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Middle Pleistocene mammal faunas of the area of Rome: recent results and ongoing work on the MUST collection

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ABSTRACT - The urban area of Rome and its surroundings (the Roman Campaign, "Campagna Romana") yielded an exceptional amount of fossil remains of terrestrial large mammals, which are of prime relevance for biochronological correlations and for reconstructing the paleoenvironmental conditions in the Italian Peninsula of the Middle Pleistocene. Apart from the mere quantity, the scientific importance of the Roman fossil record rests on the geochronological constraints that allow to date or correlate several findings, as well as on the dense chronological cover of continental deposits, for the last ~0.8 Ma. On the other hand, the case of Rome is emblematic of the challenges posed by investigating historical fossil collections, for instance, the necessity of a thoughtful integration of historical documentation (e.g., geological maps, museum labels) and indirect geological information (e.g., borehole lithology, the correlation between obliterated fossil sites and extant outcrops), owing to the intense urbanization occurred especially since the 1800s. Fossil-rich deposits of Rome have supplied collections housed in the city's major museums, geosites, and universities, creating a valuable and unique paleontological heritage. Synthesis and perspective on these entwined aspects are provided herein, offering a geological and historical background alongside an overview of Middle Pleistocene mammal faunas of the area of Rome, with special emphasis on recent results that offer examples of - and how to deal with - different kinds of recoveries (from sporadic finds to systematic excavations), and ongoing work on the collection of the University Museum of Earth Sciences of Sapienza University of Rome (MUST). Reviewing the history of the MUST collection underlines the profound link between the history of the research on large mammal faunas of Rome and the history of the collection itself. The management of the paleontological heritage of Rome, consisting of thousands of remains spanning from isolated teeth to complete skeletons, is a crucial task for providing new data and support for research and dissemination, both of which are carried out at MUST accompanying traditional and yet fundamental efforts, such as cataloging and restoration, with the digital enhancement of the collection.

Keywords: Museum collections; Geoheritage; Paleontological heritage; Biochronology; Paleoecology; Quaternary; Mediterranean; Europe.

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1. INTRODUCTION

Spanning almost three thousand years and having had a deep impact on the modern world, the history of the city of Rome is undeniably one of the most celebrated. However, the multilayered cultural legacy of Rome goes back well before the city itself was founded. Beneath the vestiges of Ancient Rome, the urban area of Rome and its surroundings (the Roman Campaign, "Campagna Romana") host an exceptional amount of fossil remains, especially of terrestrial large mammals (Palombo, 2004; Kotsakis and Barisone, 2008; Romano et al., 2021). This very large area has been affected by intense urbanization activity over the centuries, especially since the 1800s.

In the past and today, infrastructure works have often exposed fossil-rich deposits that have supplied fossil collections housed in the city's major museums, geosites, and universities, creating a valuable and unique paleontological heritage (Fig. 1).

Apart from the mere quantity, the scientific importance of the Roman fossil record rests on the geochronological constraints that allow to date or correlate several findings, as well as on the dense chronological cover of continental deposits, for the last ~0.8 Ma. This age roughly coincides with the onset of the activity of the Roman Magmatic Province (Conticelli and Peccerillo, 1992; De Rita et al., 1993; Karner et al., 2001), whose products are of prime importance for providing dating constraints on Roman fossil localities. Volcanism is nonetheless only one of the factors that contribute to this context and characterizes the unique geological history of Rome, mingled with tectonics and recurrent glacio-eustatic fluctuations.

Large mammal faunas of the area of Rome are of prime relevance for biochronological correlations and for reconstructing the paleoenvironmental conditions in the Italian Peninsula of the Middle Pleistocene (Gliozzi et al., 1997; Petronio and Sardella, 1999; Milli et al., 2004; Palombo et al., 2005; Strani et al., 2022). During this time span, the Early–Middle Pleistocene Transition climatic event influenced the paleoenvironmental conditions, leading to the exacerbation of the glacial-interglacial cycles (Head and Gibbard, 2015). This phase was marked by the definite disappearance of subtropical vegetation with the spread of temperate ecosystems with the expansion of open grasslands especially during glacial phases. Palynological data indicate that oak (*Quercus*)-dominated deciduous forests expanded through the central and southern Italian Peninsula at lower altitudes (Combourieu-Nebout et al., 2015).

The fossil vertebrate assemblage of the area of Ponte Galeria (west of Rome) has yielded information on the paleoenvironmental context of this territory during the

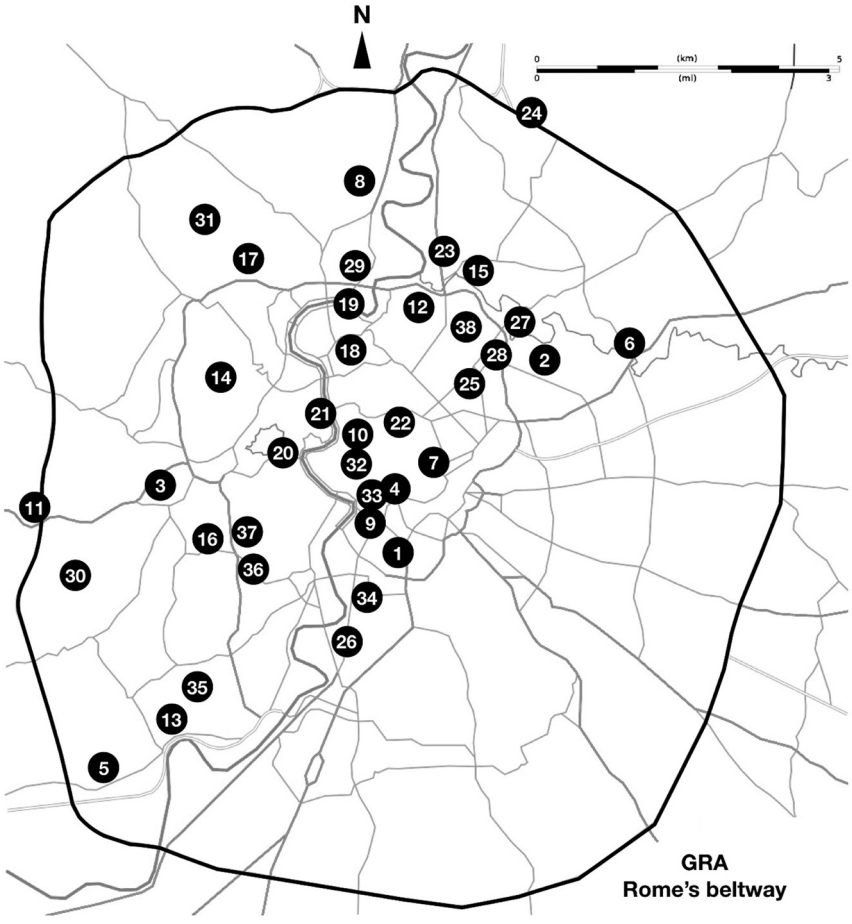

Fig. 1 - Geographical location of the fossiliferous deposits within the urban area of Rome. 1-Aventino; 2-Batteria Nomentana; 3-Boccea; 4-Campidoglio; 5-Campo di Merlo; 6-Casal de' Pazzi, Ponte Mammolo; 7-Castro Pretorio; 8-Cava Nera Molinario; 9-Monte Celio; 10-Fondamenta BNL, Pincio, Quirinale; 11-GRA Km 2; 12-Monte Antenne; 13-Monte delle Piche; 14-Monte Mario; 15-Monte Sacro; 16-Monte Verde; 17-Monti della Farnesina; 18-Parioli; 19-Ponte Molle; 20-Porta Cavalleggeri; 21-Porta Flaminia; 22-Porta Pia, Porta Salaria; 23-Prati Fiscali; 24-Redicicoli; 25-Sant'Agnese; 26-San Paolo; 27-Saccopastore; 28-Sedia del Diavolo; 29-Tor di Quinto; 30-Via Aurelia; 31-Via Cassia; 32-Via del Tritone, 33-Via Nazionale; 34-Via Ostiense; 35-Via Portuense; 36-Vigna San Carlo; 37-Vigne Torte; 38-Villa Chigi.

early Middle Pleistocene. During the interglacial phases of the early Middle Pleistocene the area surrounding the ancient course of the Tiber River was characterized mostly by open grasslands with scattered woodlands and extensive wetlands, as attested by the analysis of the long-term feeding behaviors of the fossil ungulates and by the study of the bird assemblage from Casal Selce 2 (MIS 15) (Pavia et al., 2018; Strani et al., 2022).

The late Middle Pleistocene interglacials were probably characterized by the expansion of woodlands and fluvio-palustrine habitats as recorded from the study of the fossil mammal fauna and of the dietary behavior of the straight-tusked elephant *Palaeoloxodon antiquus* from La Polledrara di Cecanibbio and Casal de' Pazzi (Palombo et al., 2005). The spread of more closed environments at lower altitudes during the last phases of the Middle Pleistocene is also recorded in the nearby Anagni Basin (around 80 Km from Rome) where long and short-term feeding behaviors of fossil herbivorous ungulates from Fontana Ranuccio (400 ka; MIS 11) points to heterogeneous habitat conditions with the prevalence of open woodlands (Strani et al., 2018; 2019).

The increase of more humid environmental conditions is also attested by the palynological data obtained from other regions of central-southern Italy (Vallo di Diano in Campania and Boiano in Molise), which point to lower mean summer precipitation and mean annual precipitation values during the MIS 15-13 interglacial than during the MIS 11 (Combourieu-Nebout et al., 2015).

On the other hand, while the paleontological record of the area of Rome offers a unique window into Middle Pleistocene terrestrial ecosystems of Europe, its study also poses many challenges, related to its history. Indeed, most paleontological findings occurred in historical times, not always accompanied by detailed stratigraphic information, which even when available requires a thoughtful contextualization. The same also applies to taxonomical and systematics considerations. Moreover, original sections are often no longer exposed and/or difficult to be precisely identified, especially in the urban area, demanding integration of indirect information (e.g., borehole lithology, correlation from nearby outcrops). Even in modern times, systematic excavations carried out in the area of Rome represent the exception rather than the norm.

Another problem concerns the dispersion of historical material in numerous institutions, especially in the second half of the 1800s and the first half of the 1900s, prior to the establishment of a chair of Paleontology (see section 3). In part, this is linked to scientific exchanges between different museums that occurred at the time, but also depends on the fact that several personalities independently collected and worked on the material (Palombo, 2004; Kotsakis and Barisone, 2008; Cerilli, 2014; Fabbi et al., 2021; Romano et al., 2021). As a result, many collections from the area of Rome and its surroundings are scattered across institutions that once hosted scientific cabinets (for instance local high schools), complicating comprehensive assessments and studies.

In this context, appropriate management and documentation of historical findings is of the utmost importance. Notwithstanding the relevance of several smaller collections, a significant portion of the extensive paleontological Roman fossil remains are currently housed in the University Museum of Earth Sciences of Sapienza University of Rome, abbreviated MUST, after the Italian "Museo Universitario di Scienze della Terra". Here, we provide some geological and historical background, alongside an overview of Middle Pleistocene mammal faunas of the area of Rome, with special emphasis on recent results that offer examples of different kinds of recoveries (from sporadic finds to systematic excavations), and ongoing work on the MUST collection.

2. GEOLOGICAL SETTING

The Roman Basin is one of the widest sedimentary basins of the western flank of the Apennines, which developed, during the Neogene-Quaternary, under a dominant W-E-directed crustal extension linked to the opening of the Tyrrhenian Sea back-arc basin and the eastward retreat of the subducting Adria Plate (Doglioni, 1991; Cavinato and De Celles, 1999; Cosentino et al., 2010).

The Roman Basin widens for more than 100 km along the NNW-SSE direction and is filled with ~1 km thick pile of syn-rift terrigenous sediments overlaying with unconformity the Mesozoic-Cenozoic carbonate and siliciclastic substratum.

The basin infill is represented by three high-rank and low-frequency depositional sequences, namely the Vaticana Sequence (Zanclean-Gelasian), the Monte Mario Sequence (Calabrian), and the Ponte Galeria Sequence (latest Early Pleistocene-Holocene), bounded by main unconformities and recording the transition from open and deep marine to nearshore and fluvio-deltaic environments, in response to the regional uplift of the Apennines and the development of the Tiber River's network (Milli, 1997; Milli et al., 2008; Mancini and Cavinato, 2005; Mancini et al., 2007).

The Ponte Galeria Sequence (PGS), comprising the former Ponte Galeria, San Cosimato, Aurelia, and Vitinia Formations *sensu* Conato et al. (1980), is of particular interest to our study because of its wealth of vertebrate fossils (Milli et al., 1994; Milli and Palombo, 2005). The PGS is composed of the complex stack of twelve low-rank and high-frequency sequences recording, in the lower reach of the Tiber, the sedimentary response to the high-frequency glacio-eustatic fluctuations of the sea level (80 to 100 kys spaced) and climate changes (Milli, 1997; Milli et al., 2016).

Moreover, since the early Middle Pleistocene, the Roman area was affected by the intense volcanism of the Sabatini Mts and Albani Hills Districts, north and south of Rome, respectively, which supplied large amounts

of pyroclastics and lavas and enhanced local uplift throughout the entire Middle Pleistocene (Karner et al., 2001; Giordano and the CARG Team, 2010).

The interplay of the regional and volcanic-induced uplift, extensional tectonics, volcanism, fluvial sedimentation, glacio-eustasy, and glacial-interglacial climate changes led to a complex stratigraphic architecture dominated by incised-valley fills (Milli et al., 2008, 2016; Mancini et al., 2014), with interbedded distal pyroclastics in most cases dated by radiometric methods (Karner et al., 2001). Among the incised valleys relevant are those related to the Valle Giulia (MIS 14-13) and Fosso del Torrino Formation (MIS 12-11) *sensu* Funiciello and Giordano (2008), and to the Aurelia (MIS 10-9) and Vitina Formation (MIS 8-7), all of them rich in fossil remains.

3. FROM THE MUSEUM OF PALEONTOLOGY TO "MUST"

The first collections of fossils and rocks that became part of the Institute of Geology of Rome, which became fully autonomous in 1873 under the direction of Giuseppe Ponzi, derived from the former Kirkerian Museum (later the Pigorini Museum) and partly from specimens collected and donated by the director. Giuseppe Ponzi was a physician and naturalist who greatly contributed to the research on the Campagna Romana (e.g., Ponzi, 1867, 1875, 1878), as well as holding the prestigious positions of senator and president of the Accademia dei Lincei (1871-1874) during his career.

Following the death of Ponzi, the Geology professorship was taken by Alessandro Portis, who enriched the paleontological collections and established a library at the institute between 1888 and 1927. Portis continued the work on the Campagna Romana carried out by his predecessor with the description and classification of Quaternary vertebrates, including rhinoceroses, elephants, canids, and bovids, among others (Portis, 1893, 1896, 1900, 1902, 1907, 1909, 1920).

This happened before the chair of Paleontology was established in 1928, being first entrusted to Giuseppe Checchia Rispoli. The establishment of a separate professorship of paleontology, previously subsumed within that of geology (since 1864), marks also the proper birth of the Museum of Paleontology. As the two chairs, Geology and Paleontology, also two museums existed as separated entities, alongside the much older Museum of Mineralogy, established in 1804 by Pope Pius VII.

During the 1930s, Checchia Rispoli jointly headed the institutes of geology and paleontology, leading the moving of the collection from the premises of Sant'Ivo alla Sapienza, to the Geology building, where it is still housed today (Fig. 2a). This is part of the modern campus of the university, built in the same years by the rationalist architect Marcello Piacentini (Fabiani and Maxia, 1953; Conti et al., 2017). The new building was designed to host the three museums (geology, mineralogy, and paleontology), with the aim of housing them in the same place.

In 1943, during the Second World War, the portion of the building that housed the Museum of Paleontology was hit by a bomb, and many collections, already compromised by a flooding of the Tiber in 1870, suffered extensive damage (Fig. 2b). With the end of the war, the works to renovate the damaged part of the building started, especially aimed at restoring the shattered showcases and reorganizing the paleontological collection.

The 1950s were years of great post-war ferment. Not only the recovery and restoration of the fossil collections in the museum, but the entire Campagna Romana studies restarted with new research projects (e.g., Fabiani and Maxia, 1953; Blanc, 1955, 1957; De Angelis d'Ossat, 1956).

Despite in 1947 the direction of the institutes of geology and paleontology passed again under the direction of a single man, Fabiani, the respective museums remained separated. The Museum of Geology was housed in a single large hall of 672 m^2, the Museum of Paleontology was located on the third floor of the building consisting of three main rooms and a fourth smaller room that served as a depository, while the Museum of Mineralogy retained its original location on the mezzanine floor of the building.

Until the 1950s, Middle Pleistocene large mammals of the Campagna Romana were exhibited in cabinets that ran around the perimeter of the largest room of the Museum of Paleontology, together with other vertebrate remains, arranged in a classic taxonomic order (Fig 2a; Fabiani and Maxia, 1953).

In the 1960s, a reorganization of the paleontological material in the Museum of Paleontology and Geology, at that time under the direction of Bruno Accordi, began, resulting in the exhibition focused on Quaternary mammals. On this occasion, the bulky display cases that occupied the entire museum hall and contained many isolated objects were replaced by reconstructions of the large mammals of the Campagna Romana (Fig. 3). The large, mounted skeletons are still in MUST today and form the core of the new exhibition. These specimens not only constitute evidence of the species that populated central Italy during the Pleistocene but also tell the story of the museum itself and of the exhibition techniques that characterized different historical periods.

Among the mounted skeletons exposed there is the majestic *Palaeloxodon* (= *Elephas*) *antiquus* from Grotte Santo Stefano (Viterbo) (Fig. 4a). This specimen was recovered in the 1950s, some years after another skeleton that has been moved to Genova (Trevisan, 1949; Palombo and Valli, 2003). Next to their large mainland relative, three composite skeletons of the smaller *Palaeloxodon* (= *Elephas*) *falconeri* from Spinagallo Cave (Syracuse, Sicily) have been mounted, which became part of the museum by donation of Fabiani (Fabiani and Maxia, 1953), and represent the museum's flagship item for the study of insularism (Fig. 4b).

The confluence of the three museums of Geology, Mineralogy, and Paleontology into one large entity, allows the MUST to acquire greater presence, authority, and

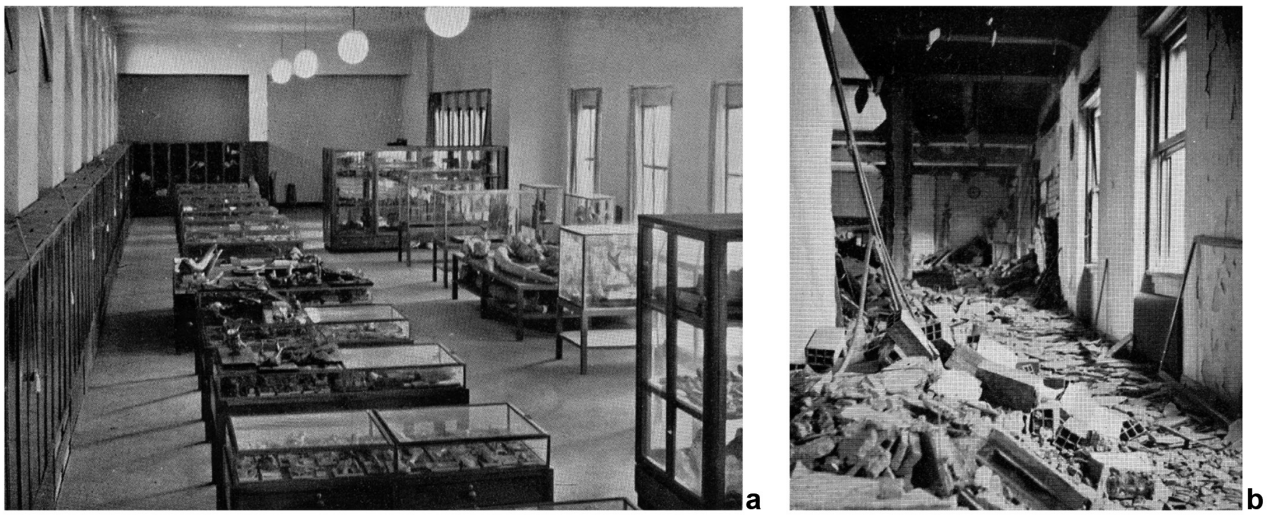

Fig. 2 - The exhibition of the Museum of Paleontology of Sapienza University of Rome in the 1930s (a) and damages caused by bombing during the Second World War (b). Modified from Fabiani and Maxia (1953).

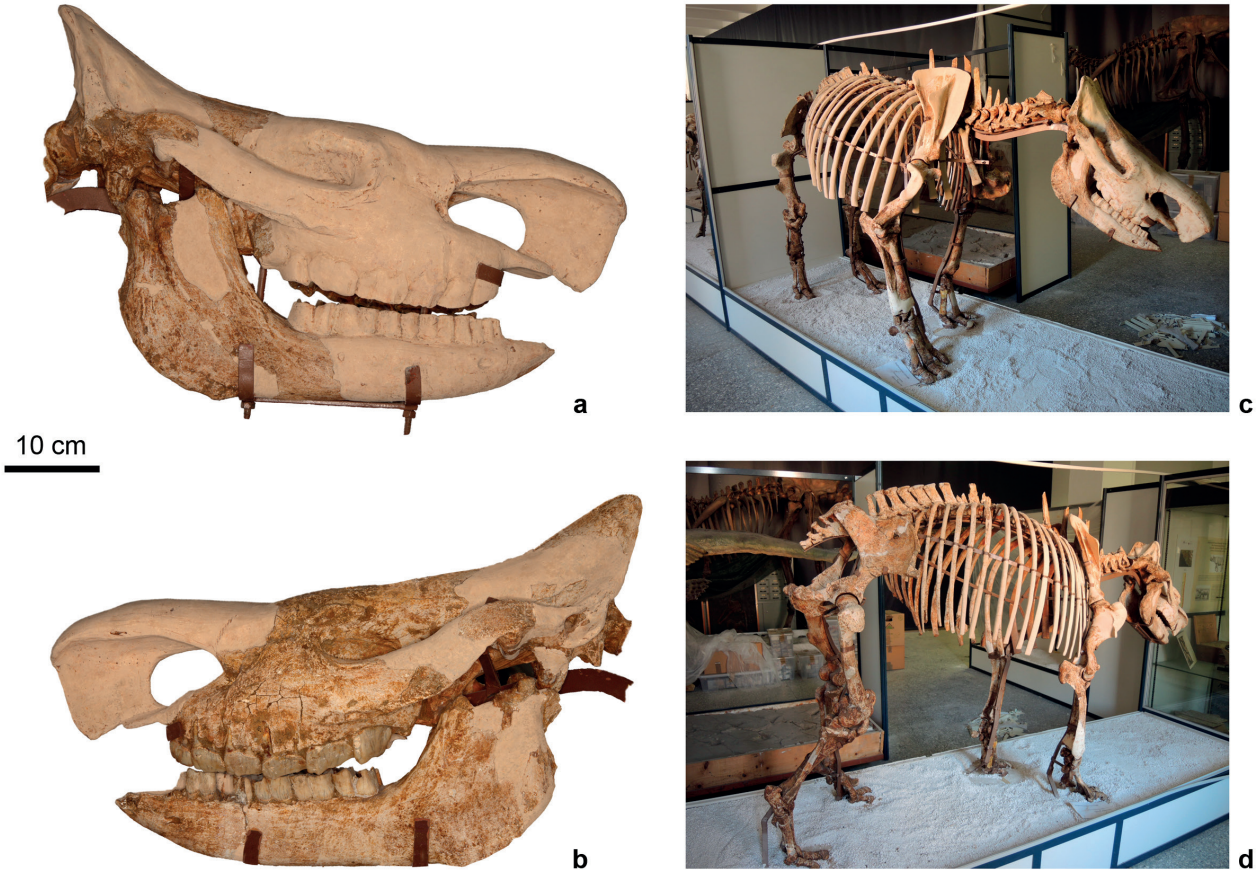

Fig. 3 - Skeleton of the rhinoceros *Stephanorhinus etruscus* from Capitone (Terni), late Villafranchian (Ambrosetti, 1972). Restored and mounted between 1962 and 1970. Lateral views of the skull (a-b) and different views of the whole specimen in exhibition (c-d).

ability to act on the territory: a single body focused on users, able to dynamically welcome the public and engage them, abandoning the static nature that had characterized the museums in the last century. The new museum structure allows both spatial and thematic continuity, including temporary exhibition areas and educational workshops (Conti et al., 2017). With this view of dynamism and the relationship between knowledge and creativity in mind, the MUST, like many other museums that perceive the need to adapt to a changing society,

Fig. 4 - Mounted skeletons of *Palaeoloxodon antiquus* from Grotte Santo Stefano (a) and *Palaeoloxodon falconeri* from Spinagallo Cave (b).

becomes a cultural hub: a platform where creativity is combined with knowledge and where visitors can create, share, and interact. The search for innovative methods, supported by new technologies, will enable the museum to deal with social and environmental issues by striving to proactively face the challenges of today's society (Margnelli et al., 2019).

4. TYPES OF RECOVERIES OF THE MAMMAL FOSSIL RECORD

From the preceding sections, it would seem evident that the paleontological remains in the area of Rome occurred over a long period and the recoveries were often contingent on other activities. This generates a series of

situations that require different research approaches.

The collections from several localities were entirely or almost entirely assembled during historical times, especially since the second half of the 1800s, requiring a careful contextualization of geological and paleontological information (e.g., Meli, 1881, 1891, 1894; Terrigi, 1882; Tuccimei, 1883, 1884; Clerici, 1888, 1891, 1892; and see Kotsakis and Barisone, 2008 and Romano et al., 2021, for more references). For instance, probably the most important in terms of the number of remains is the locality of Ponte Molle (now Ponte Milvio, northern-western urban area), from where thousands of fossil mammal specimens were collected as a by-product of quarrying activities since the 1800s (Mecozzi et al., 2021a). Ponzi (1867) discussed the presence of several mammals at Ponte Molle, recovered from the same gravels quarried as a building material. More detailed stratigraphic information on the quarry fronts opened at Ponte Molle and nearby was provided by Portis (1893), who also carried out a large number of works dedicated to the fauna in the following decades (e.g., Portis, 1900, 1902, 1907, 1909, 1920). The quarries and outcrops mentioned in those works were subsequently destroyed and/or buried by anthropogenic deposits and buildings, and considerations on the fauna of Ponte Molle discussed after the Second World War only relied on the historical collections. Since the 1950s-1960s, a renewed research impetus took place (see section 2), resulting, among other things, in a reconsideration of several localities, including Ponte Molle (Ambrosetti and Bonadonna, 1967). In the following years, divergent opinions were expressed on the age and chronological consistency of the fauna of Ponte Molle (e.g., Caloi and Palombo, 1986a; Di Stefano and Petronio, 1992; Capasso Barbato et al., 1998; Di Stefano et al., 1998; Billia and Petronio, 2009; Pandolfi and Marra, 2015). Mecozzi et al. (2021a) recently clarified that stratigraphic and historical evidence agreed in interpreting the fauna of Ponte Molle as recovered from the lower gravelly level of the Valle Giulia Formation (MIS 13), save for some Holocene "spurious" specimens. To clarify the issue, a thoughtful consideration of historical documents, including geological and topographic maps, and museum labels, has been crucial (Fig. 5).

Historical findings that would benefit from a geochronological and taxonomic reassessment are also represented by several isolated specimens, such as the cranium of the Mosbach Wolf, *Canis mosbachensis* from Via Ostiense, close to the Basilica di San Paolo in Rome (Mecozzi et al., 2021c).

Many findings in Rome also occurred sporadically in more recent years, for instance during geological surveys. The locality of Ponte Galeria (western area of Rome), in particular, has been extensively investigated since the 1960s, as it allows to observe sedimentary deposits no or limitedly exposed near the much more densely built center of the urban area (Conato et al., 1980; Milli, 1992, 1997; Bellotti et al., 1993; Marra and Rosa, 1995; Milli et al., 2004, 2008; Marra et al., 2014, 2015; Sardella et al., 2015; Iurino et al., 2022b; Strani et al., 2022). In most cases, findings recovered in these circumstances are associated with proper stratigraphic information that allows to refer them to specific formations tied to a MIS. On the other hand, these "sporadic finds" are generally limited to few remains that are seldom described in detail, either because deemed of little taxonomic relevance or because summarily reported in geological studies focused on other aspects (e.g., Conato et al., 1980; Palombo, 2004). Such small local faunas are often treated or quoted in broader studies on Roman faunas (e.g.,

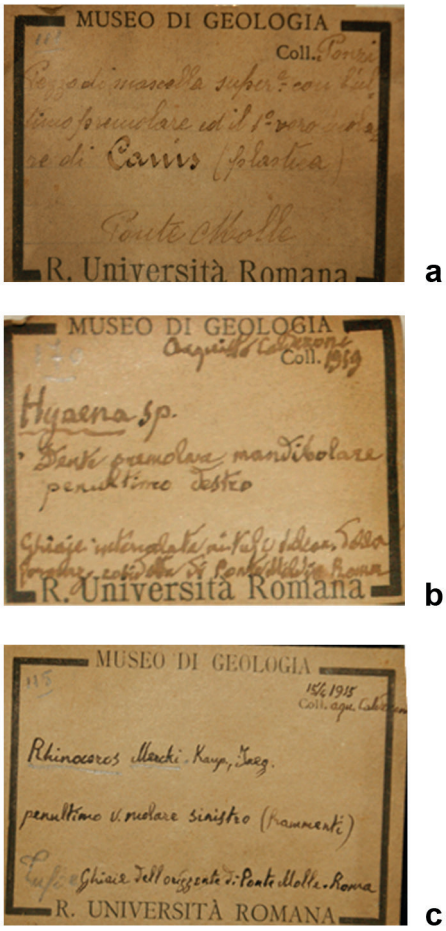

Fig. 5 - Selected historical handwritten labels associated to mammal fossil remains from Ponte Molle. On each label, information is provided on the acquisition of the specimen (upper right corner, "Coll."), taxonomic and anatomic identification (middle), and provenance/locality (bottom). The label in (a) refers to an old entry donated by Ponzi, which is simply labelled as from "Ponte Molle". In (b), information on the provenance is more extensive: "Ghiaie intercalate ai tufi vulcanici della formazione cosidetta di Ponte Molle in Roma" (gravels interleaved to the volcanic tuffs of the formation so-called of Ponte Molle in Rome). In (c), "[Tufi e] ghiaie dell'orizzonte di Ponte Molle. Roma" ([tuffs and] gravels of the horizon of Ponte Molle. Rome). Note that "tuffs and" was added on pencil subsequently. A comprehensive survey of the collection labels in MUST revealed a plethora of combinations, which were, however, different ways to refer to the same formation, not evidence for multiple layers.

Palombo, 2004), which, however, necessarily provide only succinct taxonomic and stratigraphic information. This limits further considerations and might also cause confusion on the extent of the different samples. For instance, the name "San Cosimato" has alternatively been used to refer to findings from the San Cosimato site, in a strict sense, or to all the material from the San Cosimato Formation (*sensu* Conato et al., 1980, see Iannucci et al., 2021a and references therein). Considering that deposits previously referred to as the San Cosimato Formation are today known two represent two distinct sedimentary cycles (correlated to MIS 13 and MIS 11), it is worth recognizing that findings from "San Cosimato" (broad sense) include three distinct local faunas: Fontignano 2, with *Bos primigenius* and *Cervus elaphus* (MIS 11); Via di Brava, with *P. antiquus* (MIS 13 or MIS 11); and San Cosimato (strict sense), with *Stephanorhinus* sp., *B. primigenius*, *Castor fiber*, and *Emys orbicularis* (MIS 11) (Iannucci et al., 2021a). Moreover, Fontignano 1 also yielded scanty remains assigned to *Prolagurus pannonicus* and ?*Predicrostonyx* sp. by Kotsakis et al. (1992), which are the oldest in the whole area of Ponte Galeria.

In other cases, there is little or vague information on the provenance of certain specimens. This mainly regards historical samples whose associated information went lost during the misadventures suffered by the collection (e.g., the Tiber flood of 1870, the bombing of 1943), or acquisitions from amateurs or collectors unwary of appropriate procedures. Similar conditions generally preclude many considerations, but there are exceptions. An important example is a partial cranium of the wolf *Canis lupus* recently described by Iurino et al. (2022b), representing the first reliable occurrence of this taxon in Europe at ~400 ka (Fig. 6). The only information concerning the origin of the specimen indicated a recovery from "Ponte Galeria", which was only useful to narrow its geographical provenance, but not to clarify its age. Dating the specimen was nonetheless possible owing to the sediments infilling the cavities of the bones, including pumice clasts whose geochemical characterization allowed correlation with the Vico β pyroclastites, erupted at 406.5±2.4 ka (Iurino et al., 2022b). The case of the Ponte Galeria wolf is also an example of the application of digital technologies such as tomographic scans and 3D modelling that is now widely applied for the scientific and educational enhancement of fossil remains (see section 6).

Dedicated rescue excavations or paleontological surveys, especially following the quarrying activity in the area of Ponte Galeria and its surroundings since the 1960s (Ambrosetti, 1965, 1967; Caloi and Palombo, 1980; Capasso Barbato and Petronio, 1986; Capasso Barbato and Minieri, 1987; Petronio, 1988; Petronio and Sardella, 1999), have also been quite common and accompanied by comprehensive information, although the resulting samples are seldom abundant given the time-constrained conditions of their recovery. The most extensive is the material recovered from Cava di Breccia di Casal Selce (Petronio and Sardella, 1999; Milli et al., 2004; Milli and Palombo, 2005; Sardella and Petrucci, 2012; Strani et al., 2022). Mammal fossils were collected from two levels, a lower level of gravels and sands with cross laminations dated at ~750–700 ka, and an upper level of "salmon" hued sands dated at ~600-550 ka (Petronio and Sardella, 1999; Strani et al., 2022). The two faunal assemblages are either referred to as Cava di Breccia, Casal Selce, or Cava di Breccia di Casal Selce 1 and 2, respectively, or to as Ponte Galeria 2 and 3 (Ponte Galeria 1 being Fontignano 1). Casal Selce 1 yielded the reference fauna of the Ponte Galeria Faunal Unit, at the beginning of the Galerian Land Mammal Age (Petronio and Sardella, 1999; Iannucci et al., 2021b). Paleoecological analyses have been carried out on the more abundant and diverse fauna Casal Selce 2, allowing the reconstruction of a heterogeneous environment with open areas and scattered woodlands (Strani et al., 2022). It is worth mentioning that, aside from dedicated analyses, further paleoecological information derives from the relative abundance or the very occurrence of "rare" species, for instance, the macaque (Mecozzi et al., 2021b), whose presence would have been easily missed, had the sample not be carefully recovered.

Finally, systematic excavations carried out in the Rome area are relatively few in comparison to the huge number of sporadic findings. A pioneering systematic approach was applied at the Saccopastore site on the left bank of the Aniene River (now in the densely urbanized Via Val d'Ossola neighborhood), during 1935-1936, where remains were collected considering their stratigraphical provenance (Blanc, 1948). In the same years, it is noteworthy the fortuitous discovery of *Paleoloxodon antiquus* from fluvial sediments of the ancient Tiber, during the excavation of Via dell'Impero (the former Via dei Fori Imperiali) in the center of Rome (De Angelis d'Ossat, 1936).

Further fieldwork activities were carried out at Torre del Pagliacetto, coordinated by Alberto Carlo Blanc and Luigi Cardini and with the support of the Italian Institute of Human Paleontology. In the 1970-1980s, other excavations were performed, at Capanna Murata (Cassoli et al., 1982), different sites along the Aurelia Statal Road (Anzidei and Sebastiani, 1984), Castel di Guido (Longo et al., 1981; Radmilli, 1992; Radmilli and Boschian, 1996), Casal de' Pazzi (Anzidei et al., 1984) and La Polledrara di Cecanibbio (Anzidei et al., 1989; 2012). The latter three sites are those have been object of recent excavations and research (Anzidei et al., 2012; Pereira et al., 2017; Boschian et al., 2019; Gioia, 2015, 2020; Marano et al., 2021; Lemorini et al., 2022; Marra et al., 2022).

5. AN OVERVIEW OF THE MIDDLE PLEISTOCENE MAMMAL FAUNAS OF ROME

Large mammal faunas recovered from the area of Rome play a prominent role for biochronological correlations and paleoecological inference of the Middle Pleistocene

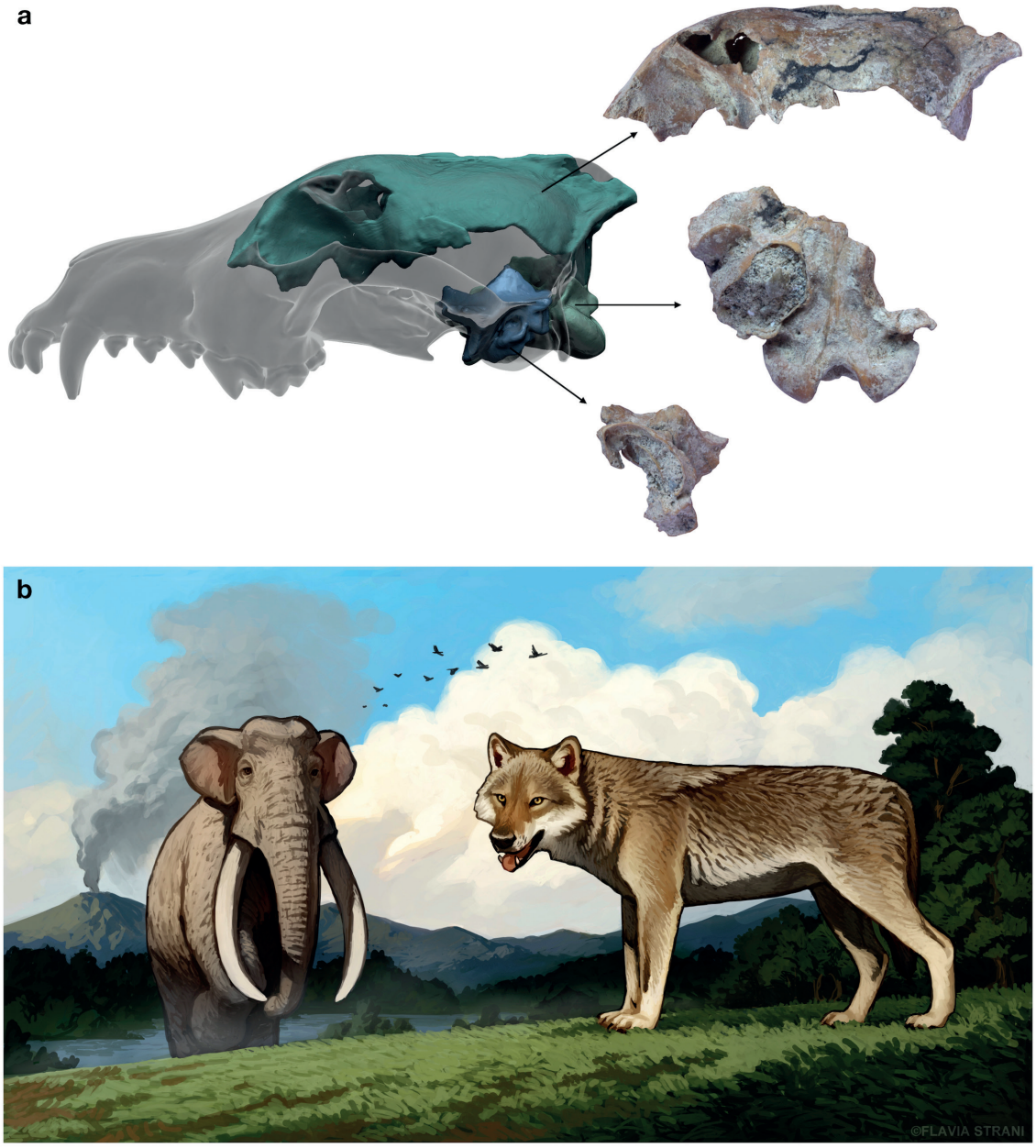

Fig. 6 - *Canis lupus* from Ponte Galeria (PF-PG1). Digital reconstruction of the specimen from the separated fragments (a) and paleoenvironmental reconstruction of the Ponte Galeria area ~400 Ka (b). Virtual restoration by D.A. Iurino, artwork by F. Strani.

of western Europe (Fig. 7). This territory also yielded abundant evidence of human presence, including premodern human fossils recovered at Casal de' Pazzi, Castel di Guido, La Polledrara di Cecanibbio, Ponte Mammolo, Saccopastore, and Sedia del Diavolo, as well as lithic and bone tools from the same sites and other deposits of the Campagna Romana (e.g., Longo and Radmilli, 1972; Longo et al., 1981; Cassoli et al., 1982; Mallegni and Radmilli, 1988; Manzi et al., 1990, 2001; Radmilli, 1992; Anzidei et al., 1993, 2012).

The names of two Land Mammal Ages (LMAs; also referred to as European Land Mammal Ages, ELMAs, but see Iannucci and Sardella, 2023, for discussion) adopted by Italian biochronologists and commonly used in western Europe derive from the Ponte Galeria area (Galerian) and the Aurelia Statal Road (Aurelian), as well as two Faunal Units (FUs), Ponte Galeria and Torre in Pietra (Gliozzi et al., 1997; Petronio and Sardella, 1999).

Ambrosetti et al. (1972) introduced the term Galerian within a chronological scheme for the Pleistocene of central Italy, to recognize a phase best represented by sediments and faunas in the area of Ponte Galeria. As stated by Ambrosetti (1967), the mammals from this area were recovered in sandy gravel levels exposed in the quarries active at that time (e.g., Cava Arnolfi, Cava Alibrandi), which were previously often referred to as

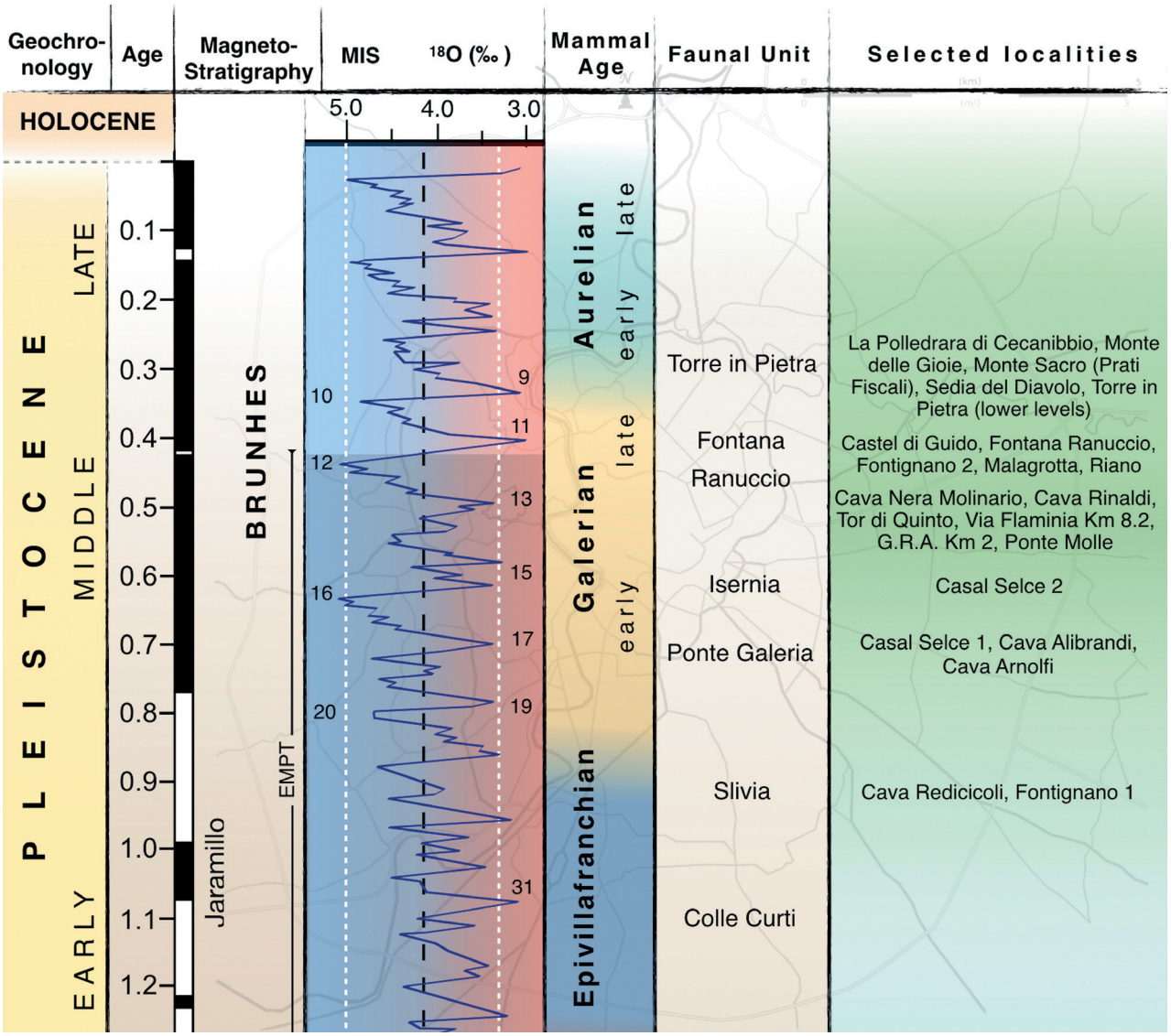

Fig. 7 - Chronological scheme.

Cromerian. The term Galerian soon became widely used as a LMA placed after the late Villafranchian (Azzaroli et al., 1982, 1988; Azzaroli 1983; Gliozzi et al., 1997). Much effort and discussion have been devoted to disentangling the timing and pace of the faunal turnover characterizing the Early-Middle Pleistocene Transition (*sensu* Head and Gibbard, 2015), resulting in different proposals concerning its subdivision (Azzaroli, 1983, 1995; Azzaroli et al., 1988; Caloi and Palombo, 1995; Kahlke, 2000, 2006, 2007, 2009; Koufos, 2001; Spassov, 2003; Bellucci et al., 2015; Palombo, 2016). Here, we recognize the earliest faunas of this period as Epivillafranchian (~1.2-0.8 Ma), and the Galerian as the latest Early to early Middle Pleistocene (~0.8-0.4 Ma). In this view, the Epivillafranchian-Galerian turnover approximates the Early-Middle Pleistocene boundary and the Ponte Galeria FU is the earliest FU of the Galerian (Petronio and Sardella, 1999; Iannucci et al., 2021b). The reference fauna of the Ponte Galeria FU (placed between Slivia and Isernia) is Casal Selce 1, dated ~750-700 ka (Sardella and Petrucci, 2012; Strani et al., 2022). This FU records the earliest appearance in the Italian Peninsula of *Crocuta crocuta, Hemibos galerianus,* and *Megaloceros savini*. (Gliozzi et al., 1997; Petronio and Sardella, 1998, 1999; Martínez-Navarro and Palombo, 2004, 2007; Milli et al., 2004; Milli and Palombo, 2005; Petronio et al., 2011; Sardella and Petrucci, 2012; Iannucci et al., 2021b). Upper levels of the same quarry (Casal Selce 2) have also yielded an abundant and diverse assemblage referable to MIS 15 (Isernia FU), including *Capreolus* sp., *Cervus elaphus*, *Dama* sp., *Praemegaceros* sp., Bovidae indet., *Hippopotamus antiquus*, *Sus scrofa*, *Equus* cf. *altidens*, *Equus* cf. *mosbachensis*, Elephantidae indet., *Macaca sylvanus*, *Canis* sp., *Vulpes* sp., *Lynx pardinus*, and *Meles meles* (Strani et al., 2022).

Fossil mammals referred to approximately 500 ka

were mainly found in the urban territory of Rome near the Tiber River, as the Tor di Quinto area, Ponte Molle, Cava Nera Molinario, Parioli, Monte Antenne, and Villa Glori. These faunal assemblages document the earliest appearance in the Italian Peninsula of *Bos primigenius*, *Dama clactoniana*, and *Stephanorhinus hemitoechus*, taxa that soon became widely diffused across the Peninsula (e.g., Pandolfi and Marra, 2015; Iannucci et al., 2021a; Mecozzi et al., 2021a). Findings at the second kilometer of the Grande Raccordo Anulare (= G.R.A. Km 2), a highway of the city of Rome, also referred to ~500 ka, yielded material of the uncommon "*Hyaena*" *prisca* (Caloi and Palombo,1986b; Milli and Palombo, 2005; Marra et al., 2014; Iannucci et al., 2021b).

The term Aurelian was introduced by Gliozzi et al. (1997), based on the rich deposits located along the Aurelia Statal Road. The first, and the only accepted, FU of the Aurelian is Torre in Pietra, customarily represented by the local faunas of Torre del Pagliacetto, La Polledrara di Cecanibbio, Castel di Guido, Riano, and Malagrotta. Although chronostratigraphic revisions carried out in the last decade suggested a slightly older age (MIS 11) for several localities of the Aurelia Statal Road (e.g., Castel di Guido, Malagrotta, Collina Barbattini). Another record referable to MIS 11 is the partial cranium of *Canis lupus* from the area of Ponte Galeria described by Iurino et al. (2022b), which allowed to backdate the arrival of the species, previously placed in the Torre in Pietra FU (Gliozzi et al., 1997).

The most important site of the Aurelian LMA of Campagna Romana is the amazing deposit of La Polledrara di Cecanibbio, dates approximately between 325-310 ka (Pereira et al., 2017). The site preserves thousands of vertebrate remains still *in situ*, among which a nearly complete skeleton of *Paleaoloxodon antiquus,* whose taphonomic analysis suggests that the specimen was entrapped in muddy sediments during the palustrine phase of the deposition (Santucci et al., 2016). Moreover, the elephant carcass was exploited by premodern humans, as testified by lithic tools found around the specimen, whose analysis suggested a short time of butchering sessions (Lemorini et al., 2022). The presence of a premodern human is also documented by a left deciduous second upper premolar (Anzidei et al., 2012). The richness of the faunal spectrum and the representativeness of mammal remains of each species (often documented by complete crania) make La Polledrara di Cecanibbio a very informative window on the late Middle Pleistocene terrestrial ecosystem of Europe and an almost unique *in situ* museum and geo-heritage site (Anzidei et al., 1989, 2004, 2010, 2012; Palombo et al., 2003; Cerilli et al., 2015; Cerilli and Fiore, 2018; Marano et al., 2021).

Late Middle Pleistocene sites (MIS 9) are also located in the Aniene valley, in the proximity of its confluence with the Tiber River: Casal de' Pazzi, Monte delle Gioie, Monte Sacro, Saccopastore, Sedia del Diavolo, and Vigne Torte. Few deposits can be referred to the end of the Middle Pleistocene (MIS 7), as Casal de' Pazzi, Castelmalnome, Ponte Mammolo, the upper levels of Torre in Pietra and Vitinia. Among these, Casal de' Pazzi is the second, and last, museum in Rome where the fossils are still *in situ* preserved (Anzidei et al., 1984), playing an important role for the dissemination and valorization of the archeological and paleontological heritage of this territory (Gioia, 2015, 2020). At Casal de' Pazzi, a cranial fragment referred to as a premodern human was also found (Manzi et al., 1990).

The last site mentioned here, but just in chronological order, is Saccopastore, a historical fossil-bearing deposit discovered during quarrying activities. The long stratigraphic succession exposed in the 1930s excavation yielded two crania of *Homo neanderthalensis* (Manzi et al., 2001; Bruner and Manzi, 2006, 2008; Buzi et al., 2018). For almost a century, the Saccopastore deposit was referred to as MIS 5 (Manzi et al., 2001; Bruner and Manzi, 2006, 2008), but a chronostratigraphic revision proposed a correlation to MIS 7 (Marra et al., 2015).

6. MANAGEMENT AND ENHANCEMENT OF THE PALEONTOLOGICAL HERITAGE

Fossils are evidence of once-living organisms from deep time representing a relevant component of geodiversity with an incredible capacity to inform the general public about the history of life, humanity, and Earth (DeMiguel et al., 2021). The management of the paleontological heritage of Rome, consisting of thousands of remains, from isolated teeth to more or less complete skeletons, thus represents a vital although challenging task, which requires considerable expertise and economic efforts. Of fundamental importance is maintaining and updating catalog information, as well as restoring fossils that need appropriate care. Several specimens of the MUST collection are currently under restoration, as a part of the ongoing renovation activities of the museum (Fig. 8). Whilst it is obvious that such efforts are of great relevance for research, there is more than mere maintenance. For instance, restorations attempted in previous years (see section 3) were often aimed at a more complete although subjective reconstruction, especially for specimens prepared to be displayed, while today priority is given to adherence to the original preservation status. In Figure 8, the cranium of *Stephanorhinus hemitoechus* is shown as an example. In a previous restoration, entire sections of a cranium, most notably the zygomatic arch and part of the snout were reconstructed, while the new restoration allows a better appreciation of the true morphology of the specimen. The previous status of the specimen complicated some morphological considerations (Pandolfi, 2011).

Alongside these traditional (however updated) efforts, over the last two decades, increasingly high-performance and user-friendly digital technologies such as photogrammetric and tomographic scans have been widely adopted in the field of paleontology, offering a broad range of tools for the study and enhancement

Fig. 8 - An example of the recent restoration ongoing at MUST. Cranium of *Stephanorhinus hemitoechus* from Fosso Malafede before (a) and after (b) the new restoration. Note that previous restorations arbitrarily reconstructed part of the cranium.

of fossil remains (e.g., Iurino et al., 2013, 2022a; Lautenschlager, 2016; Kourais et al., 2019; Iannucci et al., 2022a). Recently, these technologies have been applied to some fossil mammals recovered from different paleontological sites of Rome, including representatives of the genus *Homo*.

Since the 2000s, two skulls of *Homo neanderthalensis* recovered in 1929 and in 1935 from the homonymous locality of Saccopastore in the north-eastern suburb of the city, have undergone several digital acquisitions and analyses (Bruner and Manzi, 2006, 2008; Buzi et al., 2018). The historical and scientific value of these specimens implies strong restrictions and strict protocols for access to the originals, conditions necessary for their protection but which place severe limits on dissemination activities. The production of accurate digital models and their 3D printed copies are non-invasive methods that provide data and materials for both researchers and the public. A similar approach was adopted in 2022 on the early *Canis lupus* from Ponte Galeria (Iurino et al., 2022b; see section 4). The specimen, consisting of three separate fragments, was digitally restored to obtain a more complete version of the skull, which in turn allowed detailed anatomical analyses and clarified the taxonomic attribution (Fig. 6). To date, this rare fossil wolf represents the earliest occurrence of this species not only in Italy but on the entire European region (Iurino et al., 2022b).

In addition to individual case studies, there are several ongoing digitization projects of paleontological collections stored in some of the capital's museums, including the historic collection of fossil mammals housed at MUST. In 2018, in conjunction with the museum's renovation activities, restoration works began on the fossil mammal collections, and with them the digital acquisition of the most significant specimens (Fig. 9).

Fig. 9 - An example of digital acquisitions ongoing at MUST, laser scanning performed on a mounted skeleton of *Hippopotamus* with Artec Eva Scanner.

7. FINAL REMARKS

As the history of Rome is multilayered and complex, it is that of its Middle Pleistocene large mammal fossil record. Here, we would like to emphasize the important connection between the history of the paleontological collections of MUST and the history of the research on mammal faunas of the urban area of Rome and the Campagna Romana. Major milestones in the history of the museum were linked to the history of the city and in turn, corresponded to new stimuli in research. Because of the intimate and entwined nature between museum management and research, the renewed efforts associated to the reorganization of the long-separated earth sciences museums of Sapienza into a single entity is also promoting new research and dissemination activities. The development and spread of user-friendly digital technologies over the last decades permit a "digital enhancement" of fossil specimens that provided the content for substantial advancements in research and dissemination, but it does not neglect the importance of traditional and yet fundamental efforts such as cataloging and restoration. These two aspects are indeed profoundly connected. For instance, the digital acquisition of a specimen before and after its restoration provides a documentation tool of extreme importance, especially when previous restorations have been attempted.

It is also worth underlining that historical collections such as those housed at MUST constitute a mine of "dark" data (being every piece of information, from those directly associated with the fossils, such as their taxonomic identification, to those indirectly related to them, e.g., the chronology of the fossil-bearing deposits), especially significant when undertaking new fieldworks and excavations are not practicable or feasible, as in the urban area of Rome. Unfortunately, efforts aimed at revising historical collections are mainly limited to accompanying renewed research in old localities, aside from rediscoveries of specimens of peculiar importance (e.g., Bona, 2021; Fabbi et al., 2021; Mecozzi et al., 2022; see Iannucci et al., 2022b and Iannucci, 2023, for discussion). To facilitate and promote such revisions, appropriate collection management is of paramount importance.

In sum, the case of MUST large mammals testifies to the multiple dimensions involved in considering historical fossil collections and exemplifies the positive feedback relationship between research and collection management.

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