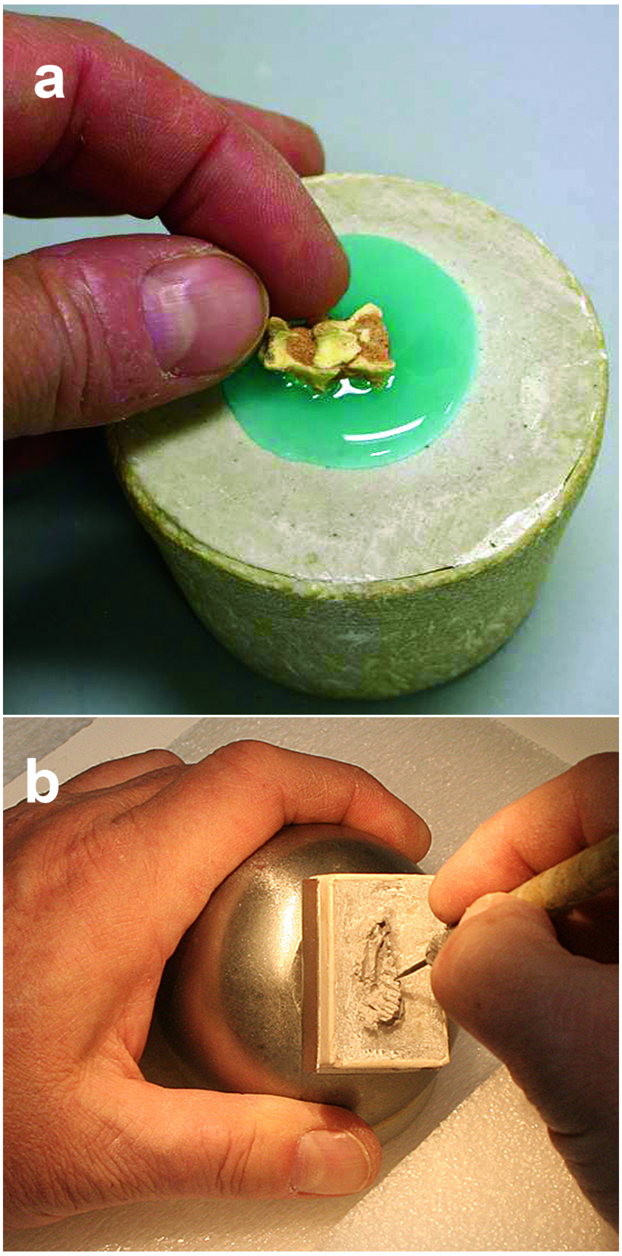

Figure 1 Mounting small specimens on work-holders: a) a small cup of set plaster with a shallow depression carved on top to provide a reservoir for Carbowax or CDD and the embedded specimen; b) specimen embedded in CDD on a steel ball-mount work-holder. Photos: G. Brown (1b), the authors (1a, 1c).

4.2 Deep crack fills

Comminuted specimens in deeply weathered friable matrix present special problems in matrix removal and stabilisation (Brown 2006). Without infilling cracks and spaces between fragmented

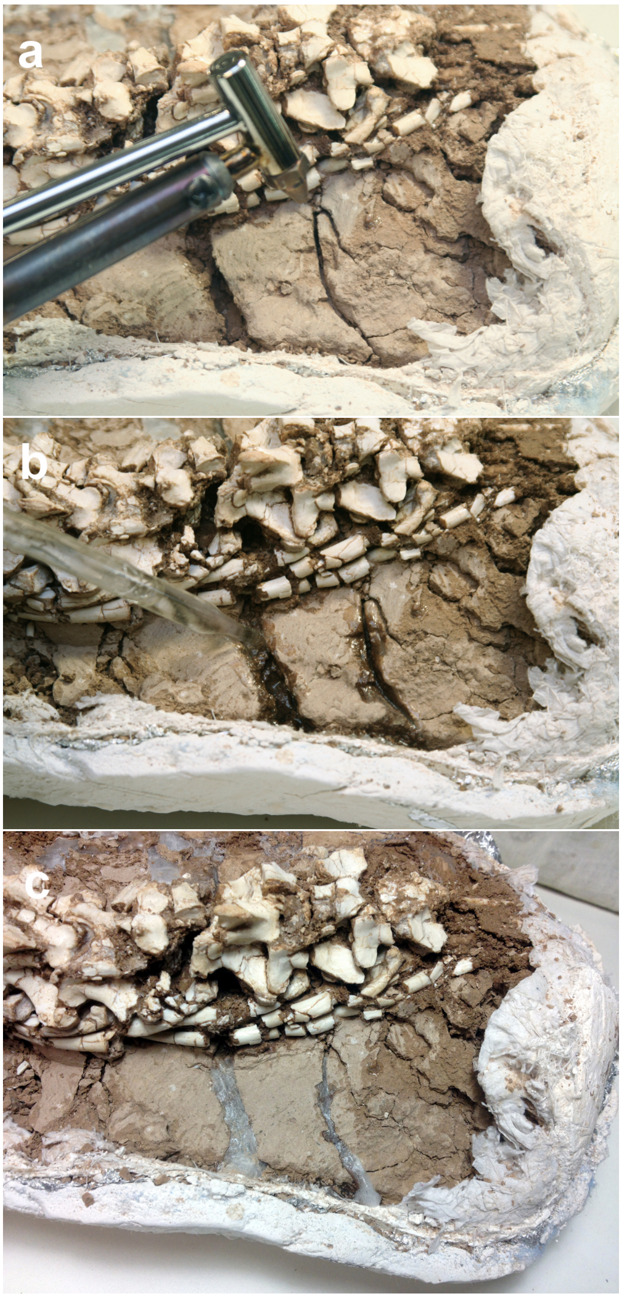

Figure 2 Filling deep matrix cracks in an unstable block of matrix with CDD: a) heating cracks to depth to facilitate penetration and filling; b) injecting molten CDD into heated cracks with an eye dropper; c) cracks are filled and stabilised. Compare with unstable, crumbling cracks to the left and right. Photo: G. Brown.

bones, attempting to remove the surrounding matrix would result in destabilisation and displacement of the enclosed bone fragments. A temporary, easily removable crack filler is required to stabilise the block during preparation. CDD is an ideal choice for this situation. A series of comminuted snake vertebrae preserved in a deeply weathered and soft, friable silt illustrates this technique (Figure 2).

First, a solution of 20% Paraloid B72 in acetone is injected into the cracks to stabilise small fragments and seal the inner matrix surfaces, ultimately directing the flow of the molten CDD into the cracks and not laterally into the matrix. Localised heating of the cracks with a modified desoldering iron (see tools section) ensures thorough infilling of all cavities in the matrix with CDD. For best filling results, the shallow surfaces of the crack should be near the CDD melting point (60 °C), but at depth the temperature should remain near ambient room temperature. This temperature gradient prevents the CDD from either solidifying at the surface (preventing penetration into the crack) or continuing to flow through the crack without filling it. Although warmed above the glass transition temperature of Paraloid B72 (about 40 °C), there is no apparent adverse interaction between the CDD and the Paraloid consolidant in the matrix. CDD between fragments of bone holds the fragments in place until they are exposed by matrix removal and CDD sublimation. When exposed, the fragments can be stabilised in place with Paraloid B72. The result is a stable specimen with no morphological information obscured by a permanent added filler. If in the future the researcher requires complete removal of all the elements, the fragments will be free of any residual filler that might interfere with rejoining them with adhesives.

4.3 Stabilisation for airscribe work

CDD has also proved useful as a temporary stabiliser for delicate specimens that must be prepared with an airscribe, a percussive pneumatic engraving tool (Brown 2013). In addition, badly weathered and fragile bones are often exposed on the surface of a large block of hard matrix that needs to be trimmed down with an airscribe before preparation continues. In both cases, exposed bones must be protected from the effects of vibration. As a gap-filler and coating, CDD applied as a melt over the exposed bone is ideal for this purpose. Consolidation with a polymer solution would not have accomplished the gap-filling needed to prevent damage.

4.4 Block impregnation

Very brittle bone in very loose matrix is often difficult to prepare without damage from the force of tools. Simple removal of the surrounding matrix can

Figure 3 Application of CDD to a heated block of porous matrix and fragile specimen. CDD easily wicks into the specimen, filling pore spaces and voids. Photo: G. Brown.

cause hollow, fragile bone to implode even without tool pressure. This condition is commonly found in fossils preserved in loess, a soft windblown silt. Such specimens are typically treated before preparation by consolidation with polymer solutions such as Paraloid B72 (acrylic copolymer) in acetone or Butvar B-98 (polyvinyl butyral) in ethanol. These treatments, however, usually do not fill gaps and also tend to be relatively superficial, due to lack of penetration and/or outward migration of the polymer.

To provide the deep, temporary consolidation necessary to prepare such specimens, the entire unconsolidated matrix block and specimen should be impregnated with molten CDD (Figure 3). This is accomplished by heating the block thoroughly with a heat lamp before applying the CDD melt, ensuring complete penetration and filling of all pore spaces and voids. It is not possible to predict the precise temperature to which a given matrix and specimen should be heated, but it should be the lowest amount of heat required to prevent premature solidification of CDD on the surface. This must be determined by experimentation. The authors believe that, for most applications, this temperature will be significantly below the melting point of CDD. Naturally, this sort of treatment should only be used on specimens that can tolerate heating without damage. After cooling, the matrix will become a cohesive, waxy solid that can be carved away with a needle. Alternatively, G. Brown uses a technique he calls 'hot prep', whereby matrix is removed with the sharpened tip of an electric wax pen heated to about 75 °C (Brown 2011). The advantage of this technique over 'cold prep' is that the wax-like matrix can be softened and removed while exerting minimal pressure on the specimen within the matrix.

4.5 Transfer preparation

Transfer preparation is a classic technique in fossil preparation (Toombs and Rixon 1950). Exposed (usually fully prepared and consolidated) bone on one side of a matrix block is embedded into a resin block and the remaining matrix prepared away, transferring the support previously provided by the matrix to the resin (usually epoxy, polyester or acrylic resin). The obvious downside to this technique is that the specimen is irreversibly adhered on one side to the resin. Although not suitable for all specimens needing transfer – notably large, thin, compressed specimens – transferring into a block of CDD provides an intermediary step to a clean, free-standing specimen. Once the specimen has been prepared on one side it can be coated or inverted into a vessel of molten CDD. Final preparation can be carried out as in the traditional transfer method, and the CDD allowed to sublime. An added advantage is that small amounts of CDD can be easily added during preparation to support newly exposed fragile elements. The translucency of CDD also allows transmitted light from below, which helps define areas where bones are covered by CDD, thus avoiding accidental 'discovery' damage during preparation.

4.6 Plaster jacket separator

Fast-setting, plaster-impregnated medical bandages are very commonly used as lightweight temporary jackets to support specimens during the preparation process (Rixon 1976). A separator of some type (commonly tissue or foil) must be used between the specimen and plaster to prevent the plaster from adhering to the bone. While effective in this regard, most separators do not provide the intimate support often required for small fragile specimens. In addition, during consolidation the tissue separator can become adhered to the specimen, requiring removal with solvents and putting the specimen in jeopardy. CDD as a separator, however, provides extremely intimate and firm temporary support and is immune from consolidant adhesion. The plaster jacket/CDD support system is created by building up a heavy coating of molten CDD over the prepared surface using a brush. A lightweight jacket of plaster bandage is applied over the coating. The block is then flipped over and matrix removed from the other side. The CDD and plaster jacket combined provide a firm support for the delicate bone as it is exposed. After preparation and sublimation the specimen is completely free of matrix and durable enough to withstand gentle handling by the researcher.

4.7 Backing for fragile elements

A common problem often encountered in the final stages of preparation, particularly of skulls, is the removal of remnant matrix from delicate bony arches, flanges and processes without damage from the force of the tool or destabilisation from the dissolution of previously applied consolidant during subsequent consolidation. Sufficient support must be provided for the bone to withstand the mechanical and chemical action of removing the remaining matrix. The support needs to be tightly conforming, resistant to the acetone used for softening and also able to withstand the consolidation treatment without becoming adhered. After treatment the support must be removable without the use of solvent or force on the bone.

To accomplish this, molten CDD is used in combination with lightweight Tietex polyester fabric as reinforcement. Once this support has been applied to the prepared side of the elements, the consolidated matrix can be safely softened with acetone and removed with a needle and pin vice without damage to the bone (Figure 4). CDD is not soluble in acetone or ethanol, so the support provided by CDD in direct contact with the bone is not undermined by application of acetone to soften consolidated matrix or the subsequent consolidation (with Paraloid B72 in acetone) of the bone. Since the CDD is applied as a pure melt to room temperature bone and matrix, the melt solidifies at the surface, leaving the bone and matrix free to accept consolidation. After treatment the CDD is allowed to sublime, leaving fully exposed and stable bone.

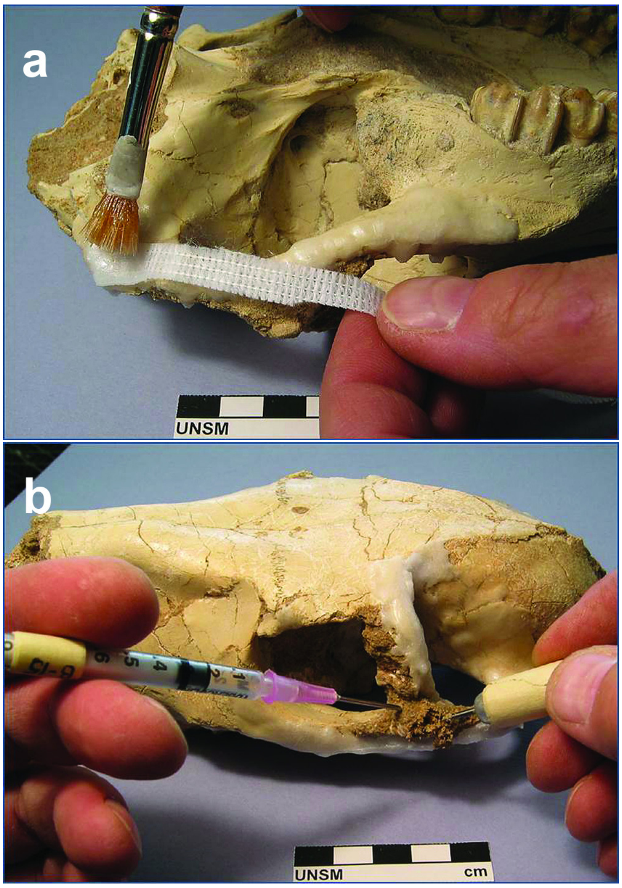

Figure 4 a) applying CDD and Tietex cloth to the zygoma and postorbital bar of a horse skull as a backing support during final matrix removal; b) remaining consolidated matrix is removed with a needle and acetone. Photos: G. Brown.

4.8 Acid preparation barrier

Dissolution of calcareous matrices with various acids is a common fossil preparation technique (Toombs 1948; Rixon 1949; Rutsky *et al.* 1994). Successful acid preparation requires the ability to localise the etching process to avoid acid penetration into hidden cracks and voids where it might attack unprotected bone. If the specimen within the matrix is an articulated skeleton, ultimately something must support the bones in their natural position, either remnants of matrix or some added filler. In an example of acid preparation using CDD as a barrier and supporting material, Groenke prepared a Palaeocene limestone nodule from Montana containing small, articulated vertebrate remains. The researcher required that the skeletal contents of the nodule be maintained in position for documentation prior to disarticulation, so it was especially important to maintain matrix support for the bones and control the shaping of the nodule as it was etched away. Filling subsurface voids, sealing cracks and masking certain areas of the matrix are essential steps in this process. They are normally accomplished with acid-resistant, thermoplastic coatings such as Paraloid B67, or with thermosetting resins such as epoxy or polyester, but these can limit the visibility of the specimen and potentially prevent disarticulation once associations are documented. A better method was developed using CDD, which is resistant to formic acid. A pure melt of CDD was applied to fill cracks and unseen voids below the surface and to coat over those bone and matrix surfaces requiring support and protection during etching (Figure 5). Some flaking of the CDD was observed during the process. Areas requiring protection were periodically brush-coated with a solution of Vinac B15 polyvinyl acetate solution in acetone (1 : 25 by volume); when applied to the surfaces of the CDD this coating was found to slow down flaking. Both the CDD melt and the Vinac B15 coating were reapplied frequently between acid baths, rinsing and drying cycles. This reapplication served to replace the CDD lost to sublimation and flaking. This work was reported in a Society of Vertebrate Paleontology poster (Maywin *et al.* 2004) and is to our knowledge the only published report on the use of CDD in acid preparation of fossils. The authors concluded that CDD was very effective for this application and held great promise for other types of acid preparation.

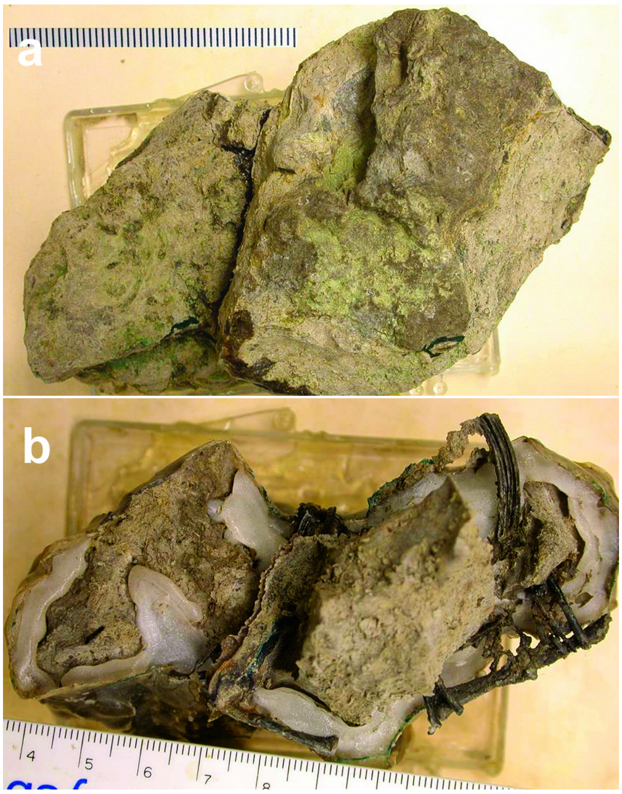

Figure 5 Acid preparation of a block of calcareous matrix containing articulated skeletal material: a) block before acid treatment; b) block partly prepared. Note the CDD covering specific matrix areas to prevent erosion of matrix supporting the skeleton. Photos: the authors.

5 Applications for moulding

CDD has been tested for its suitability as a release agent for moulding delicate fossil surfaces with silicone rubber on a fossil fish from Hubei, China (Arenstein *et al.* 2004). This specimen was preserved in fine-grained shale and was collected by splitting the matrix through the bone, producing a part and counterpart. Splitting also creates many microscopic voids and delicate broken edges. These voids had to be temporarily filled to prevent specimen damage from penetration of the RTV silicone rubber used for moulding, while not obscuring the microscopic morphology of the specimen. Molten CDD was applied with a kistka, a tool normally used to draw fine wax lines on Ukrainian Easter eggs, but it was impossible to create an even film or precise void fills. A solution of CDD in VM&P Naphtha was also tried as a separating layer over the surface but it formed an undesirable crystal pattern that would be replicated in the mould and cast, obscuring specimen detail (Figure 6). The conclusion from that study was that CDD was not appropriate as a separator for moulding this particular kind of specimen using either of these techniques.

It was determined, however, that CDD worked well for one mould-making task: the attachment of a small reservoir wall for spot-moulding just the head of the fish. The reservoir wall was made of a ¼" strip of paper saturated with cyanoacrylate. The paper was formed into a loop and attached to the specimen with a tiny bead of molten CDD applied with an electric kistka. This was found to be a cleaner alternative to traditional reservoir walls made of oil-based clay or wax.

In contrast to the mixed success of CDD in facilitating moulding reported above, G. Brown has demonstrated spectacular success using CDD as a sealant/barrier in the moulding of large scale specimens from the famous Ashfall Fossil Beds State Historical Park in Royal, Nebraska Brown (2005). This site contains hundreds of articulated Miocene rhinos, horses and camels preserved in a deposit of soft volcanic ash. Many

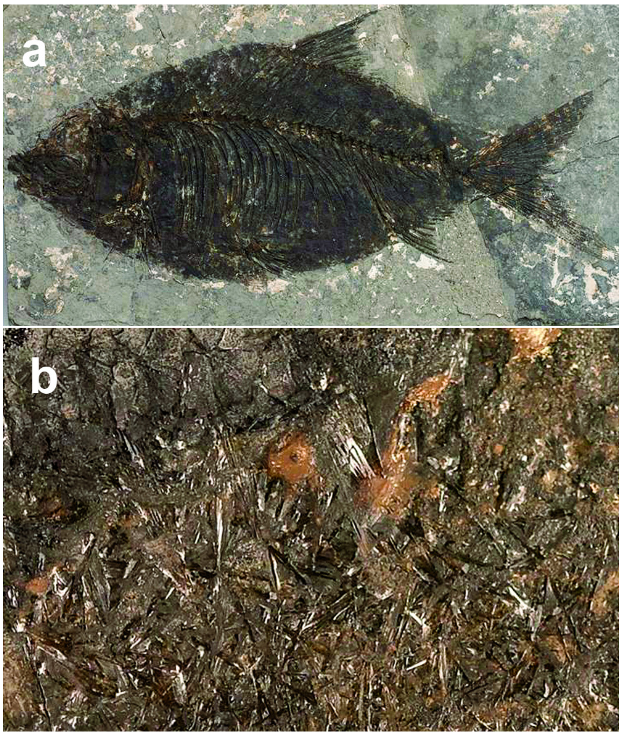

Figure 6 Results of experiment testing CDD as a separator/micro gap filler for moulding a fossil fish: a) specimen before treatment; b) close-up of specimen after the application of CDD in solution with VM&P Naphtha. The CDD has formed a typical crystalline 'felt' coating, obscuring specimen detail. Photos: the authors.

of these specimens have been exposed in situ for display and protected by a partially enclosed structure built over the site. Experiments using RTV silicone rubber moulding compounds showed that both consolidated (with Paraloid B72) and unconsolidated ash matrices exhibited microscopic mechanical adhesion to the silicone rubber during demoulding, damaging the integrity of the matrix supporting portions of the skeletons. Other separators or barrier coat materials may have solved this problem, but due to concerns about possible chemical interactions affecting long-term preservation in situ, it was decided to avoid adding other non-removable chemicals to the existing bone/matrix/consolidant composite. Before moulding, an additional thorough consolidation treatment of 10% Paraloid B72 in acetone was applied to the matrix supporting the bone using a canister sprayer designed to dispense acetone-based concrete dyes (Davidson and Brown 2012). After this was completely dry, a saturated solution of CDD in VM&P Naphtha was applied to the matrix by brush (Figure 7 (a)). The CDD was allowed to sublime for 12 hours to eliminate any surface buildup that could obscure detail, while leaving CDD in the matrix pore spaces. This eliminated the problem of mould adhesion due to microscopic mechanical interlocking. The mould was made of addition-cured platinum-catalysed silicone rubber, which was selected for its superior release properties. The initial layers were thickened with fumed silica. After ten layers of silicone rubber had been applied, the mould was thick enough to peel from the surface, with no adhesion or damage to the specimen or surrounding matrix (Figure 7 (b)). The release of the mould was possibly facilitated by CDD's continued slow sublimation during the moulding process, which may have created a microscopic gap between the mould and the matrix. Approximately two weeks after unmoulding, no trace of CDD could be detected in the specimen. The casts were made with polyester resin thickened with talc and fumed silica. Examination of the surface of these casts with magnification could detect no residual CDD crystal or 'felt' pattern.

In any application using CDD and RTV silicone rubber moulding compounds, always test the compatibility of CDD with the specific silicone rubber being used. Free silicone oil is a solvent for CDD. To date, G. Brown has found only one platinum-cured RTV silicone rubber formula that liquefies CDD during moulding, but there are most certainly others. It appears that compounds formulated to produce softer cured properties may contain excess silicone oil. Additional studies are needed.

6 Applications for shipping

Arenstein presented a talk to preparators in 2004 on the use of CDD as a temporary stabiliser for shipping ethnographic objects (described in Arenstein *et al.* 2003a,b). Since then, CDD has been used in similar ways to ship fossil vertebrates (Figure 8). M. Brown adapted the technique for the shipment of two delicate lizard skeletons that had been partially prepared out of blocks of sandstone (Brown and Davidson 2010) Figure 8. These specimens were thought to be too delicate for simple drizzling or brushing on molten CDD, so a more controlled application was required. CDD was applied under the microscope crystal by crystal with tweezers and

Figure 7 Moulding of articulated rhino skeletons in volcanic ash: a) application of a saturated solution of CDD in VM&P Naphtha to matrix areas of the specimen 12 hours prior to moulding; b) removing the RTV silicone rubber mould from the skeleton. The mould release was perfect with no damage to the fragile matrix. Photos: G. Brown.

then melted in place with a MaxWax battery operated wax pen. The MaxWax pen is very useful for CDD work under the microscope. It can be used to apply CDD and also to remove CDD in tiny amounts by localised sublimation, almost like an eraser. An additional step was taken after applying CDD to slow sublimation and ensure that the bones would not be exposed during transport by coating the CDD with Carbowax as an airtight capping layer. The Carbowax was tinted dark brown with powdered cement pigment to distinguish it from the CDD. Upon arrival in New York, the Carbowax was carefully picked off the specimen with a needle and then the CDD was allowed to sublime in the fume hood. The authors of that study concluded that the Carbowax capping layer was not necessary in this case because the packing materials themselves were enough to restrict air exchange and slow sublimation sufficiently. In addition, physical removal of the Carbowax could put the specimen at risk of damage.

7 Sublimation

After preparation is completed, excess CDD may be removed by careful melting with a wax pen or electric wax carving tool, if this can be done without putting the specimen in jeopardy. The CDD can be reclaimed for future use by storing in an air-tight container. In all processes, the preferred method of final CDD removal is by sublimation. Sublimation will take place at ambient temperatures, but can be accelerated by increasing air flow over the specimen, gentle warming or a combination of both. Sublimation from deep recesses or other confined spaces and from sediment deeply consolidated with CDD is considerably slower than that of surface coatings (Brown 2006; Watters 2007). If at all possible, accelerated sublimation should be carried out in a chemical fume hood.

8 Health and safety concerns

CDD health and safety information was thoroughly reviewed by Rowe and Rozeik in 2008. Aside from previously mentioned inconsistencies in the technical information on flashpoint and ignition temperatures, they reported a lack of information on human toxicity of CDD and insufficient study of respiratory exposure typically experienced in conservation and preparation laboratory settings. Their report included a summary of various research indicating that CDD is bioaccumulative. They concluded with recommendations to protect against inhalation of CDD until more is known about its effect on human health.

With the exception of the moulding project at Ashfall which was done in open air, much of the work presented here falls into two categories; work that can be done in the fume hood and work that must be done at the microscope or work station. Exposure to CDD in its gaseous phase is of concern during the latter. In a well-equipped lab, the preparator working outside a fume hood may have an elephant trunk positioned for fume extraction; however, it is common for molten CDD to be applied without extraction. Arenstein, Davidson and Kronthal Arenstein *et al.* (2004) have reported rapid

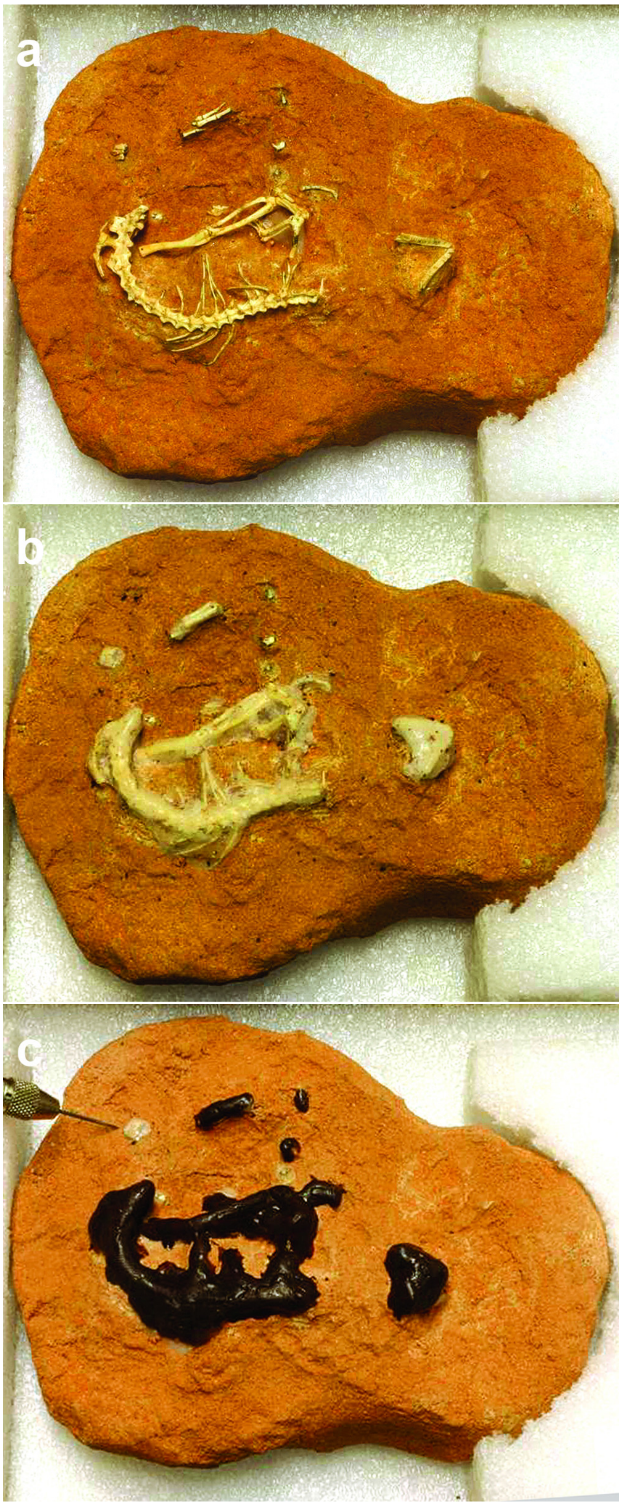

Figure 8 Preparing a delicate specimen for shipping: a) partially prepared skeleton with numerous fragile, unprotected bones that would not survive transport with standard packaging; b) all skeletal elements stabilised and protected with CDD applied as a melt; c) with a capping layer of Carbowax, originally intended to prevent premature sublimation of CDD. Photos: the authors.

sublimation of CDD during melting (losses of 0.1–3.0 g for samples of 5–10 g). There is concern about potentially unsafe levels of exposure to CDD in the gas phase during application of melts outside a fume hood, and also about the potential for exposure to CDD subliming at room temperature while the preparator works on the treated specimen under the microscope. One possible solution for limiting exposure to CDD at the work station might be to work in close proximity to benchtop extraction. G. Brown uses an extraction snorkel placed close to the specimen during micropreparation. Another possible solution might be to work inside a small glass-topped enclosure. The American Museum of Natural History (AMNH) fossil preparation laboratory was fitted out in the 1970s with home-made booths with glass tops that were originally intended for air-abrasion work under the microscope. These booths are connected to an adjustable-flow extraction system. The booths take some getting used to because they are quite confining but this might be a safer way to work with CDD under the microscope.

9 Tools

Tools for melting, applying and manipulating CDD range from commercial products to home-made (Figure 9 and Figure 10). All heating tools should have a reliable means of temperature control to prevent accidental overheating, especially to beyond the flash point and ignition point of CDD (see Section 3). Avoid ignition sources such as flame or sparks.

10 Conclusions

In conclusion, CDD has been proven to be a very versatile and useful material in fossil preparation. The use of CDD is spreading among professional and amateur palaeontologists and the need for safe handling protocols and training is pressing. Recently, fossil preparators (primarily in North America) have been incorporated into new professional organisation (spearheaded by M. Brown), the Association for Materials and Methods in Paleontology (AMMP). One of the goals of AMMP is the establishment of training standards, including safety standards for preparators. It is hoped that continued exchange of information with art and artefact

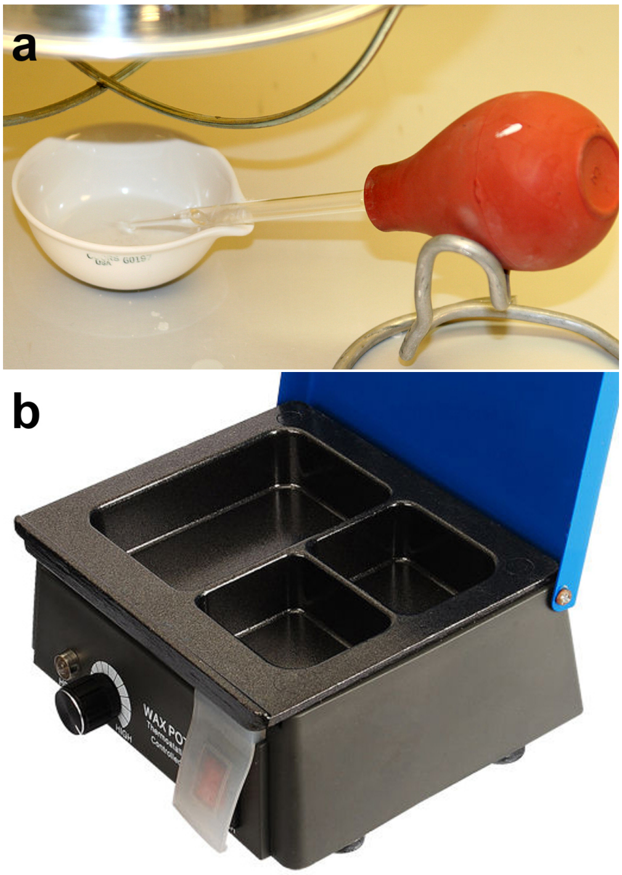

Figure 9 Two methods of preparing molten CDD: a) a ceramic bowl containing CDD placed under a heat lamp. The pipette and bulb for application is also kept warm to prevent solidification in the pipette; b) an electric wax pot with temperature control. Photos: G. Brown (9a), the authors (9b).

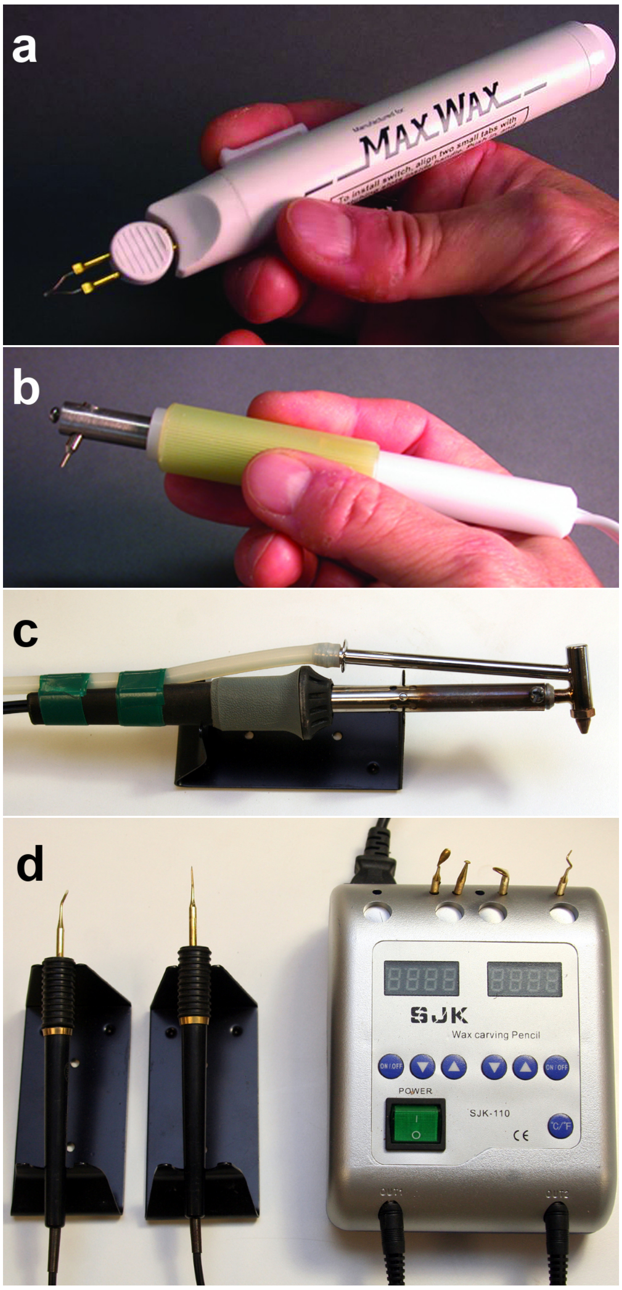

Figure 10 Tools for applying and manipulating CDD: a) a battery powered electric wax pen; b) an electric kistka; c) a modified desoldering iron with compressed air tube to provide a controlled stream of hot air; d) an electric wax carving set with multiple tips, temperature control and two hand pieces. Photos: the authors (10a, 10b), G. Brown (10c, 10d).

conservators will promote safe handling practices, encourage experimentation and spark new ideas.

Biographies

Amy Davidson is a vertebrate fossil preparator and has worked for the Paleontology Division of the American Museum of Natural History since 1993. She specialises in small dinosaurs and mammals in difficult matrices including loose sandstones, exploded mudstones and very hard volcaniclastic rock. She has collaborated with conservators since 1994 to adapt conservation methods to fossil preparation, resulting in numerous presentations, workshops and publications. Prior to her current position she apprenticed for three years in fossil preparation at the Museum of Comparative Zoology, Harvard University. She has a background in sculpture and modelmaking. She holds a BA from Oberlin College.

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Rachael Perkins Arenstein is a Professional Associate member of the American Institute for Conservation. She is currently the conservator at the Bible Lands Museum Jerusalem but remains an active partner in A.M. Art Conservation LLC, the private practice that she co-founded in 2009. Previously, she worked at the Smithsonian National Museum of the American

Indian, the Peabody Museum of Archaeology and Ethnology, the American Museum of Natural History and the Metropolitan Museum of Art. Rachael became involved with the fossil preparation community while creating content for two preservation-related web modules on the Paleontology Portal website.

Gregory Brown was, before retiring in 2014, Chief Preparator of Vertebrate Paleontology at the University of Nebraska State Museum, serving in that capacity for 33 years. His primary responsibilities were the preparation, conservation and replication of specimens in support of palaeontological research. One of the first in vertebrate palaeontology to experiment with applications for cyclododecane in the preparation laboratory, he has presented 8 papers dealing with cyclododecane techniques and over 50 papers and articles on fossil preparation and conservation. He graduated with a BS in Geology from the University of Nebraska. Continuing education has included many professional development conservation workshops.

Joseph Groenke began training in vertebrate fossil preparation at the University of Michigan Museum of Paleontology's Vertebrate Fossil Preparation Lab in 1996. In 2002, he became the Molding and Casting Technician in the Stony Brook Vertebrate Fossil Prep Lab, replicating important specimens that will be returned to Mali and Madagascar for curation. He also has responsibilities including field collection, mechanical and digital fossil preparation and collections management of specimens temporarily reposited at Stony Book University for the Department of Anatomical Science's research programs. Joseph holds a BS in Ecology and a BA in Creative Writing from the University of Michigan.

Matthew Brown directs the laboratories and collections at the University of Texas Vertebrate Paleontology Collections. Brown joined the VPL team in 2009 and began by building state-of-the-art fossil preparation and histology facilities centred on research and teaching. He designed an innovative course in palaeontology laboratory methods that integrates museum theory, conservation philosophy, emerging technologies and hands-on training to standardise methodological instruction. He holds an MSc in Museum Studies from the University of Leicester and formerly worked at the University of Chicago, the Field Museum, the US National Park Service and the Smithsonian Institution.

References

Amaral, W.W. (1994), 'Microscopic preparation', in P. Leiggi and P. May, eds, *Vertebrate Paleontological Techniques*, Cambridge University Press, New York, vol. 1, pp. 129–140.

Arenstein, R.P., Brady, C., Carroll, N., French, J., Kaplan, E., McGrew, A.Y., McGrew, A., Merritt, S. and Williamson, L. (2003a), 'Tips and treatments: NMAI living: Moving à la Martha', in *Presented at Objects Specialty Group Session, American Institute for Conservation 31st Annual Meeting*, URL `http://cool.conservation-us.org/coolaic/sg/osg/abstracts/ab2003/ab2003_1.html`. Accessed 1 April 2015.

Arenstein, R.P., Carroll, N., French, J., Kaplan, E., McGrew, A. and Williamson, L. (2003b), 'NMAI good tips: application and bulking of CDD and mass production of supports', *American Institute for Conservation Objects Specialty Group Postprints* **10**, pp. 176–187. Accessed 1 May 2015 `http://cool.conservation-us.org/cool/osg/wp-content/uploads/sites/8/2015/02/osg010-16.pdf`.

Arenstein, R.P., Davidson, A. and Kronthal, L. (2004), 'An investigation of cyclododecane for molding fossil specimens', *Journal of Vertebrate Paleontology* **24**(3, Supplement), URL `http://vertpaleo.org/PDFS/b9/b99e515c-ee14-4d8b-9795-0275b64214a1.pdf`. Accessed 1 April 2015.

Brown, G. (2004), 'Cyclododecane: vanishing support for the preparation laboratory', *Journal of Vertebrate Paleontology* **24**(3, Supplement), p. 42A.

Brown, G. (2005), 'Molding and casting of in-situ articulated skeletons in soft matrix: a case study from the Ashfall Fossil Beds, Nebraska', *Journal of Vertebrate Paleontology* **25**(3, Supplement), p. 40A, URL `http://vertpaleo.org/PDFS/28/28fdaf25-4fc5-4ad9-9528-0e355ba96384.pdf`. Accessed 1 May 2015.

Brown, G. (2006), 'Cyclododecane as a temporary sealer and filler in molding specimens with porous and penetrable surfaces', *Journal of Vertebrate Paleontology* **26**(3, Supplement), p. 45A.

Brown, G. (2012), 'Techniques and materials for microfossil preparation: Maximizing success and minimizing stress', *Journal of Vertebrate Paleontology* **32**(3, Supplement), p. 20.

Brown, G. (2013), 'Practical methods for the use of cyclododecane in vertebrate microfossil preparation', *Journal of Vertebrate Paleontology* **33**(3, Supplement), URL `https://www.academia.edu/12725905/practical_methods_for_the_use_of_cyclododecane_in_vertebrate_microfossil_preparation`. Accessed 1 May 2015.

Brown, G.W. (2011), 'An infinitely-adjustable work stage for precision preparation of microfossils under high magnification [abstract only]', in *Proceedings of the 4th Fossil Preparation and Collections Symposium, April 2011*, Brigham Young University Geology Studies, vol. 49(B), p. 1.

Brown, M. and Davidson, A. (2010), 'The use of cyclododecane to protect delicate fossils during transportation', *Journal of Vertebrate Paleontology* **30**(1), pp. 300–303, URL `http://www.tandfonline.com/doi/full/10.1080/02724630903413123`.

Camp, C. and Hanna, G. (1937), *Methods in paleontology*, University of California Press, Berkeley, CA.

Davidson, A. and Brown, G.W. (2012), 'Paraloid B-72: Practical tips for the vertebrate fossil preparator', *Collection Forum* **26**(1–2), pp. 99–119, URL `https://www.academia.edu/4483075/Paraloid_B-72_Practical_Tips_for_the_Vertebrate_Fossil_Preparator`. Accessed 1 May 2015.

Keynan, D. and Eyb-Green, S. (2000), 'Cyclododecane and modern paper: a note on ongoing research', *WAAC Newsletter* **22**(3), URL `http://cool.conservation-us.org/waac/wn/wn22/wn22-3/wn22-306.html`. Accessed 1 May 2015.

Leiggi, P. and May, P. (1994), *Vertebrate paleontological techniques*, vol. 1, Cambridge University Press, Cambridge.

Maywin, C., Groenke, J., Boyer, D. and Bloch, J. (2004), 'Novel use in acid preparation of recently recovered paleocene limestones from the western Crazy Mountains Basin, Montana', *Journal of the Society of Vertebrate Paleontology* **24**(3, Supplement), pp. 90–91, URL `http://www.tandfonline.com/doi/pdf/10.1080/02724630903413123`. Accessed 5 May 2015.

McGowan, G. (1999), 'Studio Tips session of the New York Regional Association for Conservation, New York, NY', .

Rixon, A.E. (1949), 'The use of acetic and formic acids in the preparation of fossil vertebrates', *Museums Journal, London* **49**, pp. 116–117.

Rixon, A.E. (1965), 'The use of new materials as temporary supports in the development and examination of fossils', *Museums Journal, London* **65**, pp. 54–58.

Rixon, A.E. (1976), *Fossil animal remains: their preparation and conservation*, The Athlone Press, London.

Rowe, S. and Rozeik, C. (2008), 'The uses of cyclododecane in conservation', *Reviews in Conservation* **9**, pp. 17–31.

Rutsky, I.S., Elvers, W.B., Maisey, J.G. and Kelner, A.W.A. (1994), 'Chemical preparation techniques', in P. Leiggi and P. May, eds, *Vertebrate Paleontological Techniques*, Cambridge University Press, New York, vol. 1, pp. 156–179.

Toombs, H. and Rixon, A.E. (1950), 'The use of plastics in the transfer method of preparing fossils', *The Museums Journal* **50**, pp. 105–107.

Toombs, H.A. (1948), 'The use of acetic acid in the development of vertebrate fossils', *Museums Journal, London* **48**, pp. 54–55.

Watters, C. (2007), 'Cyclododecane: a closer look at practical issues', *Anatolian Archaeological Studies* **XVI (2007)**, pp. 195–204, URL `http://www.jiaa-kaman.org/pdfs/aas_16/AAS_16_Watters_C_pp_195_204.pdf`. Accessed 1 May 2015.

Williamson, L., Arenstein, R., Carroll, N., French, J. and McGrew, A. (2004), 'Practical tips for the application of cyclododecane and creating quick, functional storage supports', *Journal of the Society of Vertebrate Paleontology* **24**(3, Supplement), pp. 129A–130A.