Journal of Paleontological Techniques

Number 5 May 2009

PREPARATION TECHNIQUES APPLIED TO A STEGOSAURIAN DINOSAUR FROM PORTUGAL

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ABSTRACT

General vertebrate paleontological techniques that have been used in the Museum of Lourinhã (Portugal) are presented here, in particular those applied to a stegosaurian dinosaur skeleton, *Miragaia longicollum*. A monolith jacket technique using polyurethane foam and plaster is presented. Mechanical preparation techniques combining the use of an electric grinder and airscribes proved effective during the initial phases of preparation on well-preserved bone embedded in hard matrix. We also present a technique to mould monoliths in the early stages of preparation, creating a thin silicone rubber mould in several contiguous parts. To mould and cast monoliths before removing individual bones has proven valuable for the preservation of taphonomic data and for display purposes. Polyurethane resin combined with plaster is useful for small casts, while polyester resin applied in four layers is the preferred technique for larger casts. The four layers are composed of: a first thin layer of polyester resin with bone colour; followed by another layer of polyester resin of sediment colour and containing glass microspheres to make it thicker. The third layer is composed of fibre glass chopped strands, and the fourth is composed of fibre glass mats embedded in plain polyester resin. 3D scanning and digitization techniques where tested for the storage of osteological information of individual bones and proved very promising.

RESUMO [in Portuguese]

As técnicas gerais de paleontologia de vertebrados que foram usadas no Museu da Lourinhã (Portugal) são apresentadas aqui, em particular as aplicadas num dinossauro estegossauro *Miragaia longicollum*. É apresentada uma técnica de revestimento de monólitos usando a espuma de poliuretano. Uma técnica de preparação mecânica revelou-se eficaz, combinando o potencial de uma rebarbadora eléctrica e de uma caneta percussora durante as fases iniciais da preparação do osso, quando envolvido em matriz dura. Foi aplicado um procedimento geral para moldar e replicar que, combina gesso e resina de poliuretano. É indicada uma técnica usando quatro camadas para a elaboração de réplicas de grandes dimensões. A primeira camada é composta por resina de poliéster colorida; a segunda adiciona microsferas de vidro e diferentes tonalidades à composição da primeira camada; a terceira é composta por fibras de vidro; e, a quarta por mantas de fibra de vidro embebidas em poliéster. A moldagem de monólitos revelou-se uma solução eficaz, preservando informação tafonómica e, ao mesmo tempo, útil para propósitos de exposição. O digitalizador 3D mostrou ser útil para o armazenamento de informação osteológica.

How to cite this article: Araújo, R., Mateus, O., Walen, A. and Christiansen, N., 2009. Preparation techniques applied to a stegosaurian dinosaur from Portugal. Journal of Paleontological Techniques, 5: 1-23.

www.jpaleontologicaltechniques.org ISSN: 1646-5806

INTRODUCTION

This paper describes the excavation, preparation, moulding, casting, and 3D scanning of a Late Jurassic dinosaur from Lourinhã, Portugal. This area is rich in dinosaurs and other vertebrates (see Antunes and Mateus 2003, Mateus 2006, and references therein). Fossil collecting and preparation in Museum of Lourinhã commenced in 1984 when the first specimens of crocodiles and dinosaurs were collected. Initially, the equipment was rudimentary little more than chisel and hammer was used. Out of curiosity, the first electric (air)scribe was acquired in 1998. The increasing number of fossils collected also brought awareness of the vital importance of preparation in the paleontological collections. The first full time preparator – Dennis Roessler – was then hired in 2001. The subsequent work was then developed by Nicolai Christiansen, Ricardo Araújo, Rui Lino and Alexandra Tomás, in consultation with Aart Walen and Museum research scientists.

Currently, Museum of Lourinhã has a modern laboratory making use of techniques designed on the basis of other preparation laboratories and adapted to our own conditions (fig. 1). "The preparation techniques applied in the Museum of Lourinhã are presented here using, as a study case, the entire process of preparation of the stegosaurian dinosaur specimen ML433 (fig. 2). This specimen was discovered in 2001 by Rui Soares, who initially discovered an exposed osteoderm (fig. 2) and formally described as a new taxon: *Miragaia longicollum* (Mateus et al. 2009).

Fig. 1 – Aspect of the paleontological preparation laboratory at Museu da Lourinhã.

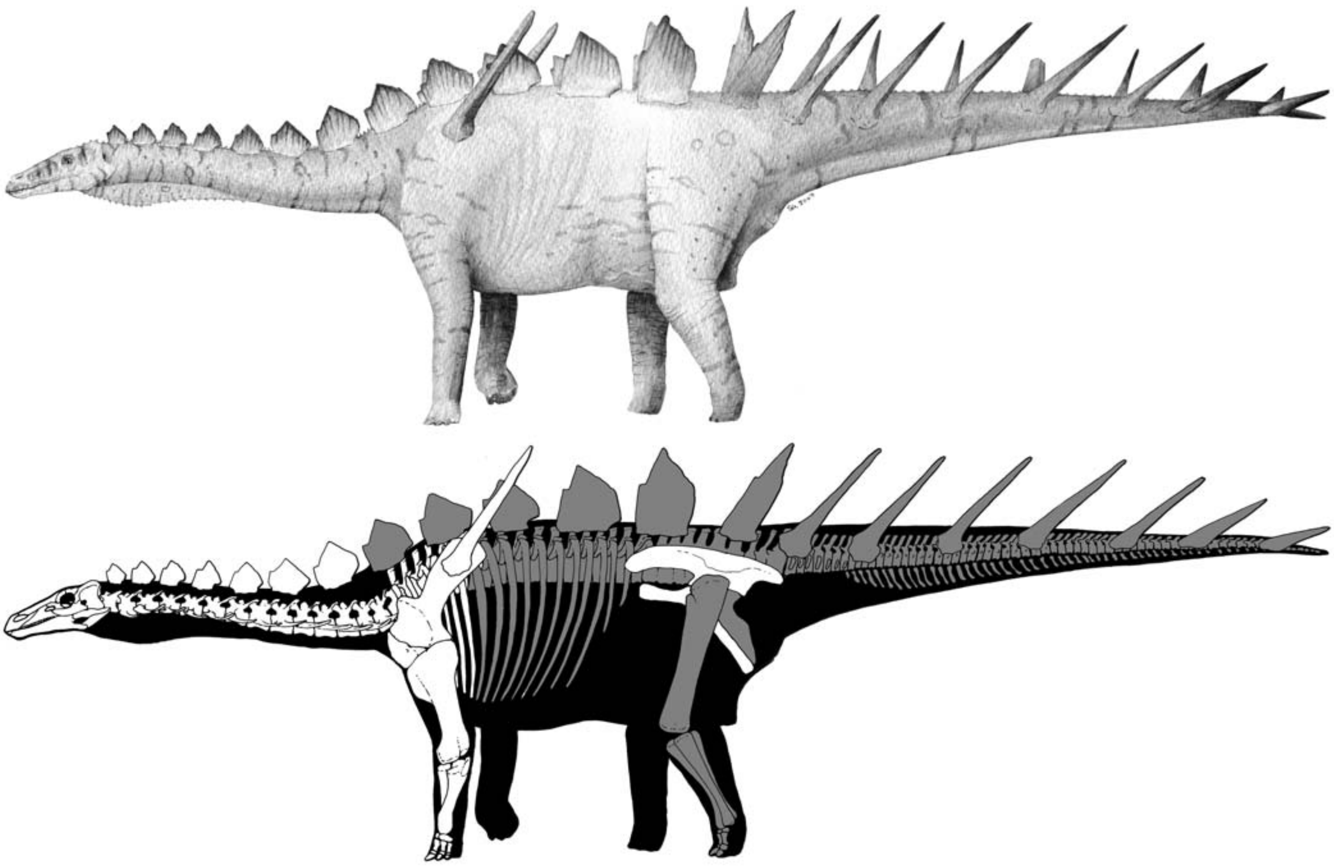

Fig. 2 – Artistic interpretation of the stegosaur dinosaur *Miragaia longicollum* and the preserved skeletal material of the specimen ML433 (illustration by Simão Mateus). For osteological purposes see Mateus *et al.* (2009).

MATERIALS AND TOOLS

The most important tools used during the process are listed below. Some of the casting and moulding products can be obtained from the same suppliers as those of fibber glass boat industries, ceramics industry, and art stores. A more complete list can be found in May *et al.* (1994).

Field:
- Hitachi® DH40FA jackhammer or hammer drill (230V; power input: 950W; 6,7kg); obtainable in a hardware shop;
- Hammer, chisel, and pickaxe (for each, four different sorts and weights, at least); obtainable in a hardware shop;
- Plexigum® 742 – 33% impregnator (base ethylmethacrylate, at 33% solids in ethanol:methoxypropanol 7:1; thermoplastic acrylic resin; medium hard polymer; soluble in acetone, alcohols, esters, aromatics – acetone has been used preferably, due to its quick volatilization); obtainable at http://kremer-pigmente.de;
- DeWalt® DW476 angle grinder; obtainable in a hardware shop;

Jacketing:
- Polyurethane foam (2-component: isocyanate and polyol); obtainable in chemical shops;
- Plaster-of-Paris; obtainable at art store;
- Gauze (regular gauze used for medical purposes – the use of this material is not recommended; burlap is preferable);
- Burlap and canvas; obtainable at fabric shop;
- Cardboard;
- Metal structure (for the monolith base).

Laboratorial mechanical preparation (fig. 3):
- Ciata® T-300/P air compressor (capacity: 284dm^3, pressure: 9,8bar); obtainable at hardware shops;
- Paleotools® airscribes obtainable at http://www.paleotools.com/:
  - Paleo-ARO™ airscribe: long bushing; solid tungsten carbide pointed stylus with 0,094inch diameter; 3,5inches long;
  - Micro-Jack®-6 airscribe: solid tungsten carbide stylus 0,063 inch diameter, 1,5inches long, 0,5inch beyond bushing;
  - Mighty-Jack™ airscribe: chisel stylus 1/4 inch diameter;

- 3M® Series 6000 respirator; obtainable in a hardware shop;
- DeWalt® DW817 electric grinder (230V; 10A; power input: 720W; 1,7kg, wheel diameter: 115mm, frequency: 10.000min^{-1}) and DeWalt® DW476 (same characteristics but different wheel diameter: 180mm); obtainable in a hardware shop;
- Renfert® basic MOBIL No. 2914 sandblaster; obtainable at http://www.krantz-online.de/de/1.html;
- Bench grinder; obtainable in a hardware shop;

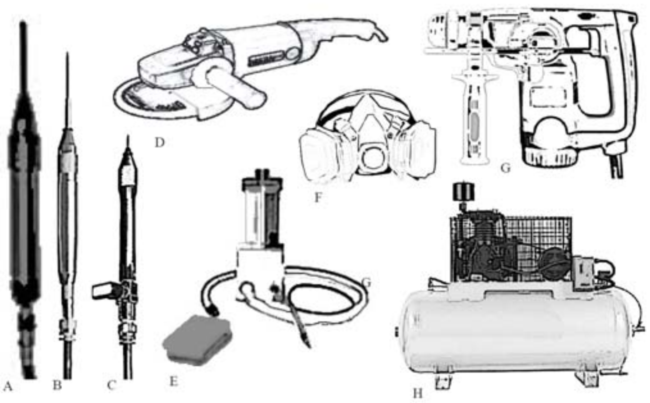

Fig. 3 – Main equipments used for mechanical preparation: A- airscribe Paleotools® Mighty-Jack™; B- airscribe Paleotools® Paleo-ARO™; C- airscibe Paleotools Micro-Jack®-6; D- electric grinder DeWalt® DW817; E- sandblaster Renfert® basic MOBIL No. 2914; F- respirator 3M® Series 6000; G- jackhammer Hitachi® DH40FA; H- air compressor Ciata® T-300/P.

Chemicals:

- Polymer acrylic resins of the brands Paraloid (Acryloid) B72, Plexigum PM381 or equivalent, dissolvable in acetone. Plexigum is a 2-Methylpropyl 2-methyl-2-propenoate homopolymer.
- Epoxy glues: Ceys® or Araldite®, two-component epoxy;
- Paleobond® PB002 penetrant/stabilizer; obtainable at http://www.paleobond.com/;
- Paleobond® bonding adhesives; obtainable at http://www.paleobond.com/;
- Paleobond® PB303 activator non-aerosol; obtainable at http://www.paleobond.com/;
- Paleobond® PB400 debonder solvent; obtainable at http://www.paleobond.com/;
- Carbowax® 4000 C005 (polyethylene glycol, storage temperature: 20ºC); obtainable at http://www.dow.com/polyglycols/carbowax/;
- Starbond® Thin EM-02; obtainable at http://www.starbond.com/;
- Starbond® accelerator; obtainable at http://www.starbond.com/;
- "Polyester putty (11-18% w/w styren; takes about 20min to dry; hardener paste: debyzoylperoxide or dibenzoil 50% w/w; aluminium powder/silica spheres. Calcium carbonate powder can be added in different proportions); obtainable at chemical stores;
- Formic acid (HCOOH); obtainable at chemical stores.

Moulding:

- Rhodorsil® RTV 863 N silicone; obtainable at http://secure.silmid.com/;
- Catalyst 863 N catalizer; obtainable at http://secure.silmid.com/;
- Rhodorsil® ADITIVO PC 12 (0,5 to 2,0% w/w) thixotropic additive; http://secure.silmid.com/
- Colour pigment powder; obtainable at a ceramics supplier;
- Ladies stockings (also known as *collants*) or anti-weed tissue (type of fabric used to avoid growth of weeds);
- Metal brush;
- Paint thinner; obtainable in a chemical store;

Casting:

- Polyurethane resin SG 130/PUR11 (stiffening time: 20-40min; recommended temperature of usage: 18-25ºC; aluminium powder and pigments can be added); obtainable in a chemical store;
- Polyester resin (11-18% styrene; takes about 20min to dry; hardener: debyzoylperoxide or methylethylketon peroxide); obtainable at most chemical stores;
- Fibre glass chopped strands; obtainable at most chemical stores;
- Glass microspheres; obtainable in a chemical store;
- Grey clay; obtainable in an art store;
- Polyurethane UV- protection coat; obtainable in a chemical store;
- Polyurethane and water based acrylic (e.g. Galeria®, Rembrandt®); obtainable in an artist store;
- Peroxide hardener; sold with polyester;
- Polyurethane foam; obtainable in a chemical store;
- Screws, wooden and metal pieces;
- Stanley-knife;
- Aluminium powder; obtainable in a chemical store;
- Silica spheres; obtainable in a chemical store;
- Fibre glass mats (300g/m^2) and strands; obtainable in a chemical store;
- Calcium carbonate powder; obtainable in a chemical store;

- Colour pigment powder; obtainable in a chemical store;
- Metal brush;
- Paint thinner; obtainable in a chemical store;
- Plastic wrapper film;
- Brushes; obtainable at art shops.

Security and health:

- First aid kit;
- Protections for eyes (goggles) and ears;
- Respiratory protection (gasmask);
- Field boots;
- Latex gloves;
- Lab coat.

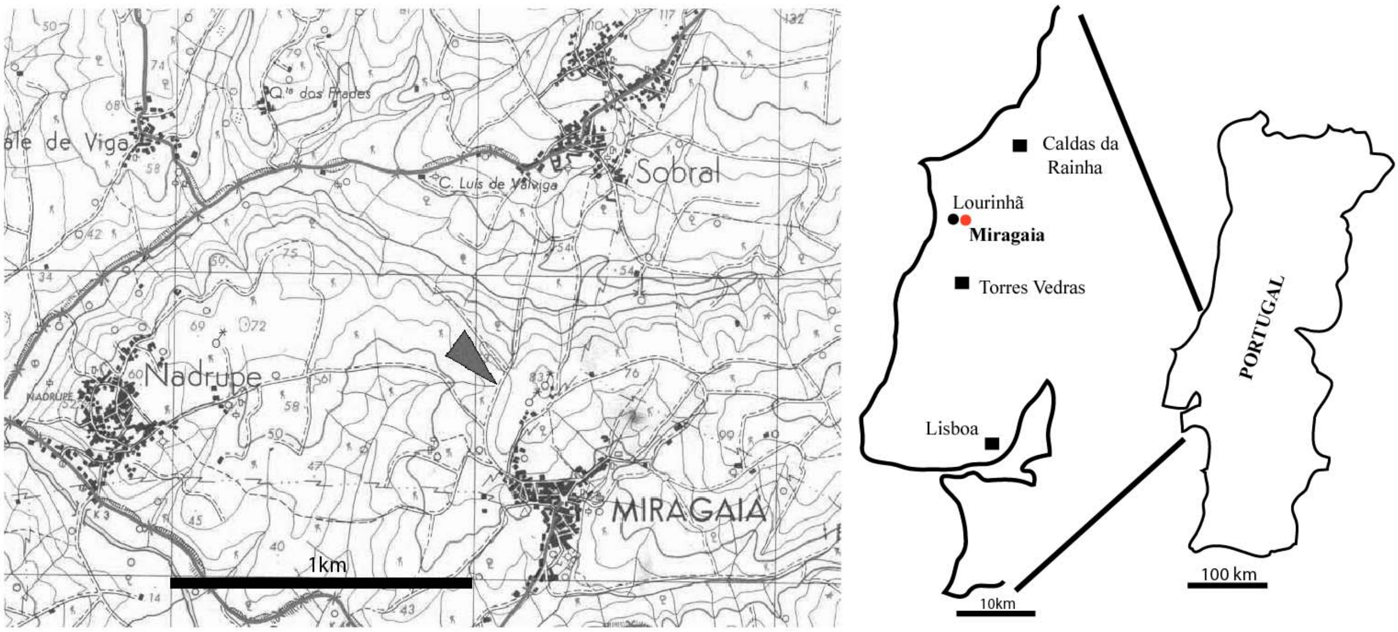

Fig. 4 – Geographical location of Lourinhã and Miragaia after Carta Militar nº349.

FIELD EXCAVATION AND POLYURETHANE JACKETING

ML433 was collected from the Miragaia Unit of the Lourinhã Group (see Mateus et al. 2009, and references therein). The stegosaurian dinosaur remains were found (fig. 4) along a secondary road linking the villages of Miragaia and Sobral. The construction of this road was the cause of destruction of the posterior part of the specimen.

The excavation and collecting of ML433 was conducted by the Museum of Lourinhã during two digging seasons in August 1999 and another in August 2001. During the first season, the quarry was opened (towards the west) with the assistance of nine volunteers. several isolated bones were extracted (fig. 5 and 7), the main block containing limb bones, ribs, pectoral girdle and cervical vertebrae was trenched but not removed until the following year.

Fig. 5 – Field techniques: A – site where the specimen was collected before excavation; B – first season of excavations; C – isolating the main block; D – jacketing technique: applying the metal frame, the block was already protected with polyester and plaster; E – applying polyurethane on the metal frame, once it hardens it attaches to the main block; F – aspect of the quarry once the main block was removed; G – transporting the main block to the museum.

The bone-bed is composed of compact calcareous sandstone overlain by more than 45cm of the sandstone with lignite lamina and carbonate nodules. The layer is subsequently overlain by 50 to 130 cm layers of mudstone, some being fossiliferous (fig. 6). The fossiliferous layer was hard to quarry, since the matrix was very dense and the preserved bone was generally more fragile than the surrounding rock. In the other hand, the cleavage between rock and fossil was perfect, enhanced by its brittle characteristics.

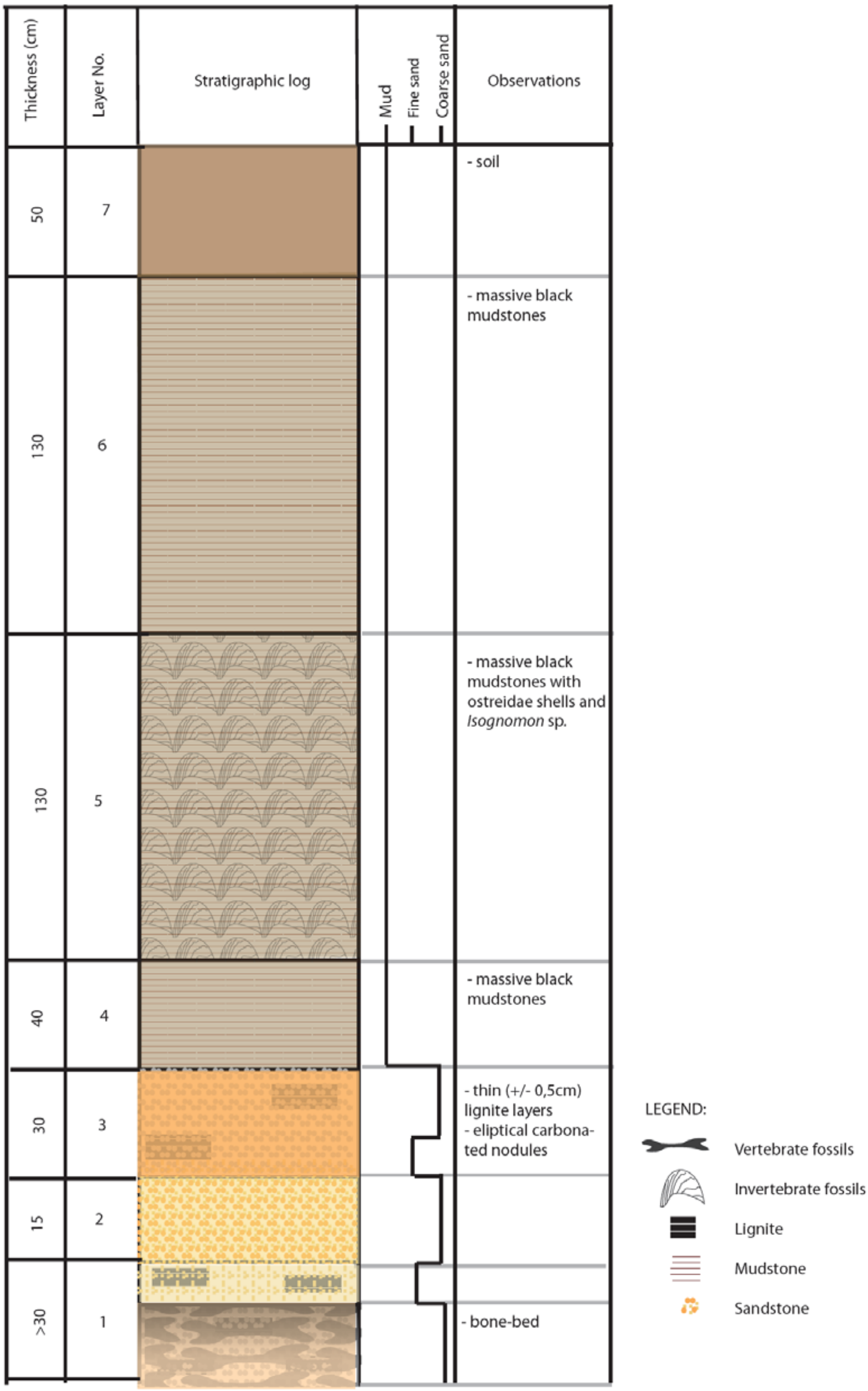

Fig. 6 – Schematic stratigraphic log of the excavated area.

During the second season, the block (then with approximate dimensions: 1,5m × 1,5m × 1m) that had been isolated during the first season was recovered from the field using a jacketing technique with expanded polyurethane (see fig.5 D, E; 7). Initially, a layer of acrylic impregnator was applied to the bones, followed by aluminum foil or wet paper. This impregnator layer, applied with a small brush (0,5cm diameter), not only prevents the surface of the freshly exposed fossil to be effaced under mechanical preparation, but also impregnates and consolidates the interior of the fossil bone. Special care should be take when the solvent is evaporating (normally 2-3minutes), since it weakens the bone while it did not evaporate completely. The solvent used is acetone. Subsequently, plaster-of-Paris with gauze was applied on the foil, although burlap has revealed to be more resistant and cheaper. Wood boards and a metal frame were placed on top of the block, increasing rigidity and at the same time making the block easier to handle. After this, regular cardboard was placed all the way around on the lateral parts of the block, serving as retaining walls to control the liquid polyurethane. As the liquid grows and solidifies into foam, the wood structure gets embedded within the polyurethane and firmly attaches to the block. Once the cardboard is removed, the mushroom-like monolith can be flipped over securely, after the base is totally excavated. The expansion of polyurethane liquid into foam takes a few minutes and grows to between twenty to thirty times its original volume. Attention must be paid when using polyurethane: the air temperature and the proportions of the two different components used will lead to different reaction time and polyurethane foam proprieties. Hot air temperatures induce a faster reaction and distinct proportion of the two components will provide a more flexible, or more brittle foam. The adhesion to the adjacent surfaces also changes with the proportions. Presence of water will enhance the expansion effect, one or two drops each 20cl are enough to produce this effect).

This polyurethane jacketing technique is particularly effective in comparison with plaster-of-Paris-only jackets when the blocks are heavy or have irregular shapes. Also, whereas a rotational cutter is mostly needed in order to open a traditional plaster-of-Paris field jacket, a polyurethane field jacket can be opened very quickly and easily using a large knife or a saw.

The foam structure absorbs physical shock and gives a strong cohesion to the block. In sum, the advantages of combining polyurethane jacketing with regular plaster-of-Paris jacketing are: 1) lighter weight (especially relevant in big monoliths), 2) the foam adapts perfectly to the block shape and fills open gaps, 3) the flexible foam absorbs shocks and gives cohesion, 4) the original liquid net volume is smaller when compared to the expanded foam, thus easier to transport and storage and 5) polyurethane foam can be reused as packing material, for example.

The large quantities of polyurethane bits that the opening of the field jacket will produce can be recycled. They can be used either as packing material or as filling for casts. By pouring freshly mixed polyurethane foam over and in between the bits will lock the two halves of a cast firmly and will dramatically decrease the amount of new polyurethane used to foam out a cast.

As disadvantages, the polyurethane is 1) more expensive, 2) less available, 3) toxic after setting if the reaction is not complete (the dust is irritating to the skin and eyes), 4) it is combustible in its solid form, and 5) it is less controllable and manageable than plaster-of Paris (the liquid is harder to control than a putty consistency).

Jacketing techniques are seldom reported; Leiggi *et al.* (1994), Schulp *et al.* (2001), Watabe *et al.* (2004) are some of the rare exceptions. Leigii *et al.* (1994, p. 75) described the traditional plaster jacketing technique. Schulp *et al.* (2001) is reported a technique where a steel collar was welded around a large block in order to remove it. One of the disadvantages of such a technique is that it requires welding in the field, which necessarily increases the logistics required. In Watabe *et al.* (2004) it is described a technique that although very safe for the block requires large quantities of plaster-of Paris.

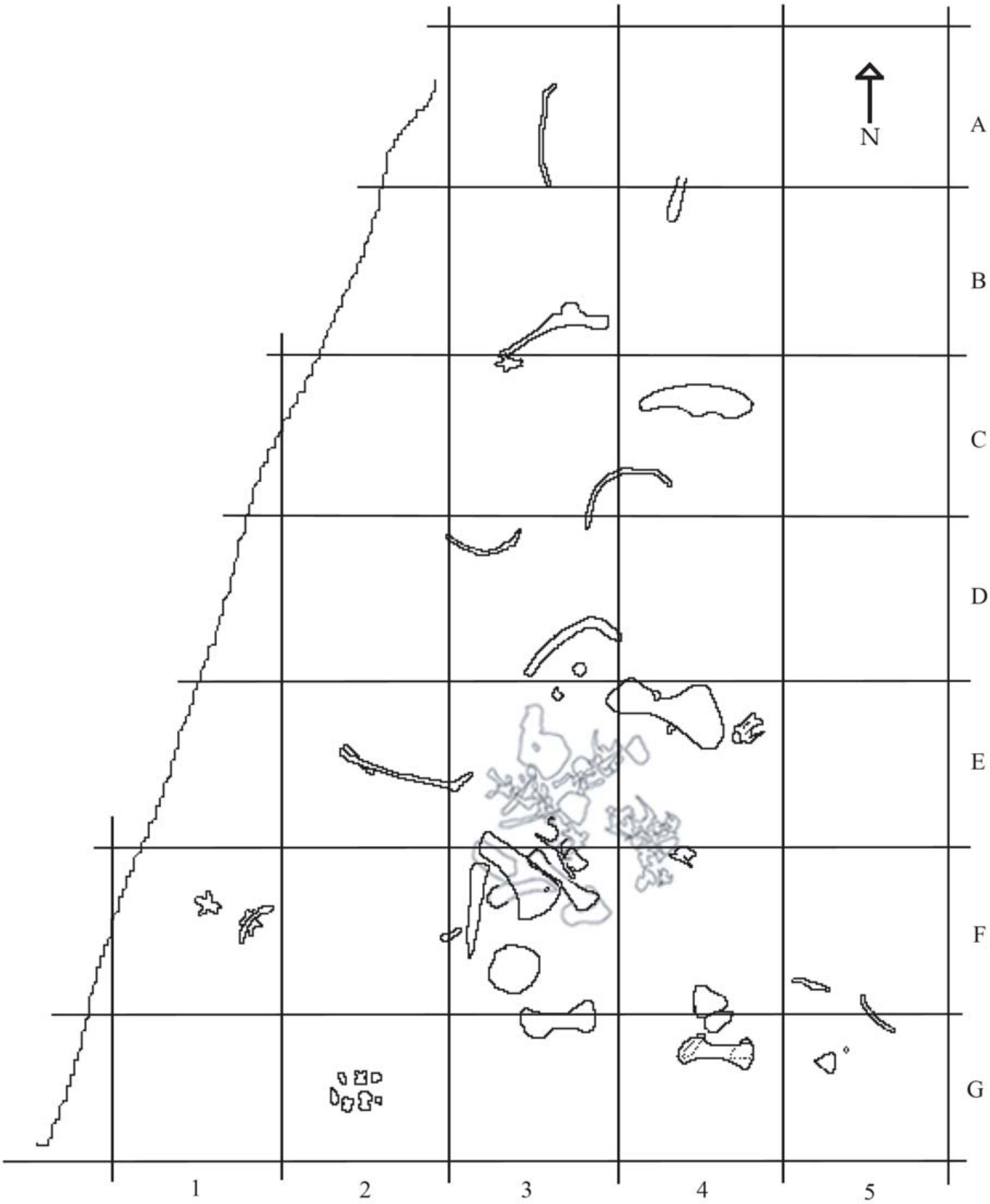

Fig. 7 – Field map. Each square scales $1m^2$ in the field. Black – isolated elements; Grey – material composing the block.

LABORATORY TECHNIQUES: MECHANICAL PREPARATION

Both airscribes and an electric grinder (also known as angle grinder) were used during the preparation of ML433. This revealed to be very effective in the initial stages of block preparation due to the extremely hard matrix composition. The use of a high-speed rotation electric grinder instead of the traditional hammer and chisel reduces vibration and damage to the specimen. The conditions that allow the effective use of these tools are 1) the contrast in colour between the matrix and fossil bones (in this case, the bone is black and the matrix is whitish, making it easy to use such heavy tools), and 2) the good preservation of the skeletal elements. Large quantities of matrix can be removed quickly using the electric grinder with minimal risk for the bone, but it is only advisable for the early stages of dismantling the block elements.

The use of the electric grinder releases a large quantity of rock dust, so working with dust extractors and in highly ventilated areas is recommended. Good dust proof masks, gloves, plastic.

Several techniques can be applied at different locations on the block relative to the position of the exposed bone:

1) "groove and break" (fig. 8A) is used when there is a high probability that what is being removed is exclusively composed of matrix. The grinder is used perpendicular to the matrix and 1 to 3 cm furrows are cut, producing a series of parallel grooves. The remaining matrix can be destroyed with the disk parallel to the matrix or with the airscribe, depending how close the exposed bone is. A long and pointed airscribe stylus should be used when applying the "groove and break" technique.

2) "polishing": with lateral movements on the matrix, slowly pulverizing the rock. This technique is used when unexposed bone is expected below the surface of the matrix (fig. 8B). It is still possible to use the electric grinder very close to the bone, but expertise is required when handling the grinder. This technique should only be performed by experienced users. It is important to have a side bar on the grinder to enhance grip, maneuverability and security. The grinder is held almost parallel to the matrix and hands must be firmly supported against the block. As the rotating disk gets closer to the matrix, thin slices start to split from the block, and the bone remains preserved. If it is not possible to reach with the electric grinder or it is too dangerous to use this tool, then the airscribe can be used as an alternative. However, using the disk parallel to the matrix might enhance risk, since unwanted pressure is developed. Nevertheless, most of the grinders are designed for lateral pressures.

One of the disadvantages of this technique is that once a mistake is made, it is irredeemable, unlike the case when using chisel and hammer, as it is still possible to glue the pieces back together. On the other hand, the time spent during preparation using the electric grinder is much reduced. Because this technique releases large quantities of dust which obscures the bone it is important to keep the block as clean as possible (with an air exhaust system, vacuum cleaner, or compressed air pistol).

In a second approach, when the block was dismantled and the bones individually separated, lighter tools were used, namely: sandblaster and micro-airscribe. Both of these tools are widely used among fossil preparators, but during the preparation of ML433 they were used in very specific circumstances (e.g. when dealing with fragile bones, such as the dermal plates). Most of the bones have a perfect cleavage between the bone and the matrix.


A

Fig. 8 – Mechanical preparation techniques using angle grinder: A- "groove and break", notice the perpendicular position of the angle grinder relative to the matrix ; B- "polishing", aspect of the matrix after applying the "polishing" technique".

LABORATORY TECHNIQUES: ADHESIVES AND CONSOLIDANTS

Consolidants have been used during mechanical preparation, impregnating the bones which increased cohesion and strength to the bone. And, adhesives were used most of the times post mechanical preparation, in order to glue separate pieces and fragments together.

Consolidants and adhesives were widely used. Acrylic polymer resins diluted in acetone were mainly used were initially (brands: Plexigum® a product of the German company Rohm, Osteofix®, and Paraloid B-72), and subsequently the cianoacrylates. Consolidant

concentration normally used was 10%v/v. Acrylic polymer dissolved in acetone was applied to the surface of the bones, which served as an impregnator, and cyanoacrylates were used as adhesives. Two-component epoxy adhesives were applied when the areas to be glued were larger than 10 cm^3, or when gaps were present between the two surfaces. Epoxy glues seem to be a better gap filler since it has have stronger binding proprieties, although it takes longer to dry (4-8h). However, cyanoacrilate adhesives were preferable than epoxy glues, since it allows a more controlled handling. The epoxy glues tend to oxidize superficially and turn into an altered yellow colour with time (two years or more), which does not happen with acrylics.
Polyethylene glycol was used successfully, serving as a rigid reversible (soluble on water and liquefiable by heat) base to prepare the very fragile skull bones and osteoderms.

LABORATORY TECHNIQUES: ACID PREPARATION

Formic (HCOOH) and hydrochloric acid (HCl) were tried at different stages of preparation of the ML433 block and were not successful for gross initial preparation. During gross preparation, the rate of dissolution using formic acid was far lower when compared to the effectiveness of mechanical preparation. Furthermore, it endangered the bone most of the times. However, during final detailed preparation, such as removing sediment traces from the bone surface, acid preparation proved useful. Formic and hydrochloric acids (5-10%) were used.
Bath immersions of specimens for a period of 2 to 5 of hours in acid proved to be very effective. In such cases, tri-calcium phosphate was used as the buffer solution (see Braillon 1973, about the use of acids in fossil preparation). One should test the efficiency of the bath immersion first only for a few minutes, in order to use adequate proportions. Acid baths allow preparation in areas that are not reachable with physical methods.

INSTRUMENT MAINTENANCE

Regular maintenance of the instruments is highly advisable: this increases average longevity, effectiveness of the equipment, and it is more secure for the user.
In order to keep the electric grinder working properly, important routine tasks need to be carried out: 1) the interior of the engine should be sprayed daily through the ventilation slots with compressed air; and 2) every six months the rubber springs in the body of the grinder should be replaced, reducing the risk of engine damage.
The separate pieces of the airscribe were oiled and cleaned every day. A jet of compressed air is particularly effective to clean each separate piece. The stylus must always be sharp. A non-controlled experiment to test the effectiveness of a sharp airscribe stylus versus a blunt one was performed: approximately three to four times more matrix can be removed while maintaining the stylus sharp. A bench grinder is recommended to perform this task. Constant cooling of the stylus while sharpening is crucial to extend its longevity and maintain the proprieties of the tungsten stylus. To cool down the stylus, it is preferable to dip it in any kind of oil rather than water, since oils are better heat conductors, but also because carbon can be incorporated. This procedure is recommended since hot temperatures reach while sharpening the stylus can alter significantly the proprieties of the tungsten.

MOULDING AND CASTING

Moulding

The partial preparation of the main block revealed an exquisite set of bones and it was decided to mould the block at this stage. Moulding a partially prepared block not only preserves precious taphonomical data, but also the cast is an informative way to show the different states of preparation for display purposes (fig. 9). In order to reduce costs a compromise between moulding a partially prepared block and the bones one by one had to be considered.

Fig. 9 – Main block cast of *Miragaia longicollum*, after being painted and mounted. The cast was painted with regular water-based colours. Note that the different pieces of the mould are not detectable, they were connected with screws, pieces of plywood and fibre glass mats with polyester resin.

Regular silicone rubber (RTV – room-temperature vulcanizing – which means it dries at ambient temperature) was used as a mould both for the individual bones and for the block. Polyurethane resin was used to cast the block (fig. 10). For individual bone casts both polyurethane resin (for small bones) and polyester resin (for larger bones) were used. Polyurethane resin is preferable for small casts because it is easier to handle: not only it hardens faster, but also when mixed with plaster it foams becoming adherent to the surface of the mould keeping the details and texture.

A general moulding procedure using silicone rubber is described in Rigby and Clark (1965) and Goodwin and Chaney (1994). However, these techniques require a large quantity of silicone, meaning more costs and risk for the bone, especially when moulding intricate-shaped bones. The technique described in this paper makes use of a relatively thin layer when compared with the techniques given in the literature, and it is therefore more economic. When compared with other materials (e.g.

latex) silicone rubber, although more expensive, is easier to detach from the bone or cast and shrinks in a lesser degree (Goodwin and Chaney 1994, p. 239). It is also flexible, long-lasting and strong.

ML433 block mould had to be made in three different parts, due to its large dimensions. A large mould is not only harder to handle, but also occupies lots of storage room. The mould and supporting moulds should be attachable to each other. To achieve this, drill through the bordering walls of the contacting areas of the supporting mould and use bolts and screws. Each piece was moulded separately by raising putty-like modeling clay walls, which separated each part of the block to be moulded. A similar procedure as explained above was performed accordingly (fig.10).

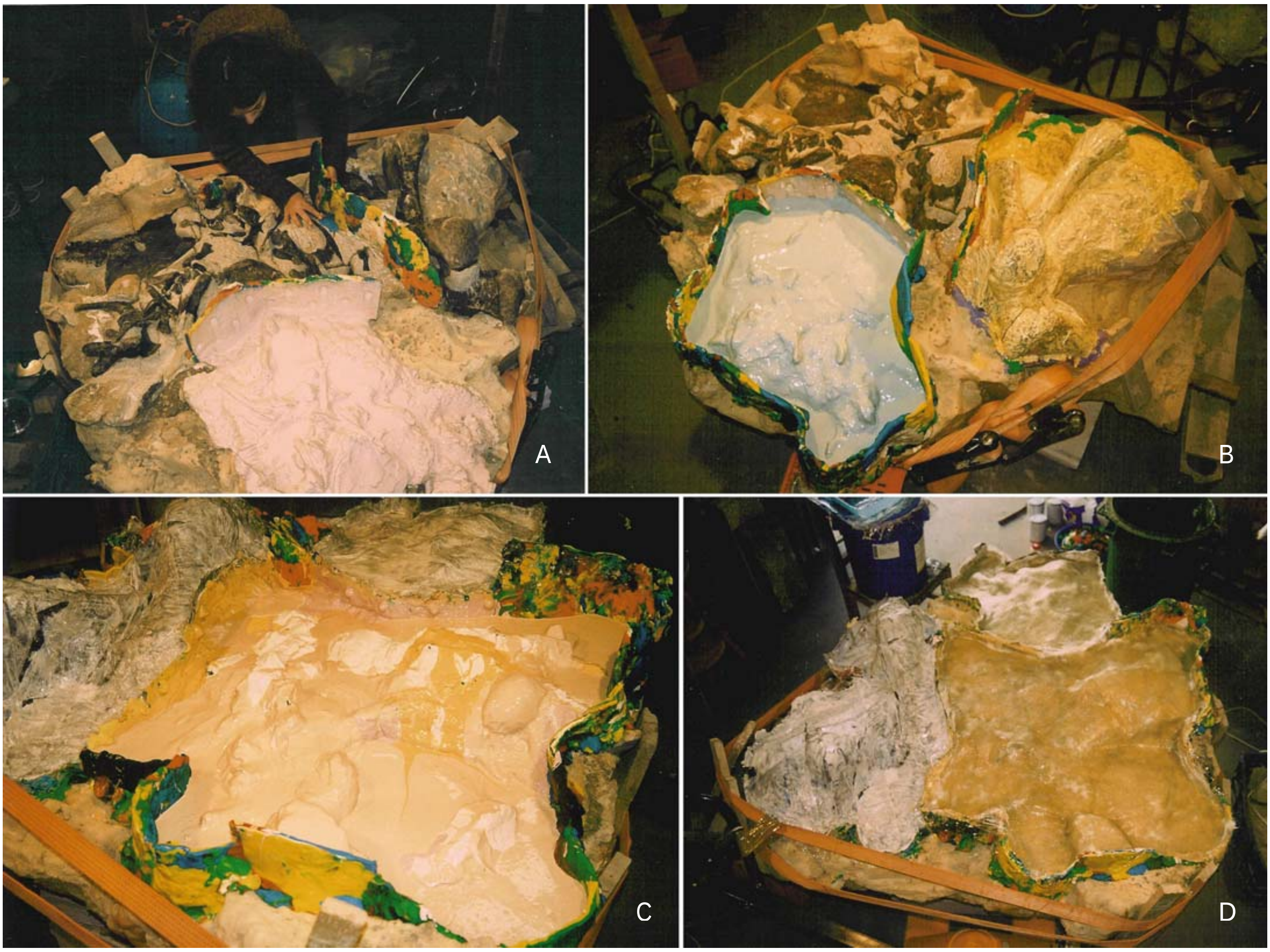

Fig. 10 – Moulding the main block: A – raising modeling clay retaining walls; B – aspect of the block after applying the first layer of silicone; C – aspect of the mould once the second and third layers of silicone were applied; D – polyester resin supporting mould.

Fig. 11 – General procedure for moulding: A – defining thoughtfully where the mould should be divided, clay is used to separate the two parts of the mould; B – application of the first thin layer; C – in the second layer thixotropic additive is added, giving a yoghurt viscosity to the silicone; D – ladies stockings can be applied directly on the mould or pieces of cotton cloths can be embedded with silicone with a spatula before proceeding to its application on the previous layer of the mould; E – aspects of the mould with all the silicone layers applied; F –plastic film should be applied before making the supporting mould; G – aspect of the supporting mould once dried; H – on the other side, the final aspect of the silicone rubber.

As Fox (2003) noted, the first decisions (e.g. establishing the mould divisions and number of parts) and steps (e.g. filling voids, adhesives used) when moulding are fundamental to avoid damage to the bone. A general procedure to mould a medium-sized bone (e.g. vertebra, fig. 11) is as follows:

Before start moulding, all the preparation work should be completely done. Thus, the bone should be well impregnated and stabilized with appropriate binding adhesives. Gaps should be filled with polyurethane putty or epoxy glue. Holes, like neural channels in vertebrae, should be closed with regular clay or modelling clay. The first layer (the most important) is composed of: hardener (5-7,5% w/w), colouring powder and thixotropic additive (0,5 to 2% w/w; 0,5% is recommended for the first layer). The colouring powder is used to check the effectiveness of stirring: the more homogeneous the colour, the better stirred the silicone is (fig.11B). Note that a temperature of approximately 20ºC works best, however it varies between different types of silicone rubber. Use a light colour pigment for the first layer, so it can contrast with the bone and the subsequent layers. It is convenient to preheat the silicone rubber (1 litre for about 1 to 2 minutes in a microwave at maximum power; 820-900W). The silicone should be slightly warmer than room temperature. Apply the second layer on top of the first when the latter is almost dried and still sticky (use a greater percentage of the thixotropic additive, so it has a viscosity approximating yoghurt; maximum: 2% w/w).

Impregnate small (10×10cm) pieces of nylon canvas (ladies' stocking is a good material for that) using a spatula. Ladies' stocking fabric can be used for intricate shapes. Alternatives are pieces of cotton cloth, or even pieces of anti-weed tissue. The silicone rubber can either be spread using a spatula or applied directly on the tissue with caution. Apply the impregnated tissue on the first two layers. Prominent areas should be reinforced with more layers of silicone or cotton cloth. Ladies' stocking fabric is flexible, resistant, porous and durable; however, it is relatively hard to apply because it is difficult to avoiding air bubbles (fig. 11D, E). Cotton cloth is easier to handle but less flexible. A fourth layer should be applied if the thickness appears to be too thin (this decision has to be made for each mould); the average thickness of a mould should be 5mm maximum.

Supporting mould casting in polyester resin

Once the silicone mould is made, and prior to its removal, a hard shell cover should be made in order to give support and keep the general shape. The technique corresponds to the following protocol:

- Cover the mould with a plastic film;
- To make the mould support, fibre glass mats impregnated with plain polyester resin are used. It is also possible to use plaster-of-Paris: a more environment-friendly solution but much less resistant and durable when compared to a polyester resin mould support;
- After stirring the polyester resin and the corresponding accelerator, the fibre glass mats should be embedded. Use an inexpensive brush and impregnate fibre glass mat pieces sweeping it on both sides. Apply the fibre glass mats onto the plastic film covering the mould; two to three layers should be enough (max 10mm), if 300g/m^2 mat is used.

It should be noted that one disadvantage of polyester resin is that it shrinks about 1% v/v. To solve that problem fibreglass mats impregnated with epoxy resin can be used instead.

Storing moulds

Since this technique makes use of a very thin layer of silicone rubber, some practical tricks should be carried out to prevent the deformation of the mould, and therefore the deformation of the next cast. For large bones (e.g. a bone from the appendicular skeleton) the borders of the mould should be attached with screws to a rigid polyester support (fig. 12). Fill the interior of the mould with toilet paper – for example – in order to keep the mould fitted as much as possible to the polyester support mould. Store the mould in a safe, constant-temperature room.

Effective storing moulds described in Jabo *et al.* (2006) were made and applied in the Smithsonian Vertebrate Paleontological collection.

Fig. 12 – Storing moulds: screws attach the silicone mould to the rigid polyester resin supporting mould.

Casting in polyester resin

The technique consists of applying three layers that, together make optimal use of the strength and flexibility of the polyester resin (fig. 13). Furthermore, polyester resin offers special characteristics which makes it useful for casting, not only it keeps all the detail from the mould, but it is also a very versatile material since it is chemically compatible with fibre glass, aluminium powder, calcium carbonate, *glass microspheres*, etcetera. When combined in different proportions with these additives, polyester resin can be adapted to many different circumstances.

For a polyester resin cast, the following procedure is generally applied:

- The first layer should be more liquid than the subsequent ones, giving the base coat the shiny characteristics of fossil bone, but most importantly the surface details. Furthermore, the right colour pigments mixture will have great relevance in the final appearance and visual texture of the cast. To prepare it, one should use: *glass microspheres* (e.g. Dacron®) working as a thixotropic powder (25-100% v/v), plus the peroxide catalyser (1-4%w/w; lower concentrations when room temperature is higher than 20ºC, and higher concentrations when applying thick layers, or in cold temperatures). In some instances other additives can be used such as calcium carbonate powder, aluminium hydroxide powder, or glass spheres that in different quantities produce different characteristics;

Fig. 13 – Casting: A – using a pouch as a pastry bag containing polyester resin; notice the piece of steel wire inside the mould, providing a rigid structure to the cast. B – applying polyester resin; this layer serves as the base colour for the subsequent painting (photos by Pedro Viegas).

- The main purpose of the second layer should be to even out the surface. This layer makes use of the same components, but it should be a thicker, more viscous liquid. Thixotropic powder stone filler (e.g. calcium carbonate powder or chalk) has been used; 10-50% w/w;
- Spread a layer of fibre glass chopped strands on top of the second layer while still moist to structurally reinforce the first layers;
- The fourth layer is made by plain polyester resin and fibre glass mats. The fibre glass mats are impregnated from both sides on the working table (not on the cast) and then applied directly onto the other three layers. Tear pieces of fibre glass by hand instead of cutting with scissors, so the fibres are loosened. Once the polyester resin is applied, leave the mat and wait for 1 to 2 min until it becomes flexible. The mats should be applied at least 2cm over the edge of the cast. Two to three layers of fibre glass mats are normally enough (with 300g/m^2 fibre glass mat);
- While the impregnated fibre glass mats are still hardening it is possible to cut them with a Stanley-knife along the edge (1 to 2h after the last layer);
- Wait a few hours to remove the cast from the mould; it still should be a little flexible. Waiting overnight is not advisable since the cast would get too rigid;
- In order to join the two parts of the cast together, one can screw pieces of plywood (5×5cm) on the inner surface of the cast with embedded fibre glass mats (5 or 10 wooden pieces per meter). Additionally, if it is too hard to hold both halves, one can use thin metal strips with holes that are screwed through the bone holding the two halves. This way, the two halves of the cast will be firmly held.

Filling with polyurethane

- Roll a piece of moist grey clay into a cylinder shape. Apply it on the space between the two halves of the cast, in order to avoid the polyurethane foaming out. The polyurethane will be applied in the next step, and if it comes out it is likely to ruin the detailed surface of the cast.
- Drill a 2cm wide hole through the cast.
- Mix a small amount of polyurethane foam and pour it through the hole. This step should be done at least three times, since an excess of polyurethane can damage the detailed surface of the cast. Wait 10 minutes and remove the clay once the polyurethane foam has reacted entirely.

Finishing the cast

- To fill the space that separates both halves of the cast, tinted polyester putty has been used successfully. It is also possible to use car body filler but it is difficult to tint the right colour and it is necessary to use much more colouring pigment powder. Preparing polyester putty requires: plain polyester resin, thixotropic powder (1000g – 25-50% v/v), gel coat (1000g 10-50% v/v), colour (pre-mixed with polyester or powder) , cobalt (2-10% w/w; it works as a catalyser), and peroxide hardener (2-3%). Mix the cobalt before the hardener;
- Once the polyester putty is made, use a plastic or rubber pouch or bag as a pastry bag (fig. 11A). Cut with scissors the corner (5mm) of the pouch. Spread some putty in the pouch and squeeze it along the space separating the two halves of the mould;
- Before it starts to harden use paint thinners (e.g. acetone) and a soaked brush on it. Manipulate the putty with the brush, creating detail on the cast surface as needed. Always keep the brush well saturated;
- After it sets, remove excess polyester putty with sandpaper. A hot air gun can be used so that the putty becomes viscous again, making it possible to scrape it off;
- To give different tonalities to the cast it can be painted in layers with a water-based acrylic. The first layer takes away the shiny appearance of the polyester resin; the second layer can be applied with a "dry brush" method. The "dry brush" method consists of: 1) spreading some water-based acrylic on a board (whitish/yellowish ochre), 2) stirring the brush on the board so the brush is coated with paint evenly, and the paint is almost dry, and 3) gently painting the cast, highlighting the natural structure of the bone. Applying two or three more layers should result in a great resemblance to the original bone.
- If the cast is going to be exposed outdoors, the polyurethane will require a UV-protection coat. Since the UV-protection is normally very shiny, add talc powder (5-10% w/w) to its original composition. This procedure allows complete mounting of skeletons in a quick and inexpensive way (fig. 14).

A few notes will be considered attending polyurethane resin. Polyurethane resin was firstly described for paleontological purposes by Jansen (1961). It is preferable to use polyurethane resin to cast bones no larger than 20cm. This happens because polyurethane resin is easier to handle and mix. If it is desired, anyway, to use polyester resin for small bones it is necessary to use special fillers and to control the heat produced during polymerization. Polyurethane resin, in the other hand, is much harder to handle for large surface bones due to its rapid set time, leaving no possibility to spread it evenly on the bone. If used for small bones with a mixture of plaster it has excellent results, giving the internal appearance of bone. The first two layers determine the quality of the cast but also the final appearance of the polyurethane resin. The colour of the first layer should be chosen carefully, reflecting the outer tonalities of the bone; the second layer is the base colour. When the second layer is applied – while the first layer is still wet – it gives some heterogeneity in the final aspect of the cast. This situation is desired since fossil bone does not have a homogeneous colour.

As noted, polyurethane resin has also been successfully applied but only for small casts or intricate structures. It is a two component compound, and when mixed with dried regular plaster in equal proportions it foams. If 1 or 2 drops of water are added it will have a similar effect. The stirring should be as homogeneous as possible, and for that purpose we recommend a drill with a mixer attached. Polyurethane resin is particularly effective when poured in single orifice moulds.

Fig. 14 – Mounted skeleton of the stegosaurian dinosaur ML433.

Further notes on the casting procedure

To accomplish the casting procedure successfully:

- Two people are preferred for this task; casting and moulding is a complex and difficult task, thus the cooperation between two people reveals much more effective. The division of the sub-tasks (e.g. stirring up components, brushing, applying chop strands, etcetera) should be consistent during the entire process;
- Use gas mask, latex gloves and a lab coat (see "Health and protection issues" section). Either polyester and polyurethane resin are extremely noxious while polymerizing;
- Use an air filter (e.g. Plymovent®) or dust extractors in order to keep the air safe to work;
- If it is necessary to save the brushes they should be immersed in thinner and cleaned with a spatula or metal brush long before the polyester or polyurethane resin dries up (polyurethane resin has a faster period of drying). In order to do that use a clean and plain surface, put the brush obliquely to the surface and scrap vigorously several times with the spatula until all the liquid polyester is removed. Then dip the brush in thinner for 12h. To reutilize brushes used in moulding a brush with metallic bristles, and scrap vigorously the already hardened silicone off against a clean and plain surface;
- All of these components are easily accessible. They are widely used for fibre glass boats industries, for example.

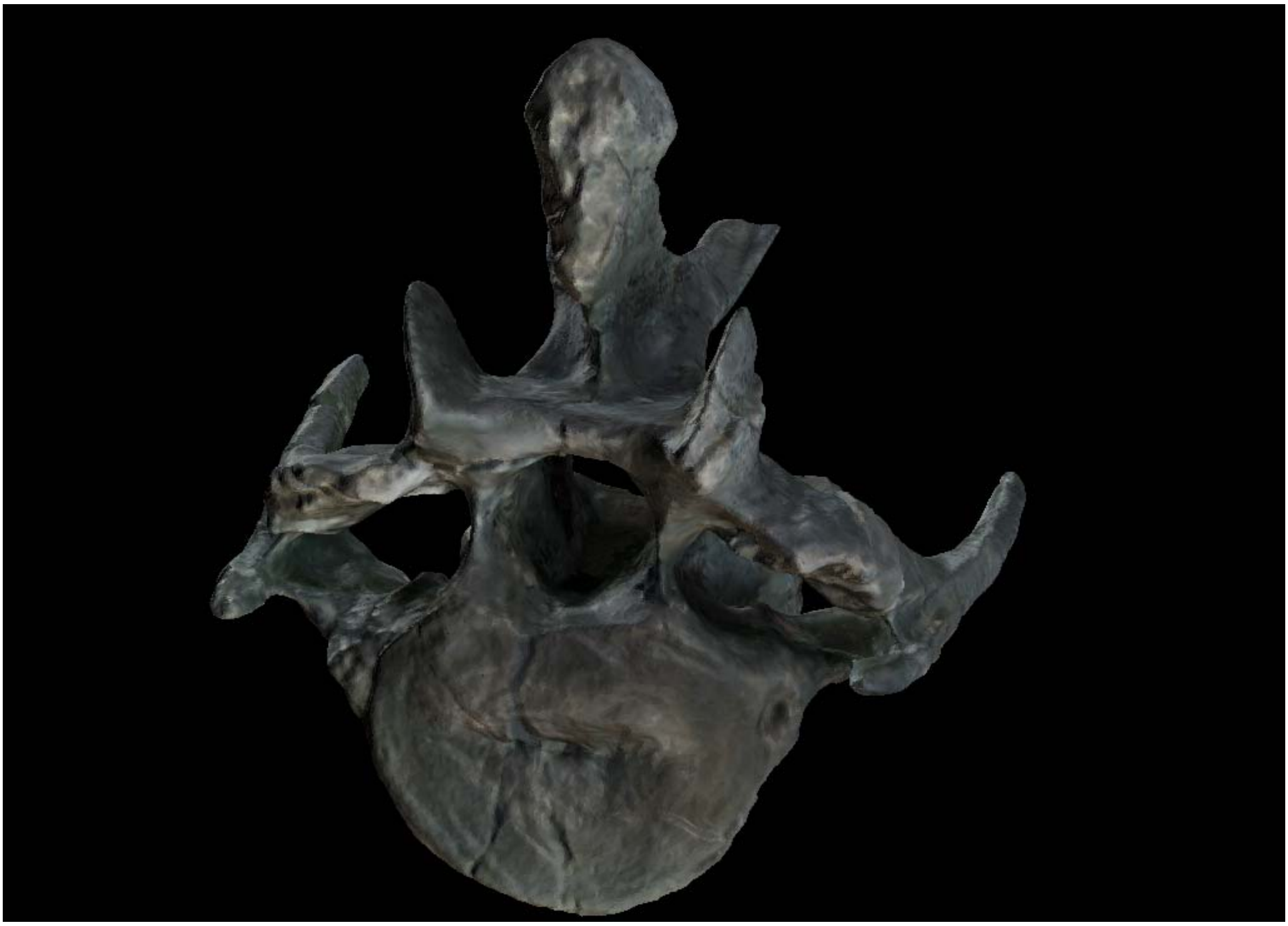

Fig. 15 – ML433 digital cervical vertebra, all the anatomical structures can be easily understood using 3D scanning.

3D SCANNING

In order to have anatomical information in digital format, the 14th cervical vertebra of ML433 was digitalized using a laser non-contact digitizer scanner Minolta Vivid VI-910 (fig. 15) with the assistance of the company Scorzio/B'Lizzard Ltd. The scanner combines the 3D surface information, acquired by a laser beamer, and real colour acquired using an incorporated photographic camera. The information obtained during each scan was a polygon representing the bone surface from that perspective. The vertebra had to be scanned in multiple perspectives in order to gather information on all sides and surfaces of the bone. Each individual scan was merged into a single analysis that gathered all perspectives, providing a complete tri-dimensional digital vertebra.

The digital vertebra file can be exported to several 3D file formats including *.stl, which allows rapid prototyping into real 3D. An optimized polygonal version was saved into an executable file permitting easy access and visualisation.

The data in the post-processing stage covers a large number of possible options. The basic options are essentially aligning and merging the unprocessed data into a complete, solid triangle mesh. The final step in the post-processing procedure is to export the completed mesh into the 3D file format and resolution desired.

This technology has multiple uses:1) to produce objects appropriate for cost-effective rapid prototyping; 2) to generate *.cnc machining paths from the object; 3) to generate 2D images of the object with optimal lighting for use within publications or on web sites; and 4) to generate 3D objects with optimal lighting for use within web sites, for example.

Advantages: 1) the scanner is portable and compact, it is possible to use it outdoors (although uncontrolled daylight is not ideal for scanning); 2) because it is a non-contact scanner the output is quickly acquired, being more effective and ideal for sensitive objects; 3) the resolution of 307.000 points each 2,5 seconds allows fast digitizing in very large objects; and 4) the file with the scanned bone morphology is easy portable.

Disadvantages: the data processing requires specialized skills that are time consuming or costly.

SAFETY

Field and laboratory work raises some health issues. Some suggestions are given here:

- Keep a complete and updated first-aid kit always easy accessible.
- Users of heavy equipment, such as jack hammers and angle grinders, should have adequate training and supervision, and always wear suitable eye, ear, hand, and respiratory protection. Adequate clothing should be used as well.
- Chiseling should be done with large-headed hammers. Classic geological hammers are not suitable for chiseling.
- Polyurethane should be handled with hand and respiratory protection.
- Acid baths should be conducted in a fume hood, with skin, eye and respiratory protection.

DISCUSSION

Monolith

A way to improve the transport of the monolith is that it is possible slide wooden bars, shovels or other tools into the hollow iron structure. These provide excellent grip for lifting and transport such block. One could imagine having especially constructed bars with wheels attached at their ends, that one could slide into the holes.

Since polyurethane foam remains relatively brittle, on could strap a net over the outside of the polyurethane in order to increase the rigidity of the block.

Mechanical preparation

Some alternatives to the grinder do exist. However, there are several disadvantages: 1) lack of power for heavy duty work (e.g. Dremel®), so if pressed too hard they might stop or jump backwards - which is dangerous both for the user and for the fossils; 2) cylindrical design (e.g. Dremel®), which makes them maneuverable, but provides a poor grip.

One of the advantages of using a grinder is that the rotational plan of the disk is follows the length of the operator's arm, i.e. it enables the preparator to operate for longer periods of time without exhausting. Whereas the rotary cylinder design goes perpendicular to the arm of the preparator, meaning wrist muscles are required.

The thickness and broadness of conventional grinders at the attachment point of the disk is one of the most limiting factors, since it makes it impossible to reach some places.

It would probably be possible to produce a tool that was more adapted to vertebrate paleontological preparation than a traditional grinder. It should be more resistant to lateral torsion on the disk as this sort of pressure is created when "polishing". So far, it has been only used regular rock cutting disks, but other types (e.g. like those used for polishing metal) could also be used. If a special tool was created it would probably be possible to create special disks that would be better adapted for the different tasks. However, a traditional grinder is relatively cheap (nowadays it can be bought for 20€, two years warranty) and can be acquired in almost any hardware shop.

3D scanning

The experimental 3D scanning work presented here projects to future possible pathways for the usage of this technology in aiding effectively preparation. As hand-held 3D scanning devices become less expensive, it is likely that they will become integrated in routine laboratory and field work. One could track the whole preparation process and it would also be possible to create 3D field maps in this way. An advantage is that it will enable to repeat the process several times, in order to visualize the advancement of work and to envisage clearly what bones lay under others as the preparation advances.

As for scanning bones completely after full preparation, it would be a huge leap ahead for scientists to be able to visualize all bones of a skeleton in 3D digital format, instead of comparing photos and notes like as it is done now. It can cut down on travel costs to see specimens and it would permit for accurate comparison of already studied specimens.

ACKNOWLEDGMENTS

We are grateful to all those that helped in the excavation, preparation and mounting of this specimen, in particular Rui Soares, Inês Fernandes, Rui Castanhinha, Dean Wright, Marisa Amaral, Rui Lino, Bruno Pereira, Dennis Roessler, Alexandra Tomás and, Plamen Ivanov. We thank Pedro Canavilhas and his team, who were essential in the 3D technology part. To Simão Mateus that provided the fig. 2, and to Pedro Viegas, Alan Lam and Jesper Milàn who kindly provided us some photographs. We are also grateful to Susannah Maidment, who reviewed the manuscript.

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