Bollettino della Società Paleontologica Italiana, 56 (3), 2017, 359-373. Modena

Mammuthus meridionalis from Madonna della Strada (Scoppito, L'Aquila): diagnostics and restoration

Maria Adelaide Rossi, Silvano Agostini, Maria Rita Palombo, Ivana Angelini, Salvatore Caramiello, Filippo Casarin, Elena Ghezzo, Federica Marano, Gianmario Molin, Paolo Reggiani, Cristina Sangati, Lisa Santello, Giorgio Socrate & Emanuela Vinciguerra

M.A. Rossi, Soprintendenza archeologia, belle arti e paesaggio dell'Abruzzo, Via degli Agostiniani 14, I-66100 Chieti, Italy; mariaadelaide.rossi@beniculturali.it

S. Agostini, Soprintendenza archeologia, belle arti e paesaggio dell'Abruzzo, Via degli Agostiniani 14, I-66100 Chieti, Italy; silvano.agostini@beniculturali.it

M.R. Palombo, Dipartimento di Scienze della Terra, Sapienza Università di Roma, Piazzale Aldo Moro 5, I-00185 Roma; CNR-IGAG, Via Salaria km 29.300, I-00015 Monterotondo (Roma), Italy; mariarita.palombo@uniroma1.it

I. Angelini, Dipartimento dei Beni Culturali, Università degli Studi di Padova, Piazza Capitaniato 7, I-35139 Padova, Italy; ivana.angelini@unipd.it

S. Caramiello, Soprintendenza archeologia, belle arti e paesaggio dell'Abruzzo, Via degli Agostiniani 14, I-66100 Chieti, Italy; salvatore.caramiello@beniculturali.it

F. Casarin, Expin srl, spin-off dell'Università degli Studi di Padova, Via Panà 56 ter, I-35027 Noventa Padovana (PD), Italy; casarin@expin.it

E. Ghezzo, www.paleogeographic.com, Via Toffoli 38, I-30175 Venezia, Italy; egpaleo@gmail.com

F. Marano, Dipartimento di Scienze della Terra, Sapienza Università di Roma, Piazzale Aldo Moro 5, I-00185 Roma; federica.marano86@gmail.com

G. Molin, Dipartimento dei Beni Culturali, Università degli Studi di Padova, Piazza Capitaniato 7, I-35139 Padova, Italy; gianmario.molin@unipd.it

P. Reggiani, Paleostudy, Via Zabarella 21, I-35028 Piove di Sacco (PD), Italy; paleostudy@libero.it

C. Sangati, AR Arte e Restauro srl, Viale Navigazione Interna 49, I-35129 Padova, Italy; sangati@arpadova.it

L. Santello, Dipartimento di Geoscienze, Università degli Studi di Padova, Via Gradenigo 6, I-35131 Padova, Italy; lisa.santello@unipd.it

G. Socrate, AR Arte e Restauro srl, Viale Navigazione Interna 49, I-35129 Padova, Italy; socrate@arpadova.it

E. Vinciguerra, AR Arte e Restauro srl, Viale Navigazione Interna 49, I-35129 Padova, Italy; emavinci@hotmail.it

KEY WORDS - Mammuthus meridionalis, *mounted skeleton, L'Aquila, restoration, diagnostics, dynamic behaviour.*

ABSTRACT - The skeleton of Mammuthus meridionalis *(Nesti, 1825), found in 1954 at Madonna della Strada (Scoppito, L'Aquila, central Italy) and exhibited since 1960 in the Spanish Fortress in L'Aquila, has recently undergone a complex diagnostic and restoration project funded by the "Guardia di Finanza" as a contribution to the reconstruction of the city of L'Aquila after the earthquake of 6 April 2009. The specimen was only slightly damaged by the seismic event. The restoration based on a highly integrated multidisciplinary approach, began with a preliminary diagnostic analysis in order to acquire information on the state of preservation of the skeleton and on the dynamic behaviour of the metal supporting frame-skeleton assembly. The restoration was carried out by combining the most common techniques applied in Palaeontology with the most advanced techniques used for the restoration of cultural artefacts. The painstaking restoration enabled the original shape of the skeleton to be restored, revealing the actual shape of the skull and its pathological modifications. Before reassembling the skeleton, a new, correct posture was also defined.*

RIASSUNTO - [*Mammuthus meridionalis* di Madonna della Strada (Scoppito, L'Aquila): diagnostica e restauro] - *Lo scheletro di* Mammuthus meridionalis *(Nesti, 1825), sul quale venne istituita la sottospecie* M. m. vestinus*, fu rinvenuto nel 1954 in una cava di argilla in località Madonna della Strada (Scoppito, L'Aquila). Il reperto, esposto dal 1960 nella Fortezza Spagnola dell'Aquila, leggermente danneggiato dal sisma del 6 aprile del 2009, è stato recentemente oggetto di un complesso progetto di diagnostica e restauro finanziato dalla "Guardia di Finanza" come contributo per la ricostruzione del patrimonio culturale della città. Un'accurata indagine diagnostica multidisciplinare è stata condotta al fine di conoscere lo stato di conservazione dello scheletro, i prodotti utilizzati nei precedenti restauri e il comportamento dinamico dell'insieme telaio metallico-scheletro. L'intervento di restauro è stato eseguito combinando le comuni tecniche applicate in paleontologia con quelle più avanzate utilizzate per le opere d'arte. I risultati delle indagini diagnostiche hanno guidato l'intervento conservativo. Lo scheletro è stato riportato al suo aspetto originale; il cranio, in particolare, è stato rimodellato sulla base della nuova superficie corticale portata alla luce. Nell'alveolo di sinistra il premascellare ha rivelato segni di un importante evento traumatico. Infine, attraverso l'uso di un modello tridimensionale è stata definita una nuova postura, che ha guidato le modifiche del telaio e il rimontaggio dello scheletro.*

INTRODUCTION

After the strong L'Aquila earthquake of 6 April 2009, the Italian "Guardia di Finanza" made a tangible contribution to the reconstruction by offering a day's earnings for the restoration of the local cultural heritage. The choice fell on an important symbol of the L'Aquila community, the *Mammuthus meridionalis* skeleton from Madonna della Strada. The "Direzione Regionale per i Beni Culturali e Paesaggistici dell'Abruzzo" (MIBACT) therefore launched a project to restore the skeleton and reorganise the display area in the east bastion of the Spanish Fortress where the mammoth has been displayed since 1960.

The nearly complete specimen in a fairly good state of preservation was discovered in 1954 in a sandy level of an early Pleistocene fluvial-lacustrine succession cropping out in the Santarelli clay quarry at Madonna della Strada (coordinates WGS84: 42.348080, 13.256035) (Scoppito, L'Aquila) (Maccagno, 1958, 1962; Mancini et al., 2012; Agostini et al., 2014), together with fragmentary remains of a small-sized rhinoceros (*Stephanorhinus* aff. *S. hundsheimensis* Toula, 1902), hippopotamus (*Hippopotamus antiquus* Desmarest, 1822) and a large

ISSN 0375-7633 doi:10.4435/BSPI.2017.31

deer (Maccagno, 1962; Magri et al., 2010). From the clays with lignite overlying the Santarelli quarry sands, some remains of amphibians (*Triturus* sp.; *Discoglossus* cf. *D. pictus* Otth, 1837; *Bufo* cf. *B. viridis* Laurenti, 1768; *Rana dalmatina* Fitzinger, in Bonaparte, 1838) and reptiles (*Emys orbicularis* Linnaeus, 1758) and a few remains of the arvicolid *Mimomys savini* Hinton, 1910 have also been reported (Kotsakis, 1988), together with terrestrial and freshwater molluscs (Esu et al., 1992, 1993).

Palynological data coming from the clayey lignitic deposits overlaying the sandy layer suggest an age of about 1.3 Ma, older than the Jaramillo Subchron and younger than MIS 40, giving a chronological constraint for the southern mammoth skeleton found in the underlain sandy deposits (Magri et al., 2010).

Maccagno (1962) regarded the elephant as a typical *M. meridionalis*, close to the Upper Valdarno specimens, whereas Azzaroli (in Ambrosetti et al., 1972) considered the Madonna della Strada specimen as an advanced representative of the *M. meridionalis* lineage and erected the new subspecies *Mammuthus meridionalis vestinus* based on this individual (cf. Azzaroli, 1977). The taxon was described as having a larger overall size with more advanced cranial morphology, including a shorter deeper skull, higher cranium with more caudally displaced vertex, more concave forehead and long narrow tusk alveoli. After a revision of the material ascribed to this subspecies, Ferretti (1999) demonstrated that the dental characteristics of *M. m. vestinus* fall within the morphological and dimensional range of those from the rich Upper Valdarno sample. The most characteristic features of *M. m. vestinus* were considered to be the distinctive shape of the skull and the large size. Any identification of the alleged subspecies would therefore be difficult if skulls were not available (cf. Palombo & Ferretti, 2005 for a discussion).

The diagnostic and restoration activities carried out between 2013 and 2015 represented a unique opportunity to improve conservation of the specimen and gain a better understanding of its distinctive anatomical characteristics.

To define the state of preservation of the mammoth, a multi-analytical investigation protocol was followed involving detailed photographs of the skeleton taken in both normal and ultraviolet light; a 3D survey of the skeleton and armature using high definition (1 mm) phase-shift laser scanner technology; radiographs of parts of the skeleton; themed mapping; mineralogical, textural and chemical analyses to characterize the original materials (bone and tusk) and the products used in previous restorations; taphonomic analysis; structural analysis of the dynamic behaviour of the supporting frame-bones assembly, and monitoring of the microclimate (humidity, temperature, dew point).

The choice of the technical and methodological approaches to apply during the restoration performed directly in the exhibition hall, was facilitated by thorough knowledge of the characteristics of the specimen and of the taphonomic processes undergone by the elephant skeleton.

TAPHONOMIC PROCESSES

A better understanding of the degradation processes taking place at the time of the fossilisation was achieved thanks to taphonomic analysis based on the description of the fossiliferous layer, study of further, recently found photographic documentation of the skeleton's excavation (Fig. 1), and new data on the depositional facies, patinas and micro-morphologies present on the bones. The skeleton was buried not far from the lake shore near a lacustrine estuary mouth. The skeleton came to rest on a ridge of fine dark grey sand above a bar in a low marsh environment. Sands, still present in the spongy tissue of the bones (particularly those of the appendicular skeleton), consist largely of quartz, feldspars, mica, calcite and minute fragments of calcareous rocks.

Fig.1 - Madonna della Strada, 1954 excavation. The stratigraphic section described in Maccagno (1962) can be seen in the background. The geometries of the layers under and englobing the skeleton enabled important sedimentary structures to be identified.

During the first burial phase in shallow-water environments (swamp and palustrine facies), oscillations of the lake level alternated with moments of subaerial exposure of the sediments testified by occurrence of iron oxide precipitation in hydromorphic conditions. The left part of the skeleton was buried first in a low-energy context, while the bones on the right side remained exposed for a longer time. Above the fossiliferous layer, there is a distinct change of facies, characterised by strata of slightly organic dark grey clay, covered by strata of clay with layers of black and brown lignite deposited in a high marsh environment. The top of the sedimentary unit is made by cross-stratified deposition of clays and sands, with limited erosion of small channels in a higher energy environment.

As shown by a number of markers, during the first phase of burial, the surface of the bones underwent limited abrasion caused by the slow flow and reflow of a mixed emulsion of water, mud and sand. The abrasion traces are short, discontinuous with various orientations and not longer than a centimetre. In addition, the alternation of reducing and oxidising conditions produced the light brown colour of the bones and more or less extensive areas (particularly on the surface of the limbs) covered by orange red patinas caused by the presence of iron hydroxides formed by oxidation of the newly formed pyrite. A number of holes of about a millimetre in size, concentrated in irregularly shaped areas smaller than 10 cm^2, have been interpreted as associated with the action of small plant roots in the damp or marshy ground. The orange red patina is overlaid by a discontinuous black patina showing in some cases lobed margins, which may have been produced by contact with clays with a moderate organic content and/or direct contact with algal mucilage.

In short, the almost complete presence of the entire skeleton and the modest degree of erosion of the bone indicate that burial occurred in a low-energy environment. Moreover, with the exception of the skull, post-burial processes did not lead to significant load deformation or fractures of the skeleton bones.

ANALYSIS OF PREVIOUS RESTORATIONS

After recovery, the skeleton was restored and studied at "La Sapienza" University of Rome (Maccagno, 1958, 1962), then exhibited in the east bastion of the Spanish Fortress in L'Aquila (Fig. 2). The restoration as described in the Maccagno report (1958) included emptying of sand from the cavities, internal reinforcement with a structure of iron bars and consolidation using mastic. As far as possible, the missing parts were reconstructed with reference to the symmetrical bone and comparison with homologous structures. The report does not, however, mention either the type of mastic, or the type of material used to reconstruct the missing parts. Each reconstructed part was made to resemble the original as closely as possible, with a fine red line around the edges to ensure it remained clearly identifiable.

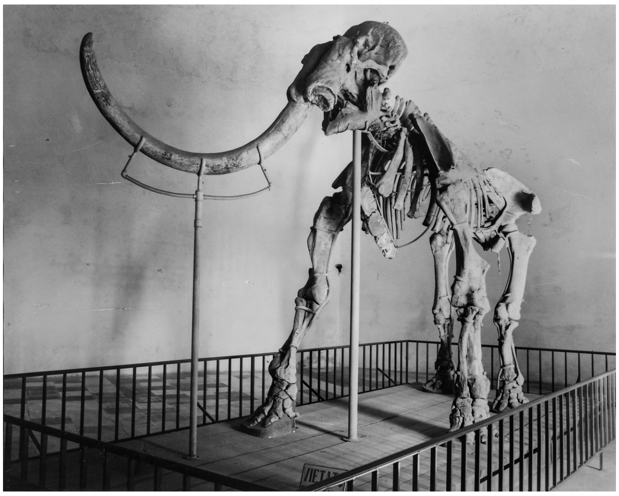

Fig. 2 - First display of *Mammuthus meridionalis* in the Spanish Fortress in L'Aquila in 1960.

Fig. 3 - The specimen after the second restoration in 1991.

In 1987, the skeleton (with the exception of the skull and pelvis) was again disassembled and transported to the University of Florence for restoration, concluded in 1991. The restoration involved cleaning and removal of part of the mastic applied during earlier restoration, consolidation with polyvinyl acetate and bonding with reversible glues as described in a similar operation (Borselli et al., 2002). Work on the cranium and pelvic bones was carried out on site. Here too a "special mastic" was used to reconstruct the missing or erroneous reconstructions, but again no information is given concerning the type of mastic.

The right tusk (weighing about 150 kg) was remodelled and reproduced with epoxy resins and polyurethane foam (weighing 10 kg), then located in place of the original tusk, which was rested at the animal's feet (Fig. 3).

The custom-made thermoplastic filler used during the first and second restorations was a glossy, waxy material, easy to scratch with scalpels, widely used in fossil restoration in Italy since the early 1900s. This is confirmed by a fragment of newspaper dated 11 December 1905 soaked in this material and found in the humeral epiphysis of a fossil elephant from the Balzi Rossi site (Ventimiglia, Imperia) (Reggiani, 2013). The filler generally consisted of 15% beeswax, 15% paraffin, 34% zinc oxide, 34% plaster-of-Paris and 2% rosin (Fabio Cozzini, personal communication). It was prepared by melting the beeswax and paraffin, then adding, in order, the melted rosin, plaster and zinc oxide. This material was also used to restore the limb long bones and tusks of a mammoth discovered in 1973 at San Giovanni di Valdobbiadene (Vidor, Treviso) (Reggiani & Sala, 1992). As in Maccagno (1958), also in this case the preparation involved removing the inner part of the bone to create space for insertion of a metal armature and subsequent addition of mastic to fill the cavity and give the fossil solidity (Borselli, 1989).

MAPPING

In line with the general principle of non-invasive pre-restoring diagnosis (Brando, 2000), the adopted method began with a fact-finding survey of the bone surfaces to identify the current state of all the osteological remains. Photographs in visible (RGB) and ultraviolet (UV) light highlighted critical areas on the periosteum (particularly fragmented elements, previous anatomical reconstructions, pre-fossilization mineral absorptions, etc.) and allowed the internal osteological structure to be characterised using X-ray images. The qualitative maps produced before the restoration thus involved a combination of detailed optical inspection, high resolution photos and X-ray plates.

The outcome also guided the following phase of chemical and physical diagnostics and defined the restoration plan, identifying areas at risk, breakage included. The maps were also used while dismantling, moving and reassembling the bones and for structural evaluations. They were updated and enhanced constantly as the amount of recorded data increased, especially when the coat of paint was removed to reveal new evidence and with the results of the diagnostic analyses.

All the analyses were performed using 156 photographs, in RGB and in UV light, and 45 X-ray plates. Mapping was carried out using AutoCAD-LT-2013. Detailed information about the methodological approach is provided in the Supplementary Online Material.

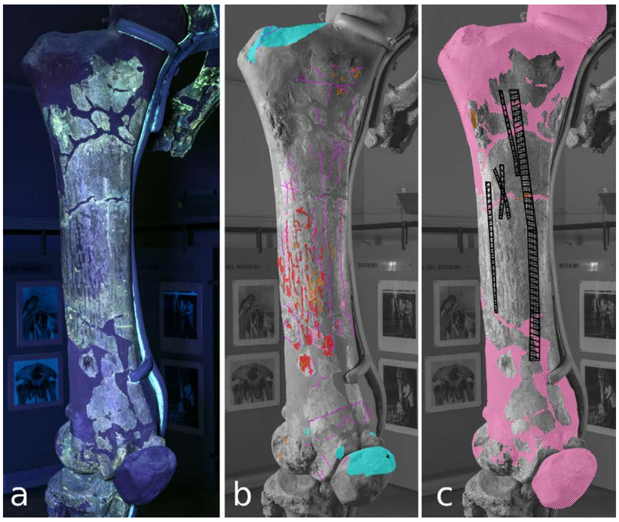

Fig. 4 - (color online) Right femur in frontal-lateral view. a) UV photo (grey scale / RGB); b) mapping showing the coating of dust (dark grey / light blue), impregnations (black and oblique lines / brown and red) and surface fractures (simple black / fuchsia); c) reconstructions (white / pink) and metal pins revealed by X-ray (black / black rectangles) (see Tab. S1 in the Supplementary Online Material for more details on the mapping).

Results

The flat surfaces of the bones and especially the vertebrae and coxae were covered with a hard coat of dust. Bones are impregnated with iron minerals accumulated as a consequence of the concentration of these minerals in the soil in the peri-depositional context. The scattered spots are visible over the entire skeleton and on the diaphysis of the limbs and are particularly noticeable on the subscapular fossa. Corresponding to these mineralized areas, there were broken, although stable, bone surfaces, most frequent on the articular processes and on thin bones such as the tusk alveoli and the scapula. The trabecular area near the epiphyses was stable and associated with post-depositional events and the age of the mammoth at the time of death.

In particular, the mapping highlighted the different materials used for the reconstructions (Fig. 4). UV light allowed two different restorations to be identified, each improving remodelling of the lost anatomies, and the different paints used to imitate the natural colour of the skeleton to be distinguished. Different materials were used for the reconstruction of the mammoth and to reproduce its phalanxes.

The body is known to have been lying on its left side when discovered and the right side was probably partially destroyed (Maccagno, 1958). As a consequence, this side of the animal is deteriorated with more reconstructions: the right occipital bone and part of the skull, the right hemimandible, part of the iliac fossa, the proximal and distal epiphyses of the femur, humerus and ulnae and most of the scapula and ribs. The left side is better preserved, although pivots and metal armatures were inserted to support the largest bones (skull, mandible, scapula, long bones, coxa and some vertebrae), on fragile structures (left zygomatic arch) and to support the diaphysis (Fig. 5).

Finally, the fossils were partly covered with organic-synthetic material (glue and epoxy resin), principally corresponding to the reconstructions and showing on the UV images as intense yellow and cyan blue (Tab. S1, Figs S1, S2 in the Supplementary Online Material).

Remarks

X-ray analysis is commonly used in palaeontology and palaeoanthropology to investigate trabecular structure and osteological resistance and to recognize pathologies, traumatic events or bone growth (Franzen et al., 2009; Blondiaux et al., 2012; Leden et al., 2012; Sami & Ghezzo, 2015; Germonpré et al., 2016). UV images have been widely used on pre-Quaternary fossils in a sedimentary matrix. These techniques are used, for example, to recognize colour patterns on shells (Hendricks, 2015), different materials in fossils and previous surface restorations (presence of organic glues or fakes) (Hone et al., 2010; Dal Sasso & Maganuco, 2011; Stone, 2010). They were recently applied to Jurassic fossils, revealing the microstructure of feathers in non-avian theropods and their evolutionary trends (Tischlinger, 2002, 2005; Tischlinger & Unwin, 2004; Hone et al., 2010).

Both techniques are less frequently used in palaeontology for pre-restoration analysis and UV

Fig. 5 - Left mandible (left) and X-ray of the mandible (right) with metal supports and reinforcement of the ascending ramus (as listed in Tab. S1 in the Supplementary Online Material), with complete reconstruction of the apical articulation (condyle).

photography is rarely used on relatively recent remains. In the case of the mammoth discovered in 1954 at Madonna della Strada, mapping revealed and defined homogeneous areas to guide sampling for mineral and chemical analysis (a method previously used by Riquelme et al., 2009). Mapping generally proved to be useful in acquiring information on the surface condition of the skeleton, identifying all criticalities, including reconstructions, fractures and the presence of sporadic organic phase responses (fluorescence) due to previous restorations.

COMPOSITIONAL AND TEXTURAL INVESTIGATIONS

Before proceeding with the restoration, a campaign of diagnostic studies was carried out to define in detail the mineralogical and chemical characteristics of the constituent materials of the specimen.

The study was divided into two phases. During the first phase, following meticulous morphological observation, a wide range of surface samples considered representative of the specimen as a whole were taken. The composition and texture of the original materials (bones and tusk) were determined, together with those of the materials used in the previous restorations (reconstructions, resins, patinas and paints) as their composition was not fully known due to a lack of detailed reports. This first phase of study was aimed at acquiring information on the complexity of the specimen to ensure that, throughout the restoration, all actions and methodological choices were guided by adequate scientific knowledge. On the basis of the acquired results, a second phase was carried out to acquire detailed information on the composition and texture of the three long bones chosen as representative (humerus, tibia and ulna). This involved core sampling the bones. The aims were to provide the structural engineer with data to evaluate the mechanical resistance of the bones and the restorer with information to guide the conservation and consolidation work, including evaluation of whether or not to replace the synthetic materials applied previously.

The analyses were performed generally on small samples measuring about 0.5 mm^3. Preliminary stereomicroscopic study of the samples was followed by detailed study by optical microscopy (OM). Furthermore studies were performed using complementary diffractometric and spectrometric techniques: X-ray powder diffraction (XRPD) and infrared (FTIR and μ-FTIR) and μ-Raman spectroscopy. Elemental analysis was carried out by X spectroscopy using a scanning electron microscope (SEM) coupled to an energy dispersive spectrometer (EDS). Textural analyses, particularly important in light of the project's objectives, were carried out with both OM and SEM.

The methodologies adopted are provided in the Supplementary Online Material whereas the principal results obtained are summarised below, in order to contextualise the study campaign prior to the restoration of the mammoth.

Results

Bones - As a whole, the histologic characteristics of the original bones are more or less well preserved.

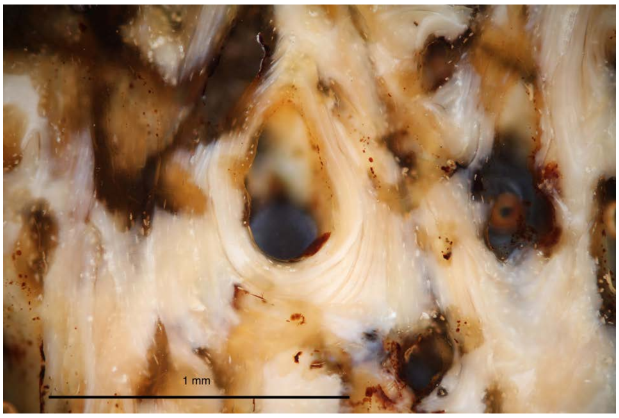

Fig. 6 - Image recorded by optical microscope in reflected light (xNicols). Thin section of the core of the right ulna: detail of an osteon in the well-preserved bone tissue. Scale bar corresponds to 1 mm.

Porosity can be attributed to the texture of the bone tissue, found to consist largely of carbonate-apatite, generally not (or only slightly) replaced by precipitation of other mineral phases during diagenesis (Fig. 6). In a number of areas, "mechanical replacement" was found to have occurred during fossilisation, with cementation of angular arenaceous clasts from the sediments of the fossil bed, almost like a "natural integration". In those cases, the presence of quartz, calcite, dolomite, feldspar and ferrous mica granules was observed, often cemented by calcite. Importantly, pyrite (FeS_2) and iron oxides and hydroxides (haematite, goethite and limonite, sometimes pseudomorphs on pyrite) deriving from alteration of the pyrite in a damp oxidising subaerial environment were found in the pores and inter-tissue spaces (Fig. 7 and Fig. S3 of the Supplementary Online Material). Pyrite is therefore the principal mineral forming during diagenesis. This finding, together with the widespread presence of its oxidation and hydration products in the bone tissue (cause of the diffuse ochre colour of the entire specimen) demonstrates that the carcass was buried and preserved in an anoxic depositional environment characteristic of lacustrine and paludine basins. The presence of

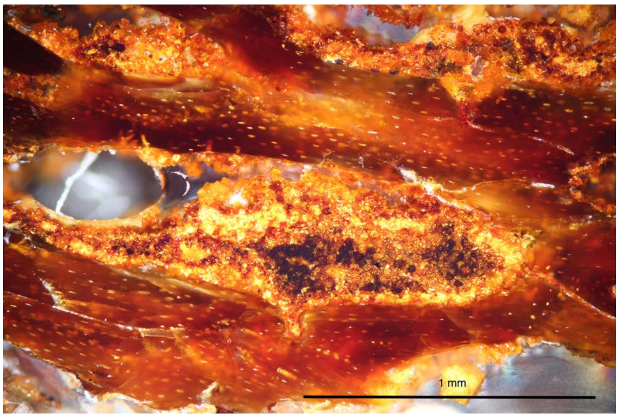

Fig. 7 - Image recorded by optical microscope in reflected light. Thin section of a bone sample from the right tibia. The apatite bone tissue is embedded in iron oxide and hydroxide, responsible for the orange colour. Secondary depositions of these phases are visible in the central large pore. Scale bar corresponds to 1 mm.

pyrite crystals also indicates that the relative process of alteration through oxidation and hydration is still active and requires accurate evaluation, given the risks for long-term conservation (Turner-Walker, 2009). These transformations, in fact, result in a notable increase in volume (leading to the disintegration of the specimen), with the creation of a markedly acid environment (due to production of sulphurous-sulphuric acid) which in turn encourages the transformation from calcite to gypsum with a further increase in volume. The products applied during previous restorations, such as polyvinyl acetate (PVAc), were identified using μ-FTIR and μ-Raman analyses.

Tusk - The examined samples revealed a compact, well-organised structure of dentine fibres (ivory) consisting of fluoro-carbonate-apatite. The crystallinity and texture of the internal sample were excellent, less so the external sample where the presence of interstitial calcite precipitated during diagenesis was found. The orange colour of the tusks is caused by interstitial diffusion of minimal quantities of iron oxides/hydroxides, as also found on the bones.

Reconstructions, patinas and resins - Unfortunately, no detailed description remains of the composition and location of the numerous reconstructions added to the bones in previous restorations. A study therefore had to be performed to define the composition of two recurrent types of material, classified on a chromatic basis as light reconstructions and dark reconstructions. Both were found to have moderate plasticity and to contain a number of minerals, with bassanite, gypsum, anhydrite and calcite predominating. They also frequently contained white pigments such as zincite and to a lesser extent barite. Importantly, the organic component consisted mainly of a polyester type compound in the case of the dark-coloured reconstructions and paraffin and paraffin waxes in the case of the light-coloured reconstructions and patinas. Five samples with a "resinous" appearance were also taken, considered as representative of the variable textures and colours observed for this type of material. Their composition was found to be very varied and multiphasic, suggesting that many materials and different technicians had been involved in previous restorations. They range, in fact, from a calcite and gypsum based filler with organic aliphatic binder used for the tusk, to bassanite with beeswax binder for the reconstructions on the right tibia. PVAc and phenoxy and epoxy resins revealed also to be present.

Paints - During previous restorations, the reconstructed areas had been painted to rectify their whiteness and blend them in with the basically ochre colour of the bones. Once again, different types of work by different technicians were observed, generally involving application of a mineral fraction consisting of a light-coloured gypsum-calcite-barite based dispersant and rutile and titanite based pigments. The organic fraction was found to consist of waxy paraffin and linseed based compounds.

Core sampling of the long bones - Core sampling enabled the texture and composition of the three selected bones (tibia, ulna and humerus) to be studied in detail, together with the nature of the consolidants used in previous restorations and the outcome of consolidation. As regards the macroscopic texture, all the bones were found to have retained the original histologic characteristics. The periosteum of the bone was found to be compact, becoming progressively more spongy towards the endosteum. The microtexture is perfectly preserved, with well-organised osteons and the Haversian canals generally open. These are largely covered by a fine layer of iron oxides-hydroxides deriving from alteration of the pyrite deposited in considerable quantities during diagenesis. By far the most predominant mineral component is carbonate-apatite, evidence of the low degree of mineral replacement during fossilisation. Of particular importance is the widespread diffusion of iron oxides-hydroxides which both give the specimen its ochre colour and also represent a significant phase of cementation. The silicon found in pores and cracks (Fig. 7) can be attributed to the presence of quartz and feldspars deriving from the surrounding sands.

In previous consolidations, epoxy resin (araldite) had been used, including to reconstruct the missing internal parts. Study of the core sampled bones showed that this may not have involved all the bones in the skeleton and that the degree of penetration of the resin into the porous bone was not homogeneous.

THE DYNAMIC BEHAVIOUR OF THE SKELETON

The bearing structure consists of an iron frame, moulded in the 1950s by a local blacksmith. This can be roughly divided into "primary" elements (leg supports, hollow pipes supporting the spine, a pole supporting the skull) and "secondary" elements (hooks connecting the bones to the primary elements).

The on-site survey, consisting in ambient dynamic identification of the supporting frame-skeleton assembly, showed the great deformability of the metal frame, with main periods in the order of 1.8 to 1.3 s. It was, in fact, possible to move the whole supporting frame virtually effortlessly by hand by several centimetres in a transverse direction, demonstrating physically that this was the predominant mode shape in the dynamic behaviour (Casarin et al., 2015).

The Finite Elements (FE) model of the mammoth was constructed using the 3D geometric model obtained with the laser scanner technique (Figs S4 and S5 in the Supplementary Online Material). The FE model was calibrated with the results of the dynamic tests. Four/five acquisition setups were employed for the dynamic identification, with eight to 12 seismic high resolution piezoelectric accelerometers fixed at different levels on the frame (Figs S6 and S7 in the Supplementary Online Material). The dynamic identification tests clearly identified the first two frequencies (0.56 Hz, 0.75Hz), representing the first vibration modes in the transverse and longitudinal directions.

Linear static analysis was carried out in order to assess the stress levels in the elements of the metal frame. The only force considered for this analysis was self-weight.

All details of the applied methodology are provided in the Supplementary Online Material.

Results

Analysing the axial stresses of the beam elements of the frame, the most stressed elements were found to be the vertical supports of the structure (leg supports) which transmitted the entire weight of the skeleton to the ground. The skeleton was not found to be subjected to evident stresses (except in a number of contact points due to singularity of the model), indicating that the stresses were correctly transferred to the steel frame.

Maximum stresses - measured in the pole below the skull - were approximately 40 N/mm^2. The axial forces on the frame elements are presented in Fig. 8.

Frequency analysis indicated the presence of well-defined global modes. The first five vibration modes are related to a participating mass of 84.5% in the x direction, namely transversal to the mammoth, and 82.9% in the y, or longitudinal, direction (Tab. S2 in the Supplementary Online Material, Fig. 9).

Spectral analysis was carried out using two real elastic response spectra (5% damped) derived from the main shock acceleration record measured at the INGV seismic station AQU at the same time as the earthquake at 03.32 on April 6, 2009 (Çelebi et al., 2010). The two spectra, in orthogonal north-south and east-west directions, were combined with the self-weight action (linear static analysis) to simulate the earthquake of April 6, 2009 and assess the most stressed frame elements.

It was found that the significant deformability of the structure - corresponding to a low overall stiffness - allowed the frame " freedom of motion" to mitigate the horizontal seismic force, which contained peaks in the response spectrum of approximately 0.8 g at a frequency of 10 Hz and measured PGA of 0.31 g.

Seismic analysis therefore indicates that the steel elements of the legs have been satisfactorily verified, given the relatively limited inertial forces involved. However, as regards the pole supporting the skull, the section has not been verified for a combination of bending moments and axial loads, according to the Italian national standard (NTC, 2008).

Moreover, the significant seismic displacements of the frame and skeleton emerging from the analysis (Fig. 10), in the range of 0.2 m or more in a transversal direction and demonstrated indirectly after the 2009 earthquake, have in reality put a considerable strain on the bones.

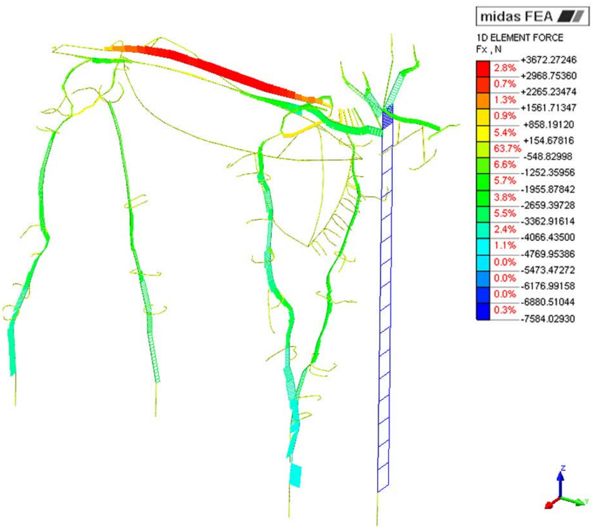

Fig. 8 - (color online) Axial forces on the supporting frame.

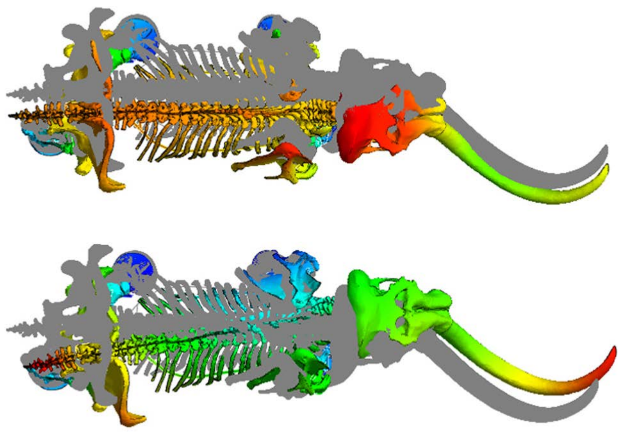
Fig. 9 - (color online) Mode shapes of the first and second vibration modes (in uniform grey the undeformed shape).

Remarks

In the case of the mammoth preserved in the Spanish Fortress in L'Aquila, an area with high seismic activity, the structural stability of the skeletal support frame plays a very important role, and it was therefore decided to study in detail the structural features, specifically in relation to the dynamic behaviour of the frame in relation to the earthquake of 2009.

Considering both numerical simulations and experimental activities, the studies highlighted the peculiar structural feature which had "saved" the mammoth from the earthquake, namely the high deformability of the metal frame. However, high differential displacements were attained during the seismic motions, and this presumably caused damage to the vulnerable bones of the mammoth.

THE RESTORATION

The most significant and innovative aspect of the restoration lies in the application of practices typical of the conservative restoration of works of art to the restoration of a palaeontological specimen, respecting the intentions, while at the same time enhancing them with the sensitivity and technical approach of the art restorer.

As with restoration of a cultural artefact where movement is complicated by dimensions, weight and fragility, the following were temporarily installed in the bastion room transformed into a fully equipped restoration laboratory: scaffolding conceived and designed to cope with all the operational necessities of the restoration, with wheels to facilitate movement, movable shelves and a top crossbeam with electric hoist; the equipment and instruments required to perform all phases of the restoration in safety; a lift platform with double pulley adequate for moving all the bones; an extraction system with filter trolleys and forced extraction hoses, and specific work stations for the various phases to rationalise and limit risky handling of the bones (Fig. 11).

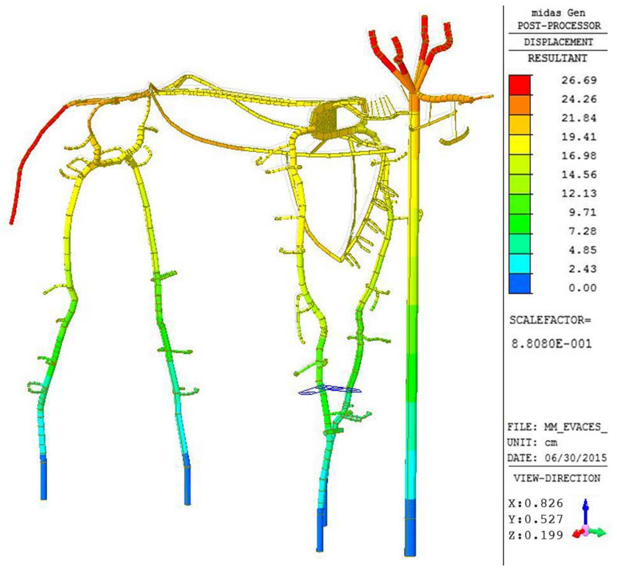

Fig. 10 - (color online) Effects of the 6 April 2009 earthquake on the supporting frame: XYZ displacements bending in transverse direction.

All details of the applied methodology are provided in the Supplementary Online Material. The chronologically ordered list and a synthetic description of the operations performed are provided below.

1. The bone elements were disassembled in three different phases; as for the largest bones, suitable lift and support systems were designed and modulated according to the anatomical characteristics and fragility of the various elements (Fig. S8 in the Supplementary Online Material). Modular systems were used for the limbs, with specific structures for the skull, pelvis and scapulae (Fig. S9 in the Supplementary Online Material).

2. Removal of paint from the surfaces of the reconstructions and bones with solvent (acetone).

3. Cleaning of the original parts with removal of the previous protective agent from the surface: the pure solvents and solvent mixtures were tested. The analytical results (FTIR) showed that cleaning with acetone completely removed the PVAc present in considerable quantities on the bone surfaces, without signs of "transport" dynamics in depth.

4. Removal of widespread plaster residues not removed after recovery of the skeleton in 1955 and mastic residues left from previous restorations necessitated the use of a precision micro-sandblaster (Fig. S10 in the Supplementary Online Material).

5. Removal of excess filler and identification of the contact surfaces between the original elements and reconstructions.

6. Pre-consolidation of a number of particularly fragile portions and consolidation by immersion (Fig. S11 in the Supplementary Online Material). The choice fell on suitable acrylic products (Keene, 1987; Shelton & Chaney, 1994; Linares Soriano & Carrascosa Moliner, 2016) with the following characteristics: low specific weight, minimum molecule size, low viscosity and high adhesive capacity. After specific research, the consolidant chosen was Degalan LP 64/12, an acrylic polymer which, unlike the more common Paraloid B72, had all the above characteristics, while Butyl acetate solvent was preferred to acetone for its lower volatility.

7. Structural consolidation with resin infiltrations and gluing.

Fig. 11 - The exhibition hall "transformed" into a restoration laboratory.

8. It was decided to modify a number of the anatomical parts reconstructed during previous restorations as these did not perfectly correspond to the anatomy of the animal. For these new reconstructions, a light two-component epoxy-based putty, reversible in polar solvents, commercially known as Balsite was used.

9. The same product was also used as a filler, with the addition of 5% weight of a mixture of natural coloured earths and walnut husk to obtain a stippled effect.

10. Colouring of the reconstructed portions. After specific testing, Maimeri paints diluted in turpentine oil were used.

Results

Observation of the bones after their removal from the metal structure revealed the presence of numerous cracks, particularly in jointed elements and above all in the sacrum and vertebrae, a likely sign of significant friction during the earthquake. The degradation was found to be worse on bones where the spongy part was exposed, due to a lack of cortex. Parts of the skull and pelvis in direct contact with the structure and not treated since the first restoration were in a very critical state of preservation.

Cleaning of the bones revealed widespread plaster residues, previously covered with a thin layer of colour. Removal of these with a precision micro-sandblaster enabled identification and enhancement of the surface morphology of the bones, in respect of the original details and colours. The cemented sand from the stratum in which fossilisation had taken place was not, on the other hand, removed.

Lowering of the edges of the reconstructions covering large portions of the bone and tusk allowed more of the original surfaces to be exposed.

There were numerous criticalities associated with the pelvis which required considerable pre-consolidation before proceeding with the consolidant bath.

Numerous tests were carried out on the extensive reconstructed areas of the cranial vault, revealing the presence of underlying bone material. The mastic, varying in thickness from about 5 to 15 cm, was found to cover a greatly altered and fragile cortical surface. Precautionary pre-consolidation had therefore to be performed on all the portions of bone exposed and the significant cracks mapped previously.

After consolidation by immersion, there was still a number of lesions affecting the skull. After mapping and study, these were held to be stable and basically settling lesions which were treated with infiltration of liquid epoxy resin and insertion of two 3 mm diameter fibreglass pins.

For the anatomical reconstructions of the front wing of the left scapula, olecranon of the left and right ulnae, mandibular symphysis and skull, see the following specific chapter.

The chromatic treatment of the reconstructions was aimed at enhancing the appearance of the skeleton as a whole. The stippling technique adopted recreated an effect not overly in contrast with the original bones, while respecting the basic restoration principle according to which each additional part must be distinguishable from the original, without disturbing the appearance of the artefact as a whole (Carta CNR, 1987).

Remarks

With respect to previous interventions, this conservative restoration paid particular attention to the identification of the bone/reconstruction contact points in order to increase the percentage of exposed original surfaces. The restoration gave back the bones their original appearance and the chromatic effect of the reconstructions further enhanced the artefact, in respect of the restoration principles (Carta CNR, 1987; Borselli et al., 1998).

GETTING BACK THE ORIGINAL SHAPE OF THE BONES: THE MAIN CHANGES

Even though the Madonna della Strada skeleton had been accurately restored and the broken/missing parts accurately integrated under the supervision of A.M. Maccagno (Maccagno, 1954, 1962), the shape of a number of skeletal elements appeared unusual with respect to the shapes characterising southern mammoths and proboscideans in general. Among the reconstructed bones, the ulnae appeared the most anomalous. At the top of the proximal epiphysis, above the olecranon process, the outline of the ulna was not, in fact, gently curved, as in nearly all proboscideans and certainly in the Elephantinae, but characterised by a marked bulge, nearly simulating a further olecranon (Fig. 12a). When the material added during the restoration was removed from the right ulna, it became clear that the erroneous reconstruction had been based on the presence of a long bone flake, probably partly fused with the olecranon during the diagenetic process. In the left ulna, the entire proximal part had been completely reconstructed. Both ulnae were therefore brought back to their original, correct shape (Fig. 12b).

However, the most important changes concerned the skull, particularly significant for their taxonomic implications. As reconstructed by Maccagno (1958, 1962) (Pl. 1, fig. 1a, c), the skull was higher and shorter than the *M. meridionalis* skulls from Valdarno (see Azzaroli, 1966, 1977; Ambrosetti et al., 1972), the medial portion of the double-domed skull is somewhat flattened anteroposteriorly and the nuchal fossa is narrow and quite deep (Pl. 1, fig. 1e). These features seem to be inconsistent with the morphology required to support the insertion of strong splenius superficialis and profundus muscles and nuchae and lateralis ligaments (e.g., Marchant & Shoshani, 2007), as required to support the weight of the large tusks, and balance the skull when a tusk was lost (see below). This observation, coupled with the fact that the skull dome had been partially preserved when the skeleton was discovered (as documented by pictures taken during excavation and recovery; Fig. 13), while after restoration it appeared completely reconstructed, led to the decision to remove the mastic to reveal the real shape of the preserved skull apex. The result was surprising, as the nearly completely preserved left side indicated that the skull was much shorter than previously reconstructed (Pl. 1, fig. 1b, d). The nuchal fossa was also wider and shallower (Pl. 1, fig. 1f).

Balsite was used to reconstruct the missing part of the right side of the skull, taking special care not to cover the original fossil portions.

Fig. 12 - Right ulna before (a) and after (b) the last restoration: the anomalous reconstruction of the top of the proximal epiphysis (olecranon process) has been brought back to its original shape.

Generally speaking, the main difference between the Scoppito skull and the Valdarno skulls is the more concave forehead (although this was reconstructed by juxtaposing a number of bone fragments whose actual position is unknown) and the very long premaxillary bone, apparently slightly converging downwards and with a deep furrow (Azzaroli, 1966, 1977; Ambrosetti et al., 1972). It is, however, worth noting that the tusk alveoli of the Scoppito *M. meridionalis* are clearly asymmetric, even considering the incompleteness of the one on the right. The left is narrow, thicker and latero-medially compressed, whereas at the distal aperture the external portion of a broken tusk is still preserved inside the alveolus. The peculiar shape suggested removal of the thick layer of mastic covering the premaxillary bone dorsally to investigate the original shape and possible presence of deformities. When the original surface was brought to light, a large hole (Pl. 1, fig. 1d) rimmed by neoformation tissue was observed, suggesting a pathological condition or traumatic injury causing deformation of the alveolus, a reduction in the width of the medial furrow between the alveoli and possibly loss of the tusk (Della Salda et al., 2016).

The new information collected during the restoration and new shape obtained for the skull, much closer to the real one than that proposed by the previous restoration, further support the hypothesis that the validity of *M. meridionalis vestinus* as a sub-species separate from the type species *M. meridionalis* should be considered with great caution (see e.g., Palombo & Ferretti, 2005).

LOOKING FOR A CORRECT POSTURE

Elephants have generally been seen as "the archetype for columnar graviportal animals" (see Ren et al., 2008 and references therein), with long pillar-like limbs remaining nearly extended even during gait, while the body axis remains more or less horizontal. During the last couple of decades, new studies on the locomotor kinematics of elephants have questioned the idea that the functioning of the nearly columnar limbs of elephants actually differs substantially from the more flexed limbs of running mammals (e.g., Hutchinson et al., 2006; Weissengruber et al., 2006; Ren et al., 2008; Genin et al., 2010). Although the actual possibility of the movement of limb segments and joints during locomotion in extant elephants is still an open question (see e.g., Hutchinson, 2009; Paul, 2009 and references therein), it is undeniable that in elephants

EXPLANATION OF PLATE 1

Comparison of the skull of *Mammuthus meridionalis* before and after the last restoration. Scale bars correspond to 10 cm.

Fig. 1a, c - Anterior and left lateral view of the skull before the last restoration, as it was reconstructed by Maccagno.

Fig. 1b, d - Anterior and left lateral view of the skull after the last restoration. The bone lesion in the left tusk alveolus is clearly detectable.

Fig. 1e - The nuchal fossa, as reconstructed by Maccagno, was narrow and quite deep.

Fig. 1f - Posterior view of the skull, showing the new reconstruction of the nuchal fossa, wider and less deep.


1a
1b
1c
1d
1e
1f

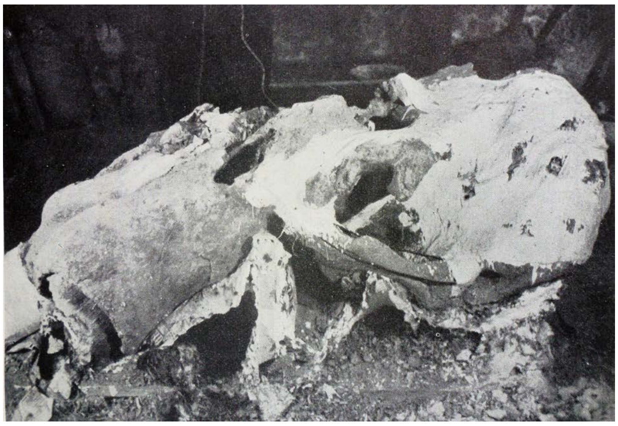

Fig. 13 - The skull as it appeared in 1954, just after its recovery.

the acropodia (manus and pes) can neither be positioned too far apart from the sagittal plane, as was the case in the first arrangement of the Scoppito mammoth skeleton (Fig. 2), nor in line with the glenohumeral joint or closer to the sagittal planes as they were positioned after the restoration.

We therefore analysed the position of the feet in the largest African and Asian elephants and painstakingly evaluated the accuracy of joint manoeuvrability while positioning each limb segment to ensure the Scoppito mammoth was positioned in a correct posture. The position of the metapodials and phalanges was established taking into account the angled foot structure of elephant feet, due to the presence of large subcutaneous cushions. These cushions consist in fibrous connective compartments filled with adipose tissue, allowing the body weight and mechanical forces to be absorbed (Weissengruber & Forstenpointner, 2004; Hutchinson et al., 2006). They represent an advanced feature of subunguligrade elephantiforms with respect to the most primitive plantigrade proboscideans (Hutchinson et al., 2011).

Basing on these observations, a number of potential postures were considered and verified by means of 3D models in order to correctly make any change necessary on the metal structure supporting the skeleton. The armature was modified by Icra Italia. To obtain a correct posture, the spinal column was lengthened by 6 cm, the limb joints were repositioned to keep the articular surfaces in an anatomical position and the angle between the scapula and humerus on the left forelimb was reduced (Fig. 14).

Some improvements were also made to the metal structure. In particular, polyethylene shock absorbers (Pasiuk, 2004; Del Favero, 2007) were inserted to separate the vertebral endplates and between the support elements and bones, the cervical vertebrae supports were lightened (Pl. 1, fig. 1d) and, where necessary, the metal supports for the thoracic and lumbar vertebrae and hooks supporting the ribs were modified. Finally, the plaster bases for the autopodia were replaced with specific metal supports.

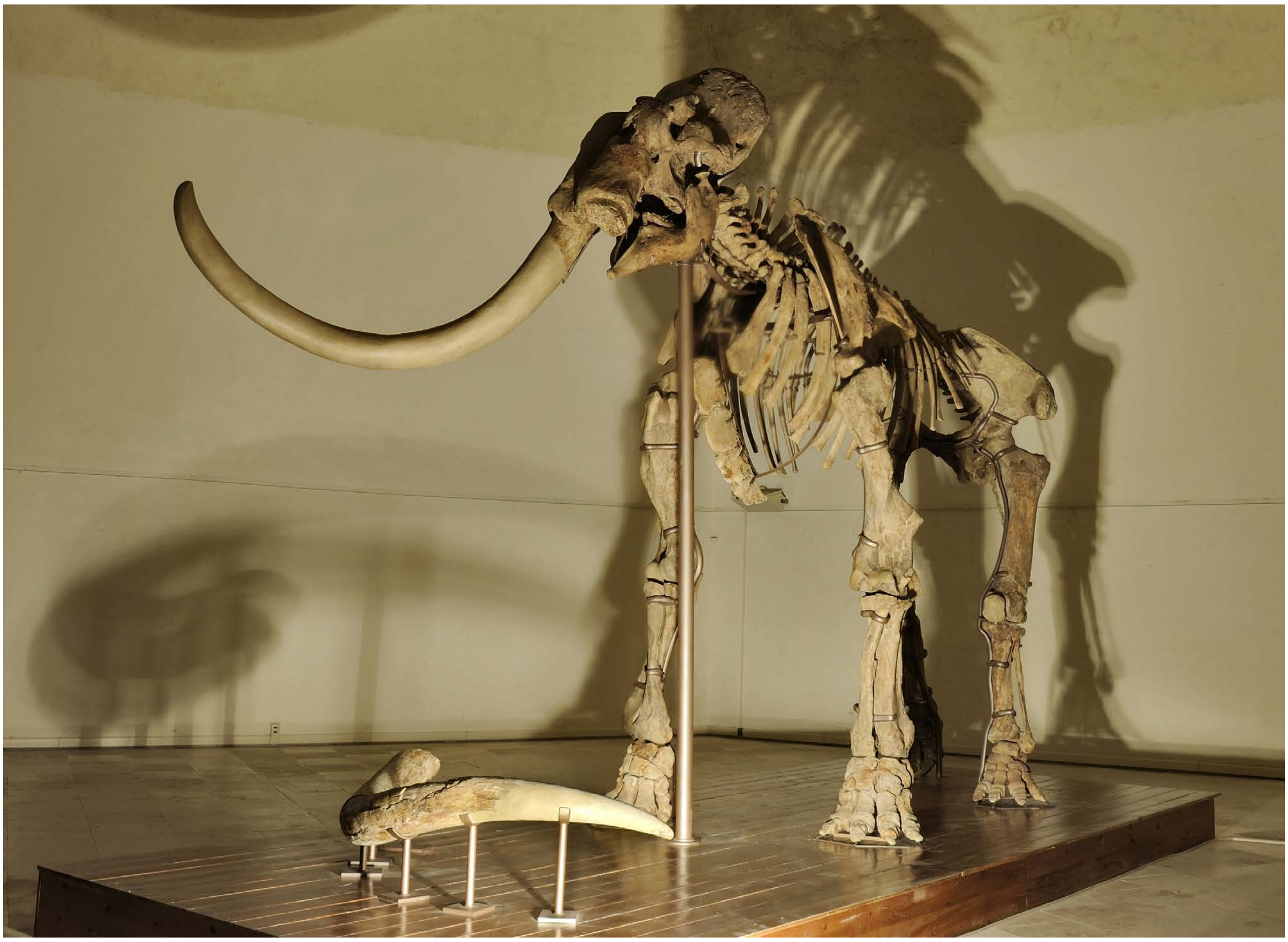

Fig. 14 - The *Mammuthus meridionalis* from Madonna della Strada as it appears after the 2015 restoration.

At the end of the complex reassembly operations, the static and dynamic behaviour of the skeleton-armature assembly was verified again.

CONCLUSION

The numerous and complex issues emerging during the restoration design phase necessitated the involvement and collaboration of various professional figures. Application of diagnostic methods typically applied to cultural artefacts improved our understanding of what had been done in the past and led to a more precise evaluation of the actual state of preservation of the specimen. The most suitable restoration techniques were chosen on the basis of the results obtained from the diagnostic studies. Particular attention was paid to the bone parts hidden by the mastic. Exposing them improved knowledge of the individual, clarified the configuration of the skull and revealed interesting pathological aspects. Through suitable chromatic treatment of the reconstructions, the conservative restoration further enhanced the specimen. Analysis of the dynamic behaviour of the frame-skeleton assembly showed the metal structure to be highly deformable, a characteristic which had prevented significant damage to the mammoth during the L'Aquila earthquake of 6 April 2009. To avoid and mitigate the future effects of vibration, shaped polyethylene elements were inserted between the support elements and bones and between the vertebrae.

In conclusion, the project, implemented in respect of the principles of restoration, was based on accurate diagnostics and the use of advanced techniques allowing optimum conservative restoration and improving the appearance and visibility of both the original and reconstructed parts of the specimen.

SUPPLEMENTARY ONLINE MATERIAL

All the Supplementary data of this work are available on the BSPI website at http://paleoitalia.org/archives/bollettino-spi/

ACKNOWLEDGEMENTS

Our thanks to the "Guardia di Finanza" for financing the project, the "Direzione Regionale Beni Culturali per l'Abruzzo" for promoting and managing the restoration, the "Soprintendenza Archeologia, belle arti e paesaggio per la città dell'Aquila e i comuni del cratere" now responsible for administering the project.

Our thanks also to Lorenzo Rook for his participation in the first work meetings at the beginning of the restoration, to Fabio Cozzini for the information provided to P. Reggiani concerning the material used during the restoration performed in Florence, to Gianfranco Callori and Cecilia Santarelli for the historic photograph of the site and to Mauro Vitale for the photographs taken during the restoration. Finally our thanks to the Reviewers Marco Ferretti and Emanuel Tschopp and the Editor Massimo Delfino for their useful comments and suggestions.

REFERENCES

Agostini S., Rossi M.A. & Tallini M. (2014). Geologia e paleontologia del Quaternario nel territorio aquilano. Atti del Convegno "Nei dintorni di L'Aquila. Ricerche archeologiche nel territorio dei Vestini Cismontani prima e dopo il terremoto del 6 aprile 2009", Roma, 12-13 Febbraio 2010. *Collection de l'Ecole Francaise de Rome*, 494: 7-19.

Ambrosetti P., Azzaroli A., Bonadonna F.P. & Follieri M. (1972). A scheme of Pleistocene chronology for the Thyrrhenian side of central Italy. *Bollettino della Società Geologica Italiana,* 91: 169-184.

Azzaroli A. (1966). La valeur des caractéres craniens dans la classification des eléphants. *Eclogae Geologicae Helvetiae,* 59: 541-564.

Azzaroli A. (1977). Evolutionary patterns of Villafranchian elephants in Central Italy. *Atti dell'Accademia Nazionale dei Lincei, Memorie Classe Scienze Fisiche,* 14: 149-168.

Blondiaux J., Fontaine C., Demondion X., Flipo R.M., Colard T. Mitchell P.D., Buzon M. & Walker P. (2012). Bilateral fractures of the scapula: possible archeological examples of beatings from Europe, Africa and America. *International Journal of Paleopathology*, 2: 223-230.

Bonaparte C. L. J. L. (1838). Amphibiorum Tabula Analytica. *Nuovi Annali delle Scienze Naturali.* 1: 394-397.

Borselli V. (1989). Il mammut di Vidor. *In* Gasparini D. (ed.), Due villaggi della collina trevigiana Vidor e Colbertaldo. Comune di Vidor: 161-181.

Borselli V., Confortini F., Dal Sasso C., Malanni M., Muscio G., Paganoni A., Simonetto L. & Teruzzi G. (1998). Carta del restauro dei fossili. *Museologia Scientifica*, 15: 215-226.

Borselli V., Cozzini F. & Landucci F. (2002). Il restauro dell'elefante fossile (*Elephas antiquus italicus*) esposto nel museo di storia naturale di Genova. *Museologia Scientifica*, 17: 75-86.

Brando C. ed. (2000). Teoria del restauro.154 pp. Piccola Biblioteca Einaudi, Nuova Serie.

Carta C.N.R. (1987). Carta 1987 della conservazione e del restauro degli oggetti d'arte e di cultura. Roma, Consiglio Nazionale delle Ricerche.

Casarin F., Beccaro E., Fattoretto M., Girardello P. & Caldon M. (2015). The dynamic behavior of mammoth in the Spanish fortress, L'Aquila, Italy. *MATEC Web of Conferences,* 24, 2015 - 05001, EVACES'15, 6th International Conference on Experimental Vibration Analysis for Civil Engineering Structures: 207-214.

Çelebi M., Bazzurro P., Chiaraluce L., Clemente P., Decanini L., De Sortis A., Ellsworth W., Gorini A., Kalkan E., Marcucci S., Milana G., Mollaioli F., Olivieri M., Paolucci R., Rinaldis D., Rovelli A., Sabetta F. & Stephens C. (2010). Recorded motions of the 6 April 2009 Mw 6.3 L'Aquila, Italy, earthquake and implications for building structural damage: overview, earthquake spectra. *Earthquake Engineering Research Institute,* 26: 651-684.

Dal Sasso C. & Maganuco S. (2011). *Scipionyx samniticus* (Theropoda: Compsognathidae) from the Lower Cretaceous of Italy. Osteology, ontogenetic assessment, phylogeny, soft tissue anatomy, taphonomy and palaeobiology. *Memorie della Società Italiana di Scienze Naturali e del Museo Civico di Storia Naturale di Milano*, 37: 1-281.

Del Favero L. (2007). La conservazione preventiva delle collezioni geopaleontologiche. *Museologia Scientifica n.s.*, 1: 57-67.

Della Salda L., Rossi M.A., Agostini S., Cuomo A., Palombo M.R. & Fornaciari G. (2016). Paleopathological study of *Mammuthus meridionalis* of Madonna della Strada (L'Aquila). II Meeting Nazionale Gruppo Italiano di Paleopatologia, L'Aquila 31 ottobre 2015. *Patologica*, 107: 215-216.

Desmarest A.G. (1822). Mammologie ou description des espèces de mammifères. *Mme Veuve Agasse imprimeur édit*., 2: 277-555.

Esu D., Girotti O. & Kotsakis T. (1992). Molluschi e vertebrati di alcuni bacini continentali dell'Appennino centrale: indicazioni biostratigrafiche e paleoecologiche. *Studi Geologici Camerti v.s. 1992/2 CROP 11*: 295-299.

Esu D., Girotti O. & Kotsakis T. (1993). Palaeobiogeographical observations on Villafranchian continental molluscs of Italy. *Scripta Geologica*, 2: 101-119.

Ferretti M.P. (1999). *Mammuthus meridionalis* (Mammalia, Proboscidea, Elephantidae) from the "Sabbie Gialle" of Oriolo (Cava La Salita, Faenza, Northern Italy) and other European late population of southern mammoth. *Eclogae Geologicae Helvetiae*, 92: 503-515.

Franzen J.L., Gingerich P.D., Habersetzer J., Hurum J.H., von Koenigswald W. & Smith H. (2009). Complete primate skeleton from the Middle Eocene of Messel in Germany: morphology and paleobiology. PloS ONE 4: e5723.

Genin J.J., Willems P.A., Cavagna G.A, Lair R. & Heglund N.C. (2010). Biomechanics of locomotion in Asian elephants. *Journal of Experimental Biology*, 213: 694-706.

Germonpré M., Losey R., Lázničková-Galetová M., Galeta P., Sablin M.V. , Latham K. & Räikkönen J. (2016). Spondylosis deformans in three large canids from the Gravettian Předmostí site: comparison with other canid populations. *International Journal of Paleopathology,* 15: 83-91.

Hendricks J.R. (2015). Glowing seashells: diversity of fossilized coloration patterns on coral reef-associated cone snail (Gastropoda: Conidae) shells from the Neogene of the Dominican Republic. PloS ONE 10: e0120924.

Hinton M.A.C. (1910). A preliminary account of the British voles and lemmings; with some remarks on the Pleistocene climate and geography. *Proceedings of the Zoological Society*, 1: 102-107.

Hone D.W.E., Tischlinger H., Xu X. & Zhang F. (2010). The extent of the preserved feathers on the four-winged dinosaur *Microraptorgui* under ultraviolet light. PloS ONE 5: e9223.

Hutchinson J.R. (2009). Response: of ideas, dichotomies, methods, and data–how much do elephant kinematics differ from those of other large animals? *Journal of Experimental Biology*, 212: 153-154.

Hutchinson J.R., Delmer C., Miller C. E., Hildebrandt T., Pitsillides A.A. & Boyde A. (2011). From flat foot to fat foot: structure, ontogeny, function, and evolution of elephant "sixth toes". *Science*, 334(6063): 1699-1703.

Hutchinson J.R., Schwerda D., Famini D.J., Dale R.H., Fischer M.S. & Kram R. (2006). The locomotor kinematics of Asian and African elephants: changes with speed and size. *Journal of Experimental Biology*, 209: 3812-3827.

Keene S. (1987). Some adhesive and consolidants used in conservation. *The geological Curator*, 1: 421-425.

Kotsakis T. (1988). Biostratigraphy of Plio-Pleistocene Arvicolids (rodents) of Italy. *Modern Geology*, 13: 163-175.

Laurenti J.N. (1768). Specimen medicum, exhibens synopsin reptilium emendatam cum experimentis circa venena et antidota Reptilium austriacorum. *J.T. Nob. de Trattner.* 215 pp. Vienna.

Leden I., Forslind K., Svensson B. & the BARFOT study group (2012). Ankylosis of wrist and small joints of he hand occurs in rheumatoid arthritis: diagnostic implication in paleopathology. *International Journal of Paleopathology,* 2: 249-251.

Linares Soriano A. & Carrascosa Moliner B. (2016). Consolidation of bone material: chromatic evolution of resins after UV accelerated aging. *Journal of Paleontological Techniques*, 15: 46-67.

Linnaeus C. (1758). Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Tomus 1. 10th edition. 824 pp. Laurentius Salvius, Holmiae.

Maccagno A.M. (1958). Relazione sulla tecnica di scavo, restauro e montaggio dell'elefante fossile rinvenuto presso l'Aquila*. Annuario delle Istituzioni di Alta Cultura sorte nella città dell'Aquila dal 1948 al 1957*, 2: 124-137.

Maccagno A.M. (1962). *L'Elephas meridionalis* Nesti di Contrada "Madonna della Strada" Scoppito (L'Aquila). *Atti dell'Accademia di Scienze Fisiche e Matematiche di Napoli*, *Memoria*, 4: 1-132.

Magri D., Di Rita F. & Palombo M.R. (2010). An Early Pleistocene interglacial record from a intermontane basin of central Italy (Scoppito, L'Aquila). *Quaternary International*, 225: 106-113.

Mancini M., Cavuoto G., Pandolfi L., Petronio C., Salari L. & Sardella R. (2012). Coupling basin infill history and mammal biochronology in a Pleistocene intramontane basin: the case of western L'Aquila Basin (central Apennines, Italy). *Quaternary International*, 267: 62-77.

Marchant G.H. & Shoshani J. (2007). Head muscles of *Loxodonta africana* and *Elephas maximus* with comments on *Mammuthus primigenius* muscles. *Quaternary International*, 169: 186-191.

Nesti F. (1825). Sulla nuova specie di elefante fossile del Valdarno all'Illustrissimo Sig. Dott. Prof. Ottaviano Targioni Tozzetti (Lettere sopra alcune ossa fossili del Valdarno non per anco descritte). *Nuovo Giornale di Lettere,* 11: 195-216.

NTC (2008). Norme Tecniche per le Costruzioni. Decreto Ministeriale 14.01.2008.

Otth A. (1837). Beschreibung einer neuen europäischen Froschgattung, Discoglossus. *Neue Denkschriften der Allgemeinen Schweizerischen Gesellschaft für die Gesammten Naturwissenschaften,* 1: 1-8.

Palombo M.R. & Ferretti M.P. (2005). Elephant fossil record from Italy: knowledge, problems, and perspectives. *Quaternary International*, 126: 107-136.

Pasiuk J. (2004). Safe plastics and fabrics for exhibit and storage. *Conserve O Gram*, 1: 1-7.

Paul G. (2009). The nearly columnar limbs of elephants are very different from the more flexed, spring action limbs of running mammals and birds. *Journal of Experimental Biology*, 212: 152-153.

Reggiani P. (2013). Relazione sul restauro dei resti di elefante pleistocenico conservati presso il Museo Preistorico dei Balzi Rossi. Archivio Soprintendenza Archeologica, Belle Arti e Paesaggio per la città metropolitana di Genova e le provincie di Imperia, La Spezia e Savona: 1-2.

Reggiani P. & Sala B. (1992). I mammut del Veneto. *Memorie della Società Geologica*, 44: 171-191.

Ren L., Butler M., Miller C., Paxton H., Schwerda D., Fischer M.S. & Hutchinson J.R. (2008). The movement of limb segments and joints during locomotion in African and Asian elephants. *Journal of Experimental Biology*, 211: 2735-2751.

Riquelme F., Ruvalcaba-Sil J.L. & Alvarado-Ortega J. (2009). Palaeometry: non-destructive analysis of fossil materials. *Boletín de la Sociedad Geológica Mexicana*, 61: 177-183.

Sami M. & Ghezzo E. (2015). Mammiferi del Pleistocene superiore nelle Grotte dei Gessi di Brisighella e Rontana. *In* Lucci P. & Piastra S. (eds), I gessi di Brisighella e Rontana. Studio Multidisciplinare di un'area carsica nella vena del gesso romagnola. *Memorie dell'Istituto Italiano di Speleologia*, II, 28: 101-112.

Shelton Y.S. & Chaney D.S. (1994). An evaluation of adhesives and consolidants recommended for fossil vertebrates. *In* Leiggi P. & May P. (eds), Vertebrate Paleontological Techniques, 1, Cambridge University Press: 35-43.

Stone R. (2010). Altering the past: China's faked fossils problem. *Science*, 330: 1740-1741.

Tischlinger H. (2002). Der Eichstätter *Archaeopteryx* im langwelligen UV-Licht. *Archaeopteryx*, 20: 21-38.

Tischlinger H.(2005). Neue Informationen zum Berliner Exemplar von *Archaeopteryx lithographica* H. v. Meyer 1861. *Archaeopteryx*, 23: 33-50.

Tischlinger H. & Unwin D.M. (2004). UV-Untersuchungen des Berliner Exemplars von *Archaeopteryx lithographica* H. v. Meyer 1861 und der isolierten Archaeopteryx-Feder. *Archaeopteryx,* 22: 17-50.

Toula F. (1902). Das Nashorn von Hundsheim Rhinoceros (Ceratorhinus Osborn) hundsheimensis nov. form. mit Ausführungen über die Verhältnisse von elf Schädeln von Rhinoceros (Ceratorhinus) sumatrensis. *Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt*, 57: 445-454.

Turner-Walker G. (2009). Degradation pathways and conservation strategies for ancient bone from wet, anoxic sites. Proceedings of the 10th Triennial Meeting of the ICOM-CC Working Group for Wet Organic Archaeological Materials. Huisman H.D.J. & Strætkvern K. (eds) 10-15th September 2007: 659-674.

Weissengruber G.E. & Forstenpointner G. (2004). Musculature of the crus and pes of the African elephant (*Loxodonta africana*): insight into semiplantigrade limb architecture. *Anatomy and Embryology*, 208: 451-461.

Weissengruber G.E., Fuss F.K., Egger G., Stanek G., Hittmair K.M. & Forstenpointner G. (2006). The elephant knee joint: morphological and biomechanical considerations. *Journal of Anatomy*, 208: 59-72.

Manuscript received 3 March 2017
Revised manuscript accepted 6 December 2017
Published online 30 December 2017
Editor Massimo Delfino