Technical note

The remedial conservation and support jacketing of the *Massospondylus carinatus* neotype

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INTRODUCTION

Massopondylus carinatus Owen, 1854 is a non-sauropodan sauropodomorph ('prosauropod') dinosaur whose remains are abundant in the Upper Karoo Supergroup sediments of southern Africa (e.g. Owen 1854; Seeley 1895; Cooper 1981; Gow 1990; Gow *et al.* 1990; Sues *et al.* 2004; Barrett & Yates 2006; Reisz *et al.* 2005). It occurs at numerous localities in the Upper Elliot and Clarens formations of South Africa and Lesotho, as well as in the Forest Sandstone Formation of Zimbabwe (Haughton 1924; Cooper 1981; Kitching & Raath 1984). Several almost complete skeletons are known, including skulls, and as a result *Massospondylus* has featured heavily in discussions of early dinosaur ecology, phylogeny and palaeobiology (e.g. Cooper 1981; Barrett 2000; Zelenitsky & Modesto 2002; Reisz *et al.* 2005, 2012; Apaldetti *et al.* 2011, among many others). However, the original syntype series of *Massospondylus carinatus* was destroyed during World War II and shown to be taxonomically indeterminate, undermining the nomenclatural stability of this important taxon (Sues *et al.* 2004; Yates & Barrett 2010).

In order to rectify this problem, a complete skeleton representing an adult individual, BP/1/4934 (nicknamed 'Big Momma'), was designated as the neotype (Yates & Barrett 2010). BP/1/4934 was collected from the Upper Elliot Formation of Bormansdrift Farm, in the Clocholan District of the Free State, by Lucas Huma and James Kitching in 1980 (see Kitching & Raath 1984, for locality details). This farm is also the type locality of the early turtle *Australochelys* (Gaffney and Kitching, 1994) and has yielded other Upper Elliot formation tetrapod material including the cynodont *Pachygenelus* and other sauropodomorph remains (Kitching & Raath 1984). BP/1/4934 is the most complete specimen of a non-sauropodan sauropodomorph dinosaur known from the entire African continent and is therefore of major regional and international significance. In addition, since 1990 it has formed part of a permanent public exhibit showcasing African palaeontological discoveries in the J. W. Kitching Gallery of the Evolutionary Studies Institute (ESI) of the University of the Witwatersrand.

During recent research work on BP/1/4934, as part of an on-going collaboration on early dinosaurs between the ESI and Natural History Museum, London (NHMUK), it was noted that its condition had deteriorated and that urgent remedial conservation work was required in order to preserve it for future generations. As a result, the specimen was temporarily removed from public display to facilitate this work, which is described in detail below (see also Graham 2017). The primary purpose of the conservation project was to assess the condition of the specimen, undertake conservation in order to stabilise it and to manufacture 'clam-shell' type support mounts/jackets for each of the blocks to enable the specimen to be displayed in an articulated posture within a purpose-built display case. An important consideration was that the blocks should be readily accessible from both left and right sides to researchers whilst securing the fossil safely. Finally, this project also provided an opportunity to facilitate knowledge exchange between the conservation staff at the ESI and NHMUK, in order to share and extend technical expertise.

GENERAL OBSERVATIONS

The skeleton had previously undergone mechanical preparation, with most of its surrounding matrix removed with percussive air scribes and matrix manually removed from areas close to fossil bone. This work subdivided BP/1/4934 from a single slab to a fully prepared skull and six other individual blocks (Fig. 1), which were variously supported on plaster, resin, putty and over-painted tissue paper. Block 7 was fractured into two parts. Relatively little of the original matrix remains and the blocks have been held in position to form the display with wires set into a fibreglass faux-matrix surround. The weight of the three heaviest sections (estimated at 15, 20 and 35 kg, respectively), together with frequent handling over several years, has led to their partial collapse, with damage exacerbated by the supporting wires. Bone surfaces were originally coated with Glyptal resin (S.J., pers. obs.), a cellulose polynitrate ester (Elder *et al.* 1997), and some areas were partially coated with over-painted plaster.

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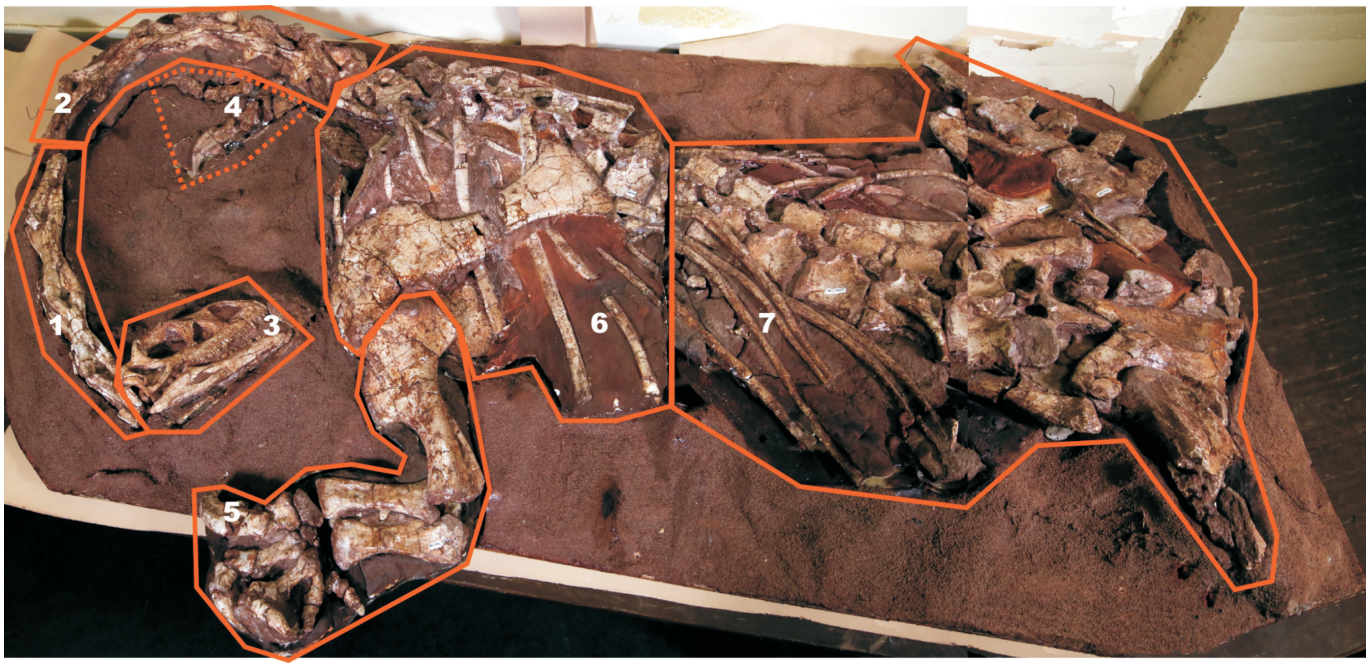

Figure 1. Composite photograph of BP/1/4934 prior to conservation with the various blocks numbered (see text for details).

The radius, ulna and left manus currently rest in a separate plaster support that formerly overhung the main fibreglass mount in the original display. Many of the larger bones, such as the humerus and femur, possess numerous small cracks and fractures. In addition to the main seven blocks, numerous fragments are associated with the specimen. Many of these represent chips of broken limb elements or sections of ribs, gastralia and vertebral processes, but it was not possible to identify where any of these were originally located on the skeleton.

CONDITION REPORT ON BP/1/4934

A composite photograph of the specimen prior to conservation is provided in Fig. 1, with the various component blocks numbered from 1–7. The condition reporting, based on assessment of the specimen prior to the commencement of work, is reproduced below and includes observations and suggested conservation actions for each block:

Block 1: A partial axis, two complete cervicals, and one partial mid-cervical. All of the vertebrae were embedded in plaster-of-Paris and coated with a Butvar resin. These elements were in a stable condition and required minimal intervention.

Block 2: Comprised four complete cervical and one partial cervical vertebra in articulation, also embedded in plaster-of-Paris with a Butvar resin coating. This block was positioned against the right manus contained in Block 4. These vertebrae required jacketing separately to facilitate access, provide additional support and to improve display options. The manus was removed via mechanical preparation.

Block 3: The cranium and mandible were virtually matrix-free and in good condition with a Butvar coating. A thin Epopast jacket was required for support.

Block 4: The right manus elements underlying the posterior cervical vertebra were embedded in a fibreglass mount. These elements were in a stable condition, but for longer-term stability it was considered advisable to remove and jacket these separately.

Block 5: The left humerus, radius, ulna and manus were articulated and contained within a fibreglass support, but were not fixed in place, so that many of these elements could be easily removed. Due to its size, and the position it needed to occupy within the final mounted skeleton, this block needed to be included with Block 6 when forming the overlying Epopast jacket, in order to retain its orientation, but removed and jacketed separately for display purposes.

Block 6: Containing the left scapulocoracoid, ribs and an articulated series of dorsal vertebrae, this was the largest individual block and required a significant amount of infilling to gaps and undercuts around and between the vertebral processes prior to jacketing. Some loose dorsal process elements also required consolidation. The ribs were positioned on a flexible fibreglass and papier-mâché mount.

Block 7: This fractured block included numerous ribs, a second series of articulated dorsal vertebrae, two disarticulated vertebrae, the sacrum, pelvic elements and a series of articulated caudal vertebrae. Consolidation was required and a complete break extended across the sacrum. All of the margins of this block required consolidation. The ribs were supported by a flexible fibreglass and papier-mâché base, which required bolstering or additional support. The heavier parts were embedded in plaster-of-Paris and matrix and/or matrix replaced by fibreglass and resin. Some surface delamination had occurred, which required consolidation to prevent further bone loss.

MATERIALS, PROCESSES AND TECHNIQUES APPLIED TO THE CONSERVATION OF BP/1/4934

Repair

Several broken pieces (mainly in the pelvic area) were

reattached with viscous Paraloid B72 dissolved in acetone (*c.* 30% by volume) and supported with foam cuts while setting. A thinner (5–10% by volume) solution of Paraloid B72 was introduced into the wider cracks and allowed to dry. As a temporary gap fill measure, thin tissue was worked into cracks and also used as a temporary substrate for deeper voids and overhangs in readiness for Epopast jacketing. After Epopast jacketing, these cracks were filled, in thin layers, with a mixture of Cabosil silicon microbeads mixed with Paraloid B72 to form a general putty-like consistency. Each layer was allowed to dry prior to application of the next, so that a flat, clear finish was achieved.

Jacketing considerations

A number of techniques exist to form support jackets from various materials, including padded plaster jackets (e.g. Jabo *et al.* 2006). An epoxy/fibreglass resin paste 'Epopast' which has been used successfully at the NHMUK was used and applied in accordance with a process developed at the NHMUK and described below.

Each block was clamshell jacketed (i.e. with jackets fitted to both the bottom and top sides of each block) to allow for safe handling by collections staff and researchers, while also facilitating a display of the articulated skeleton in a bespoke display case. The dimensions of each block were double-checked to determine the maximum height, depth and width of the jackets, given the fixed size constraints of the display case, especially with respect to the height of its glass top. These measurements are shown in Table 1.

Table 1. Dimensions of specimen, cabinet and jacket maxima in cm.

	Specimen	Cabinet	Max Jacket
Depth	107	113	6
Length	190	212	22
Height	15	17	2

For the top half of each clamshell jacket (i.e. that covering the surface of the block that would be exposed on display), the maxima shown at Table 1 are not critical, as these parts of the jacket are for use during curation and research projects only and will not be incorporated into the display cabinet). However, when forming the bottom halves of the clamshell (i.e. those cradling the 'hidden' underside of each block, thus providing its primary support within the case), care needed to be taken with the depth and height dimensions to avoid exceeding the available display cabinet space. In particular, the highest block, Block 6 (containing the scapula), was tested in the cabinet prior to installation to ensure that no contact was present between it and the glass top. The overall length of the displayed specimen was minimized by either not forming, or cutting away, the Epopast at either end of the bottom halves of the jackets, thereby allowing adjacent skeletal elements to abut directly, which also improved display aesthetics.

When constructing the clamshell jackets, the topside was created first, as this served initially as the base of the jacket enabling the blocks to be turned to reveal their undersides. The undersides of most blocks had not been exposed since the prior round of preparation of the specimen in 1980 providing an opportunity to assess their conservation status and exposing elements for research. This also enabled the undersides of the blocks to be prepared further, by removal of plaster-of-Paris from around the specimen and additional conservation by gap-filling cracks with Paraloid B72 in acetone that had been bulked out with a silica based powder (Cabosil) to form a reversible filler. A decision was taken to remove part of the old fibreglass support containing three fragile ribs, and the Block 4, containing the right manus, from the specimen as displayed. These and other undisplayed elements of the specimen are stored separately.

Options for positioning the blocks in either a wood/conservation-grade foam recessed base or by inserting metal pins into the display cabinet were discussed. The former was considered the best solution as it provided a stable base onto which to position the jackets and would allow individual jackets to be removed with minimal disruption to the rest of the specimen. It was agreed that a black cloth (or similar) draped beneath the blocks would help display the specimen to good effect.

Preparation and application of epoxy/fibreglass resin

Properties and uses of Epopast resins in conservation

Epopast E400 and E200 are two-part epoxies, consisting of fibreglass solids/paste and liquid activator/hardener that is added at 10–14% by volume (depending on the manufacturer's instructions in each case). The paste is delivered and stored in sealed metal containers and the activator in plastic bottles. Its uses include the manufacturing of bespoke support mounts and jackets for specimens and it is important to protect the surfaces of the specimen thoroughly prior to the application of the resin.

Variation in the properties of Epopast ingredients

Epopast E200 is a proprietary two part epoxy resin that is similar in its properties to Epopast E400, a product that is used routinely for the production of support mounts and jackets at the NHMUK (Verveniotou *et al.* 2011), and that has also been introduced to other museums via presentations on conservation and preparation materials and techniques and to visiting colleagues at The Conservation Centre, NHMUK. However, some differences in the two products were apparent, namely 1) that the fibre paste for E200 is more powdery and drier than that for E400 and 2) the setting resin (an aliphatic amine) for E200 has a strong ammonia-like smell requiring relevant precautions to be taken with respect to staff health and safety requirements, especially where large quantities need to be made. The supplier confirmed that the E200 product reacted by cross-linking epoxy in the same way as E400 and presented the same health and safety considerations. They also supplied an MSDS sheet (available to download from: https://www.amtcomposites.co.za/sites/default/files/media/msdata-sheets/epopast400-r-gb.pdf) that was checked prior to the product being mixed to ensure that

the process was undertaken safely. The combined E200 mix is much looser than that for E400, but the setting time is considerably shorter. Following application, it was noted that the E200 crept and pulled under the specimen so had the potential to form undercuts that would make lifting the hardened jackets impossible. This was remedied by: 1) mixing the E200 a little ahead of the time that it was needed and allowing the curing process to start, 2) applying resin from the centre of the block outward, and 3) forming a physical barrier at the rim of the jacket to prevent oozing. These simple precautions helped to mitigate the formation of undercuts, though regular inspections were carried out until the resin was fully set to allow remedial action if necessary.

Specimen preparation

As the resin can work its way into voids and then harden irreversibly, it is critical to fill any undercuts, cracks, gaps and voids with a suitable temporary filler (e.g. plasticine). Areas to be filled were lined with cling film, to avoid direct contact between plasticine and the specimen, and then the plasticine was pressed into place by hand (Fig. 2). In awkward areas, masking tape was applied to hold the plasticine in place. The filled surface was then covered with another layer of cling film, applying masking tape as necessary (Fig. 3), and a final layer of aluminium foil applied as a separator. If a Plastazote® (cross-linked, closed cell, polyethylene nitrogen expanded foam) padded jacket or support is required (to provide additional support to a very fragile specimen, for example), this can be achieved by applying a layer of plasticine to the specimen surface that is of equal depth to the Plastazote® that will be added to the interior surface of the resin jacket prior to applying the aluminium foil. This option was used for BP/1/4934 as seen in Fig. 4.

Mixing and applying Epopast

Personal protective equipment is required in order to safeguard the user from contact with, or fume ingestion from, the epoxy resin when applying Epopast, including: rubber gloves (if larger quantities are to be mixed), latex gloves, a laboratory coat, Tyvek apron and sleeves, cloth gloves, and a face mask. Due to the fumes that result from this work it should be conducted in a well-ventilated area (Fig. 5). The protocol used for the preparation of the resin is as follows:

1) Line a suitably-sized mixing container with aluminium foil, thereby allowing easy cleaning, the disposal of leftover paste and the re-use of the container.
2) Place the container on weighing scales and calibrate to zero. Remove the Epopast in small quantities and shred by hand into the container until the required weight is measured out. Shredding the resin at this stage makes mixing considerably easier.
3) Add the required amount of activator/hardener and mix thoroughly so that the mix becomes a uniform light green colour and until no grey pieces of 'raw' fibre paste remain. Any 'raw' fibre remaining results in areas of weakness following hardening.
4) To apply the mix easily and smoothly to the protected surface of the specimen, wear clean latex gloves and roll a small quantity into a fist-sized ball, then flatten it between the palms and place it onto the surface. Repeat and gently push the paste together following the contours of the specimen to form the jacket.
5) Place cling film over the resin surface and press down to minimize the formation of potentially hazardous sharp fibreglass strands that can otherwise form on the surface during hardening (Fig. 6; Supplementary information 1).
6) Check periodically, while the mix remains malleable, that the resin has not crept under any of the surfaces and, if it has, remove any excess, as once set this has the potential to create a lock between the specimen and jacket, which would cause problems removing

Figure 2. Checking for, and filling, undercuts and voids with plasticine.

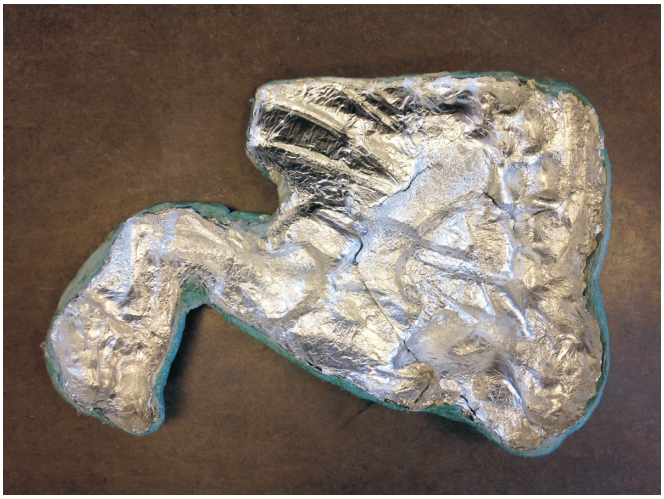

Figure 3. Blocks 5 and 6 protected by aluminium foil and cling film.

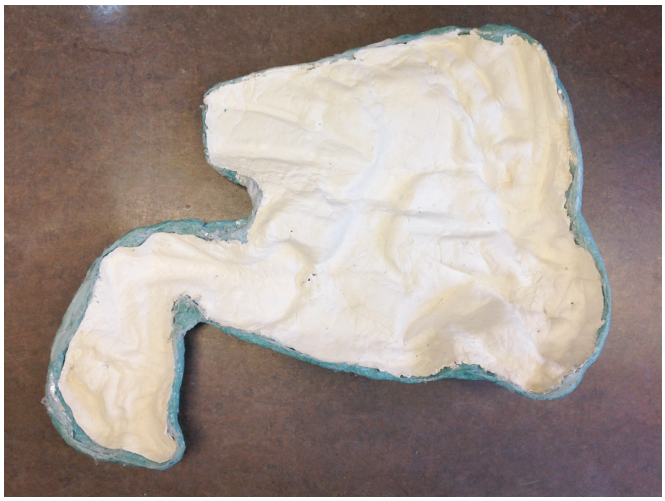

Figure 4. Application of a rolled, removable plastecine layer creates space within the jacket for the addition of a Plastazote® foam lining.

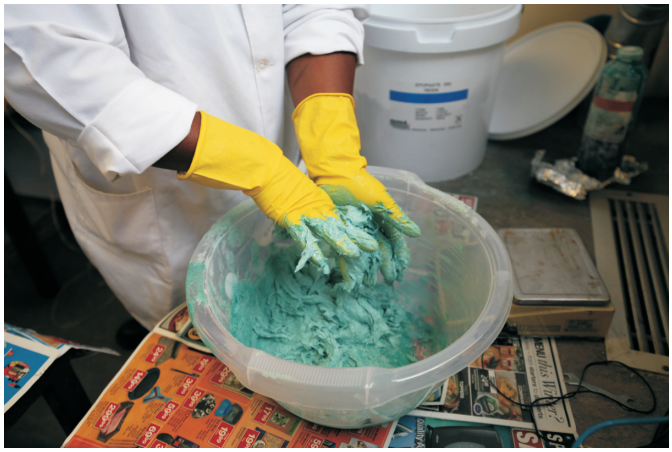

Figure 5. Resin being mixed with the activator. Note the need for personal protective equipment.

the jacket safely when hardened. Note that once the resin starts to warm and set, it becomes increasingly difficult to remove any excess without cutting.

7) Remove and dispose of the aluminium foil from the mixing container and wipe any excess mix from the container to allow for safe re-use. Any resin left to dry will otherwise form sharp fibres.
8) Allow the jacket to cure overnight and, wearing protective gloves, gently lift from the surface of the specimen.
9) Remove the plasticine (if applicable) and cling film from the inside of the shell. Then smooth the edges and surfaces of the jacket by either sanding or grinding them as necessary, in an extractor booth using appropriate personal protective equipment (i.e. a face mask) to avoid inhaling hazardous dust and fibres.
10) In the case of a padded jacket/support, cut Plastazote® of the required thickness to size and affix to the interior surface with a hot glue gun using low-melt glue sticks (Fig. 7).
11) Any uneven areas on the exterior may be filled and smoothed prior to painting or the application of a smoothing epoxy resin if required.

A short time lapse of this procedure is available in Supplementary information 1.

OUTCOMES

The condition of BP/1/4934 has been reviewed in the light of the report and recommendations that were jointly developed between the ESI and NHMUK during the appraisal and conservation visit. The technical processes involved in appraisal and condition reporting were shared and an agreed approach to the specimen's conservation and rehousing developed. During the pre-planning phase of the project, the key materials required were identified and most were procured by the ESI ahead of the visit, so that the practical work could be commenced in the available time.

Two blocks were jacketed by the ESI and NHMUK staff during the visit and this provided the opportunity for all involved to familiarize themselves with the techniques and processes. Following the visit, ESI staff continued the remedial conservation of the specimen, which included the removal, by solvents and/or by mechanical means, of the historic resins that had yellowed on the specimen's surface as well as removal of remaining failed support materials. This enabled more effective consolidation and gap-filling of the fossil and provided the basis for safer and more detailed handling of the specimen. The remaining

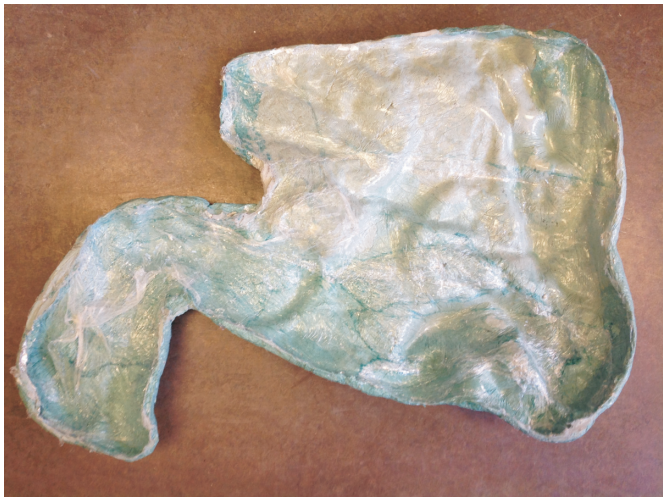

Figure 6. Resin being applied over the cling film covered plasticine, to be followed by a second cling film layer added over the entire surface.

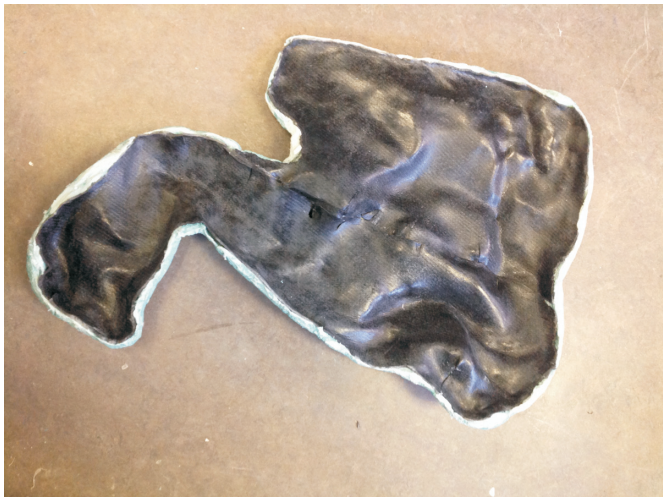

Figure 7. Plasticine removed from the hardened resin jacket and plastezote foam layer glued into place.

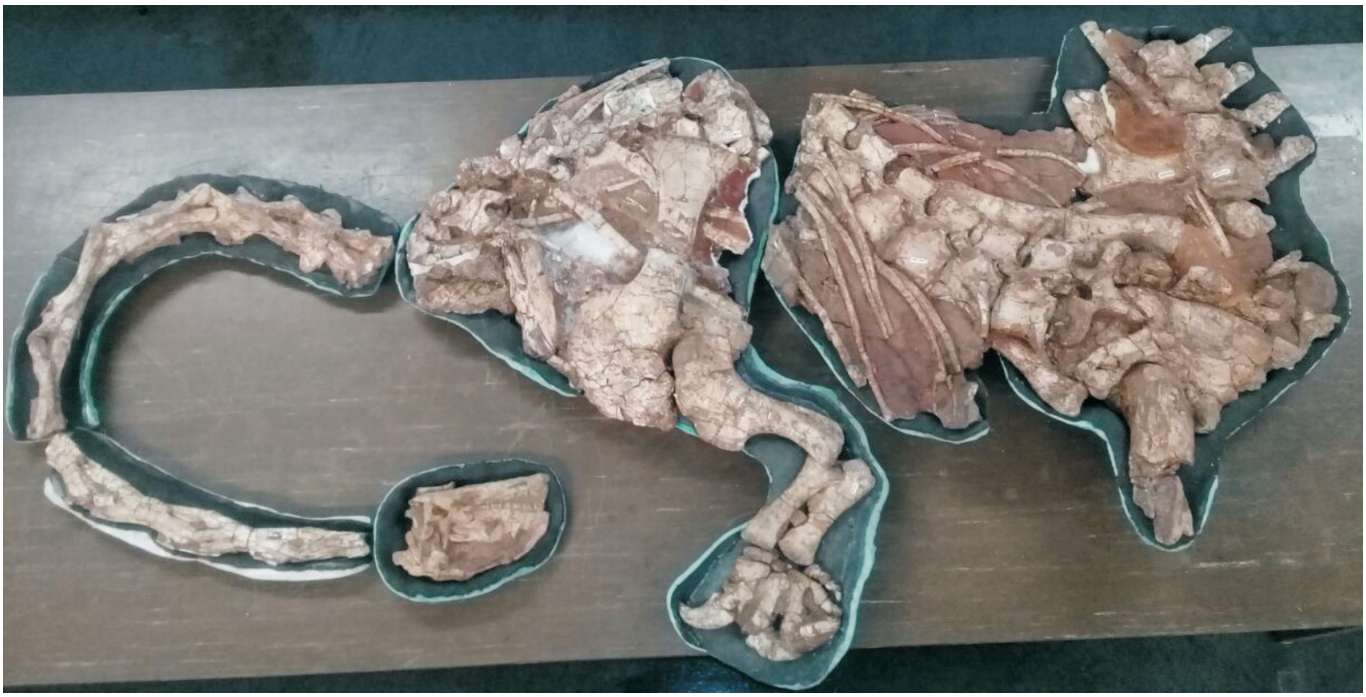

Figure 8. Remedial conservation and support jacketing completed.

support jackets were successfully manufactured and this conservation methodology may now be extended to other material in the ESI collections. It is to be hoped that, following this successful project, future collaborative field and laboratory-based conservation exchanges will follow. As a result of this joint effort, the remounted 'Big Momma' (Fig. 8) will again be exhibited as the centrepiece of the Evolutionary Studies Institute foyer where the specimen will be on permanent display for students and visitors.

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