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The intriguing history of two elephant molariform teeth from Sardinia (Italy): which relationships between the lost tooth from Chiaramonti and the molar displayed at Civic Ozieri's Archeological Museum?

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ABSTRACT - Thus far, a few moderately reduced-size mammoth remains have been reported from six Sardinian (Italy) sites, presumably ranging in age from the late Middle to the Late Pleistocene. All remains have been tentatively ascribed to a single endemic species, *Mammuthus lamarmorai*, but the uncertainties about the actual chronology of most of the remains, their minimal number, and some differences in their size hamper any attempt to infer the exact number of mammoth taxa that inhabited Sardinia and their evolutionary history. Therefore, even a single specimen might provide a piece of interesting information to answer open questions. This note aims to give notice of an elephant tooth found in the neighborhood of the Chiaramonti village (Sassari, Northwestern Sardinia), investigate its history from its first report to the disappearance of any information about its current collocation, and describe a quite large molariform tooth that was given by a donor to the archeological museum of the rather close village of Ozieri (Sassari). The morphology and morphometry of the Ozieri upper penultimate molar (M2) are more similar to, but not fully typical of, *Mammuthus* than *Palaeoloxodon* representatives. The tooth seems to belong to an elephant rather larger than the *M. lamarmorai* molar (M3) from that from San Giovanni di Sinis (Cabras, Oristano, central-western Sardinia). Its length, indeed, is comparable with the minimum length values of some continental representative of *Mammuthus meridionalis* and *Mammuthus trogontherii.* However, the similarity and principal component multivariate analyses indicate major affinity with the latter species. The lack of any information about the Chiaramonti molar and the unknown chronological setting of the molar stored at the Ozieri's Civic Archeological Museum, further underline the scantiness of sound geologic s.l. and taphonomic data provided by most of the Sardinian specimens. Indeed, the exact provenance of some remains is unknown, while others were collected without paying any attention to the geological and depositional context or are currently lost, obscuring the evolutionary scenario of elephant populations in Sardinia.

Keywords: insular *Mammuthus*; upper molar; systematic; taxonomy.

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1. INTRODUCTION

Insular endemic elephants are one of the most common taxa of the disharmonic insular fauna that inhabited Mediterranean islands during the Pleistocene. *Palaeoloxodon* dwarf representatives were especially abundant on the Aegean islands (Crete, Cyclades, Dodecanese, Cyprus) (Athanassiou et al., 2019 and references therein), and central Mediterranean islands (Malta, Sicily, and Favignana) (Herridge, 2010; Palombo et al., 2021 and references therein). Conversely, remains of endemic dwarf mammoths are rare. A few specimens of a mammoth extremely reduced in size, *Mammuthus creticus,* have been reported from a single latest Early Pleistocene site in Crete (Athanassiou et al., 2019 and references therein) and a few specimens currently ascribed to *Mammuthus lamarmorai* are known in a few Sardinian late Middle to Late Pleistocene sites (Palombo et al., 2024 and references therein). The insular diminutive descendants of both continental lineages, which colonized islands by oversea dispersal and sometimes entered the same island more than one time, include examples of one of the most intriguing and distinctive phenomena exclusive of the insular large mammals' evolution: the reduction in size concerning their mainland ancestors (i.e., *M. creticus* from Crete and *Palaeoloxodon falconeri* from Malta and Sicily).

The Corso-Sardinian Massif is the single large central Mediterranean insular area never colonized by straight-tusked elephants. Moreover, the moderately dwarfed Sardinian mammoth is the only insular mammoth present on Mediterranean islands at the time when *Palaeoloxodon antiquus* populations were widely present on the neighboring mainland. The attribution to the *Mammuthus* genus of the few Sardinian specimens, which have been retrieved in Western Sardinia from late Middle to Late Pleistocene deposits (see Palombo et al., 2024 for a discussion), is mainly based on the taxonomic characters shown by the last upper molar found at San Giovanni di Sinis (SG hereinafter) (Cabras, Oristano) (Ambrosetti, 1972; Palombo et al., 2024) and Campu Giavesu (CG hereinafter) (Giave, Sassari) (Palombo et al., 2005), and the Schreger line patterns of the tusk's large fragment from Guardia Pisano Hill (Gonnesa) (Palombo et al., 2012, 2024). Various factors contribute to hamper any attempt to infer the actual number of mammoth taxa that inhabited Sardinian and their evolutionary history. Among others, the extremely small number of remains; the uncertainties about the actual chronology of some specimens, in particular those collected in the past without any information about either the depositional context of the fossil remains and the exact localization of the findings (e.g. the incomplete skeleton from Guardia Pisano that lacks cranial remains) (Zoboli et al., 2018); the unavailability of some specimens, which were described and figured but currently are apparently lost [e.g., molariform teeth from Tramariglio (Malatesta, 1954) and CG]; and some differences in the last molars' size (see, Palombo et al., 2024 for a discussion). Therefore, even a new single specimen might provide a piece of interesting information useful to answer open questions, such as the chronology of mammoth remains, whether some differences shown by the molars fall within the intra- and inter-population variation of the morphobiometric characters or not; how many elephant species inhabited Sardinia; how long each population or species persisted on the island, and, in turn, how many times the putative ancestor entered Sardinia. Moreover, we know that *M. lamarmorai* was most likely still present during MIS 4-MIS 3 and that no mammoth remains have been reported in more recent deposits, but there is not enough data to hypothesize the time and causes of its extinction on the island. Finally, a new discovery might shed some light on the actual absence of *P. antiquus* on the Corso-Sardinian Massif.

The purpose of this note is twofold: to give notice of a molar found in the neighborhood of the Chiaramonti village (Sassari, Northwestern Sardinia) (CH hereinafter) and report the scanty information about its discovery and following events until the disappearance of the lack of information about its current collocation; and to describe and briefly discuss the provenance of a quite large molar (Oz hereinafter) that was given by a donor inhabiting the rather close village of Ozieri (Sassari) to the Ozieri's Civic Archeological Museum (CAMOz, hereinafter) (Fig. 1).

Fig. 1 - Map of Sardinia showing the location of Chiaramonti and Ozieri villages.

2. THE LOST ELEPHANT MOLAR FROM CHIARAMONTI

The history of the discovery of mysterious and strange remains in sediments of various ages is a fairly common fact that has often found ample and lasting space in popular memory because they were believed to be remains of mythic creatures or unexpected fossils. Sometimes, the discovery's news was accompanied by the description of findings and often by unrealistic hypotheses about both their origin and the organism to which they might have belonged (e.g., Mazzella, 1591; Romano and Palombo, 2017; Romano and Avanzini, 2019 and references therein, as regards to mammal bones). Sometimes the report was merely fake news that was not based on any realistic data. Sometimes, the news has been confirmed by reliable sources, but the current collocation of remains, which were not described or depicted, is unknown. Sometimes, the remains have been lost.

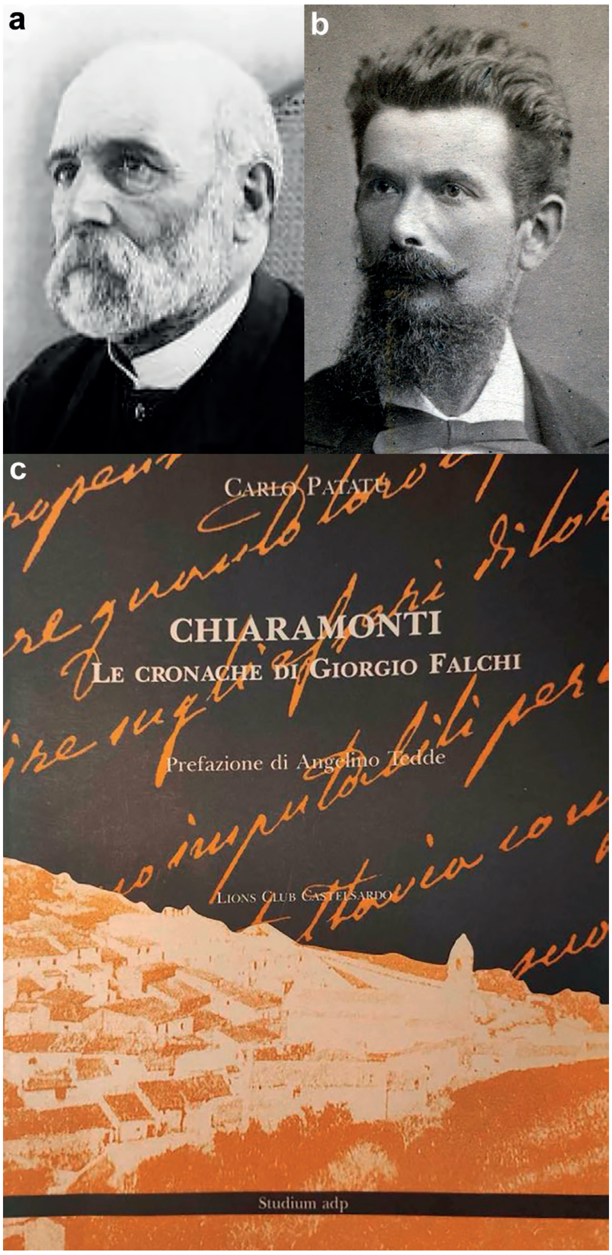


Fig. 2 - Historical portraits of a) the historian Giorgio Falchi (1843-1922), b) the geologist and paleontologist Domenico Lovisato (1842-1916), and c) the front cover of "Chiaramonti - Le cronache di Giorgio Falchi" (Chiaramonti - The Giorgio Falchi chronicles) published by Carlo Patatu in 2004.

This is the case, for instance, of the elephant molar found in the surroundings of the CH village, that Giorgio Falchi (1843-1922) (Fig. 2a), a prominent figure and historian of the village, mentioned in 1894 in his historical chronicles. More than a century later, Carlo Patatu published Falchi's historical chronicles (Patatu, 2004) (Fig. 2c).

In his work, Falchi reported the results of several paleontological surveys that he had performed in the Chiaramonti area together with his friend Francesco Grixoni (1833-1906) and the geologist Domenico Lovisato (1842-1916) (Fig. 2b) During one survey, "an elephant tooth from prehistoric times" was collected in the area of "Orria Pizzinna" (Orria Pitzinna or Orria Pithinna), a locality about 2 km west of Chiaramonti (Fig. 3a). Unfortunately, neither Falchi nor Lovisato described, or illustrated the elephant tooth, or gave some information about the level that yielded the fossil. Recently, one of us (MZ) surveyed the Orria Pitzinna locality looking for the presence of Quaternary deposits, which consist of important thin deposits of uncertain age, covering here and there the Oligo-Miocene volcanic rocks.

Probably the elephant tooth remained in the possession either of Falchi or, maybe, of Grixoni, both enthusiasts

Fig. 3 - Maps showing the two putative localities where the second upper molar stored at the Ozieri's Civic Archeological Museum would have been collected. The site of Orria Pitzinna near the village of Chiaramonti (a), the private garden at Ozieri (b).

in and collectors of antique objects. After Falchi's death, part of his private collection of archeological and paleontological heritage was lost, as it possibly occurred to the elephant molar, if it was part of the collection (Patatu personal communication). Some descendants of the Falchi family possibly inhabited the village of Ozieri, which is less than 30 km from Chiaramonti, or had close relationships with people who inhabited this village (unconfirmed information from anonymous people).

3. THE PROBLEMATIC ELEPHANT MOLAR STORED AT THE CIVIC ARCHEOLOGICAL MUSEUM OF OZIERI

In 1985, Raimondo Madau, a gardener with a passion for antiquities, donated an elephant molar together with other fossils from different localities of Sardinia to the CAMOz (Figs. 4-6). Giving the molar to the museum, Madau reported that the elephant molar had been collected in a private garden at the center of the Ozieri village, but without providing further information about the year of the molar's discovery and its depositional context. A recent survey in the presumed area of the finding made by two of us (MZ and DZ) did not lead to the identification of any Quaternary deposits (Fig. 3). However, the hypothesis that Quaternary deposits are currently masked or have been removed during the intensive urbanization and anthropization of the area cannot be completely ruled out. Therefore, based on the limited available data, establishing what might have been the actual stratigraphic provenance and whether the garden was or not the original place of molar's burial remains open questions. Indeed, although a few pieces of historical information suggest some relationships between a few Ozieri's and Chiaramonti's citizens, no firm data support the hypothesis that the Oz mammoth molar could be the same that Falchi cited in its chronicles.

3.1. MATERIAL AND METHODS

3.1.1. Material

We have analyzed the morphobiometric characteristics of the Oz elephant molar, currently housed (without an inventory number) and on display at CAMOz. We have compared the dimensional data (Tab. 1) with those of the selected M3 Sardinian specimens (i.e., SG and CG upper last molars) and those of M2 and M3 *M. meridionalis* and *M. trogontherii* belonging to selected continental Early and Middle Pleistocene European populations (Tab. 2) and with the dimensional variation of Italian *Palaeoloxodon antiquus* molars provided by Palombo and Ferretti (2005).

3.1.2. Methods

3.1.2.1. Tooth nomenclature and measurements

Elephants chewing teeth, which differ from each other in dimensions but are morphologically similar (molariform teeth), develop sequentially over about 50 years in a series that displaces horizontally and moves gradually, progressively increasing in size and number of enamel plates (lamellae). Some authors, considering that permanent premolars are lacking in the majority of advanced Elephantinae, named the six molariform teeth present in each upper and lower quadrant (M/m from 1 to 6). However, permanent premolars occur in a few mammoth specimens (cfr. Sanders, 2018). Therefore, we adopted the nomenclature generally used by the majority of specialists, naming the first three upper and lower molariform teeth, homologous to deciduous premolar,

Tab. 1 - Tooth measurements of second and last upper molars of Sardinian *Mammuthus*. Abbreviations and symbols: * talon is actually missing (see subparagraph 3.2.1); **, width estimated excluding the width of the gap between lateral cement and plates; ∞= missing plates; x = talon; p = platelet; > = minimum measure of incomplete tooth; - = unavailable measurement. Source of data: 1 = Ambrosetti (1972); Melis et al. (2001); 2 = Palombo et al. (2005).

Taxon	Site	Tooth	Plates			Length		Width		Crown Heigth	
			Formula (Pl)	Total PlT	in use (PlF)	Total (L)	Occlusal (LF)	Crown (W)	Occlusal (WF)	Crown (H)	Functional (HF)
Mammuthus sp.	Ozieri's Museum	M2	∞12.5(x)*	> 13	12.5	>174	c.156	c. 73.5**	c. 63**	143	139
M. lamarmorai	San Giovanni di Sinis	M3	∞11x	11	8	130	116	69	55	> 90	90
M. lamarmorai	Campu Giavesu	M3	16	15.5	7	225	-	76.5	-	129	129

Taxon	Site	Tooth	Lamellar Frequency				Enamel tickness			Hypsodonty index (HI = H/W)	Source
			Average (F)	Occlusal (Fo)	Labial (Fl)	Buccal (Fb)	Minimum (em)	Average (e)	Maximum (emax)		
Mammuthus sp.	Ozieri's Museum	M2	8	8	8.1	7.75	1.4	1.75	c. 3	c.1.9	
M. lamarmorai	San Giovanni di Sinis	M3	8	-	-	-	-	1.8	-	>1.55	1
M. lamarmorai	Campu Giavesu	M3	7	-	-	-	-	2.8	-	1.69	2

Tab. 2 - Comparison among dimensional data of Sardinian molars and those of *Mammuthus meridionalis, M. trogontherii*, mammoth molars showing a mixture of dental characteristics of both species, and *M. trogontherii*-like M2 and M3 from selected European sites. Abbreviations and symbols as in Tab. 1. Source of data: 1 = Melis et al. (2001); 2 = Palombo et al. (2005); 3 = Palombo and Ferretti (2005); 4 = Maglio (1973); 5 = Ferretti (1999); 6 = Maccagno (1962); 7 = Van Essen (2011); 8 = Konidaris et al. (2020); 9 = Albayrak and Lister (2012); 10 = Agostini et al. (2012); 11 = Coppens et al. (1982); 12 = Palombo (unpublished data); 13 = Lister et al. (2012); 14 = Dubrovo (1977); 15 = Lister and Stuart (2010); 16 = Athanassiou (2012); 17 = Baygusheva et al. (2012); 18 = Pawlowska et al. (2014); 19 = Lenardić, J. (1994); 20 = Garutt and Foronova (1976) (fide Lenardić, 1994).

Taxon	Tooth	Site	Number of Plates° (Pl)		Length (L)		Width (W) (including cement)		Crown Height (H)		Average Lamellar Frequency (F)		Average Enamel Tickness (e)		Hypsodonty index (HI=H/W)		Source
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
Mammuthus sp.	M2	Ozieri's Museum	> 13	-	>174	-	c. 73.5^	-	143	-	8	-	1.95		c.1.9	-	
M. lamarmorai	M3	San Giovanni di Sinis	>11	-	130	-	69	-	> 90	-	8	-	1.8		>1.55	-	1
M. lamarmorai		Campu Giavesu	>15.5 (16)	-	225	-	76.5	-	129	-	7	-	2.8		1.69	-	2
M. meridionalis	M3	Valdarno (It)	13	11-14	269	226-343	101	83-123	131	101-160	5	4.0-6.0	3.2	2.6-3.9	1.3	1.2-1.6	3
		various sites*	12.8	11-14	273	223-317	104.8	86-126	122.7	100-142	4.9	3.7-6.1	3.3	2.6-4.1			4
		Montopoli (IGF 1077) (It)	9	-	263	-	109	-	-	-	4	-	3.8	-	-	-	3
		Pietrafitta (It)	14	13-16	245	-	93	84-103	131	-	6	-	2.9	2.6-3.3	1.5	-	5
		Pietrafitta (CET80) (It)	14	-	318	-	115	-	130	-	5	-	3.3	-	1.32	-	3
		Pietrafitta (CET1119) (It)	14	-	245	-	103	-	131	-	6	-	2.6	-	1.5	-	3
		Farneta (IGF12434) (It)	14	-	301	-	115	-	134.5	-	5	-	2.9	-	1.17	-	3
		Madonna della Strada (right) (It)	>7	-	255	-	98	-	110	-	5	-	-	-	1.12	-	6
		Madonna della Strada (left) (It)	>8	-	258	-	95	-	-	-	5	-	-	-	-	-	6
		North Sea (TNe)	13.3	13-14	265.8	220-335	101.2	84-117.5	120.8	104-147	5.4	4.9-5.8	3.96	2.3-3.8	1,31	1.23-1.49	7
		Apollonia (APL-686B) Gr)	>13 (?14)	-	231	-	c. 87	-	128.8	-	5.5	-	2.9	-	1.48	-	8
		Eskişehire Yukarısögütönü (Tu)	12		309.5		119.5		134.1		c. 3.9		3.67		1.2		9
	M2	Valdarno (It)	9	8-10	212	175-243	89	80-103	120	103-148	5.0	4.5-6.0	2.7	2.2-3.4	1.40	1.00-1.60	3
		various sites	9.7	8-11	206.7	167-242	86.8	76-106	113.9	98-138	5.1	4.0-5.7	2.9	1.9-3.6			4
		Pietrafitta (It)	11	8-12	-	-	84	73-95	-	-	5.4	4.8-5.8	2.7	2.6-2.9	1.3	1.2-1.4	5
		Campo di Pile (SBAAp 320)	9	-	206	-	90	-	94	-	4.5	-	3.1	-	1.04	-	10
		Campo di Pile (SBAAp 321)	9	-	197	-	92	-	91	-	4.5	-	3.1	-	0.99	-	10
		Redicicoli (MR E2)	9	-	201	-	94	-	123	-	6.0	-	2.6	-	1.30	-	3
		Monte Tenda (MCSN 10688)	10	-	206	-	90	-	115	-	6.0	-	3.0	-	1.28	-	3
		North Sea	9.7	9-10	212.3	195-242	92.2	79-104.5	119.7	105-135	5.5	4.5-6.3	2.72	2.2-3.3	1.34	1.29-1.51	7
		Konya-Zengen (Tu)	8		202.7		87.7		c.107.1		c.5.3		2.97		c.1.22		9

Tab. 2 - ... Continued

Taxon	Tooth	Site	Number of Plates° (Pl)		Length (L)		Width (W) (including cement)		Crown Height (H)		Average Lamellar Frequency (F)		Average Enamel Tickness (e)		Hypsodonty index(HI = H/W)		Source
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
Specimens showing a mosaic of advanced (*M. trogontherii*) and primitive (*M. meridionalis*) characters	M3	Rio Pradella (It)	14	-	235	-	90	-	158	-	6	-	2.4	-	1.76	-	3
		Saint Prest (Fr)	14-15	-	-	245-312	-	85-105	-	108-141	-	3.8-6.0	-	2.4-3.7	-	1.11-1.40	7,11
	M2	Saint Prest (Fr)	10	-	-	175-215	-	74-102	85	-	-	3.6-5.7	-	2.3-3.5	-	-	7,11
M. trogontherii-like	M3	Sinyaya Balka (Ru)	15	13-17	294.9	254-328	98.5	82-122	-	-	4.8	4.0-6.0	3.1	2.5-3.5	1.42	1.25-1.58	12
	M2	Sinyaya Balka (Ru)	11.4	10-14	225.7	195-245	77.7	87-116	140.9	122-166	5.65	4.5-6.5	2.7	2.3-3.0	1.6	1.2-1.9	12
M. trogontherii	M3	Süssenborn (Ge)	19.7	17-22	300	230-397	101.6	77-123	147	122-210	8.94	5.80-9.98	2.39	1.7-3.0	1.8*	1.3-2.3*	13,5
		various sites	18.6	14-21	293	213-358	85.2	57-108	162.5	118-218	6.5	5.0-8.2	2.2	1.5-3.0	-	-	4
		Tiraspol (MD)	-	16-22	-	303-370	-	86-115	-	160-211	-	5.0-7.0	-	2.0-3.0	-	-	14
		Via Flaminia Km 7.2 (It)	18	-	303	-	119	-	-	-	7	-	2.3	-	-	-	3
		West Runton (UK)	21	-	c. 400	-	c. 118	-	196	-	5.25	-	2.3	-	c. 1.66	-	15
		Laussikà (Gr)	> 14	-	350	-	102	-	-	-	6.3	-	-	2.6-2.9	-	-	16
		Kagal'nik (Azov Sea) (right) (Ru)	18	-	354	-	104	-	191	-	5.5	-	2.4	-	-	-	17
		Kagal'nik (Azov Sea) (left) (Ru)	20	-	372	-	105	-	189	-	5.5	-	2.3	-	1.84	-	17
		Belchatów (Pl) (Pl)	>19	-	289	-	114.4	-	-	-	6.75	-	2.2	157	-	-	18
		Amasya-Suluova (Tu)	19	-	323	-	109	-	181.8	-	6.41	-	2.79	-	1.68	-	9
		Konya-Dursunlu (Tu)	18	-	295	-	106.5	-	c.165.4	-	6.13	-	2.92	-	c.1.52	-	9
	M2	Süssenborn (Ge)	15	13-16	-	-	85	68-103	-	-	5.6	4.4-6.8	2.5	2.0-2.9	1.8	1.3-2.3	5
		various sites (Europe)	13.3	11-17	206.7	168-240	77.4	55.0-95.0	134.3	105-162	6.9	5.5-7.8	1.8	1.3-2.8	-	-	4
		Pratola Peligna (It)	?13	-	> 198	-	87	-	-	-	8.0	-	2.8	-	2.0	-	3
		Belchatów (Pl)	14	-	187	-	77.7	-	-	-	7.5	-	1.8	-	1.78	-	18
		Slavonski (left) (Cr)	>11	-	178	-	83	-	-	-	-	-	1.42	-	-	-	19
		Slavonski (right) (Cr)	>11	-	>157	-	81	-	-	-	-	-	1.34	-	-	-	19
		various sites (Ru)	13	10-16	-	144-250	82	70-109	167	124-196	7.5	4.8-9.8	2.0	1.0-2.65	-	-	20

respectively DP2/dp2, DP3/dp3, DP4/dp4, and the three molars M1/m1, M2/m2, and M3/m3.

The plates (laminae) present at the mesial (anterior) and distal (posterior) ends of the tooth, which do not extend to the base of the crown, are known as "talons", while we named "platelet" the small additional lamella that sometimes extends to the roots both on the posterior and anterior sides of the molar. Lister and van Essen (2003) introduced in literature this term for the platelet lamina extending to the crown base at the posterior end of the M3 from Cernătesti (Romania), neotype of the *M. rumanus* species.

Measurements of the molariform tooth were taken with a digital caliper following Aguirre (1968-1969), Maglio (1973), and Lister (1996), with minor modifications. For instance, lamellar frequency (F = number of enamel plates in 100 mm in teeth with a total length >/= 100 mm, F* = number of plates in 50 mm in teeth with a length < 10 mm) was estimated averaging the F measured on the occlusal (Foccl), lateral (LFl), and medial (LFm) surfaces to avoid possible mistakes due to the convergence of enamel plates towards the top of the crown, especially in lower molariform teeth. We compared the morphometric data of the tooth with data available in the literature and derived from personal observations.

3.1.2.2. Quantitative analysis

Box plots - We use the descriptive box plots method for graphically describing the dimensional variation of each analyzed variable in the data set of the compared measurements of the upper second molar (M2) with that of selected molar samples of continental European elephants. The box plots (i.e., the diagrams resulting from the explanatory analysis, also known as whisker plots) are particularly suitable for comparing distributions in the analyzed data sets because they provide an easy-to-read visual representation of the variation range in data, as well as the symmetry of the data distribution and, in turn, of the possible occurrence of kurtosis and skewness. Box plots, indeed, represent a visual effective statistical summary of data, distributed into quartiles (or percentiles) and medians.

Clustering analysis - We evaluated the similarity among multiple variables (the tooth quantifiable characteristics) defined for each case (selected M2 and M3 of *Mammuthus* species) using the classic cluster analysis. Cluster analysis is a classification method that gathers cases based on the similarity of their attributes and permits them to be grouped by minimizing the distance within each group and between groups. The cluster multivariate analysis technique is frequently used to group a series of samples. We used the unweighted pair-group average method for clustering (UPGMA). In UPGMA, the level at which a member joins an existing cluster is determined by calculating the average similarities of all existing members using the original matrix of coefficients. As a result, each member of a cluster has the same weight at all levels of clustering. The average distance between all members in the two groups is used to join clusters.

Principal Component Analysis - Principal Component Analysis (PCA) (a direction that minimizes the variance of the projected data) is a descriptive and exploratory multivariate technique, useful in summarizing all the information that describes the similarities/differences of a set of cases in a small number of dimensions, regardless of the statistical properties of the data (Hammer and Harper, 2006). According to this method, the positions of cases (here, molariform teeth) plotted against the two axes (each corresponding to a dimension in space) depict the gradient of greatest variation along the "first" axis and the second largest gradient of variation along the "second" axis. The PCA finds, indeed, new hypothetical variables (linear combinations of the original variables) accounting for as much as possible of the variance in multivariate data. The SVD algorithm determines the eigenvalues and eigenvectors of the variance-covariance matrix or the correlation matrix, highlighting the factors (variables) that more contribute to join/separate cases (here, molariform teeth) each other.

Analyses were executed with the PAST (PAleontological STatistics) 4.16 software (Hammer et al., 2001).

3.2. DESCRIPTION

The Oz moderately worn tooth is a first (M1) or a penultimate (M2) upper molar as several morphological features suggest. Indeed, the clear deformation of the posterior surface, worn flat due to the pressure of the following tooth; the posterior outline of the crown angulated, with the upper third slightly closer to the occlusal surface and almost straight towards the crown base; the slightly convex occlusal surface; the almost parallel arrangement of plates; and the most posterior plates that do not significantly reduce their height indicate that the tooth cannot be a last molar (M3) (Figs. 4, 5). Its width (measured excluding the vestibular and lingual gap between cement and plates) suggests it may be a penultimate rather than a first molar (Tab. 1).

The conservation status and a peculiar mixture of some morphologic features complicate the correct identification of some diagnostic characters.

3.2.1. Conservation status and its effects on a few diagnostic characters

The right Oz molar was rather damaged mainly during biostratinomic processes and, maybe, after its discovery during the transfer from one collection to another (Figs. 4-6). The cement shows some cracks, and two large fissures separate the cement from the plates along the central and anterior parts of the tooth, preventing correctly measuring the molar maximum width that can only be estimated considering the breadth of the gap between cement and vestibular and lingual edges of the largest plate's enamel loops. This rather unusual feature was probably caused by a weathering disturbance during a

Fig. 4 - *Mammuthus* sp.: penultimate right upper molar stored at the Ozieri's Civic Archeological Museum, in occlusal view.

moderately long period of tooth exposure to atmospheric agents before its definitive burial. Other taphonomic biases variously alter the lingual and vestibular sides of the crown cement surface. For instance, a few plant root marks, localized in minute areas, document bioerosion alteration due to short phases of superficial burial, whilst the chemical corrosion caused by acid meteoric or circulating water, previously to or contemporary with the burial, might account for the small or large pits or rather large traces scattered on the cement surfaces, mainly on the vestibular one (Fig. 5). On the occlusal surface, the enamel bands are variously altered. Some portions of the enamel bands and most folds of the first three preserved plates are barely detectable, as are the loops, rings, and folds of the not-fully fused enamel bands of plates in early wear (Fig. 4).

The molar is broken at its mesial side, particularly on the lingual one, and lacks a small portion of the crown's distal side. The first plates and the anterior talon (if present) are missing (Figs. 4, 6b). At the anterior edge of the occlusal surface, only the vestibular-posterior enamel band of the first preserved lamina is present, whereas the print of a missing small plate that does not reach the crown base is detectable on the posterior tooth's side (Fig. 6b). Therefore, the distal talon was conceivably present (Fig. 5).

Although the bad preservation of the enamel bands of the distal plates and the thick cement with altered and coarse vestibular and lingual surfaces somehow hamper easy recognition of the plate numbers both on the occlusal surface and on the crown sides, it is possible to count two plates and a half plate in very advanced wear, five more or less moderately worn, four with partially fused of infused enamel rings, and a nearly unworn

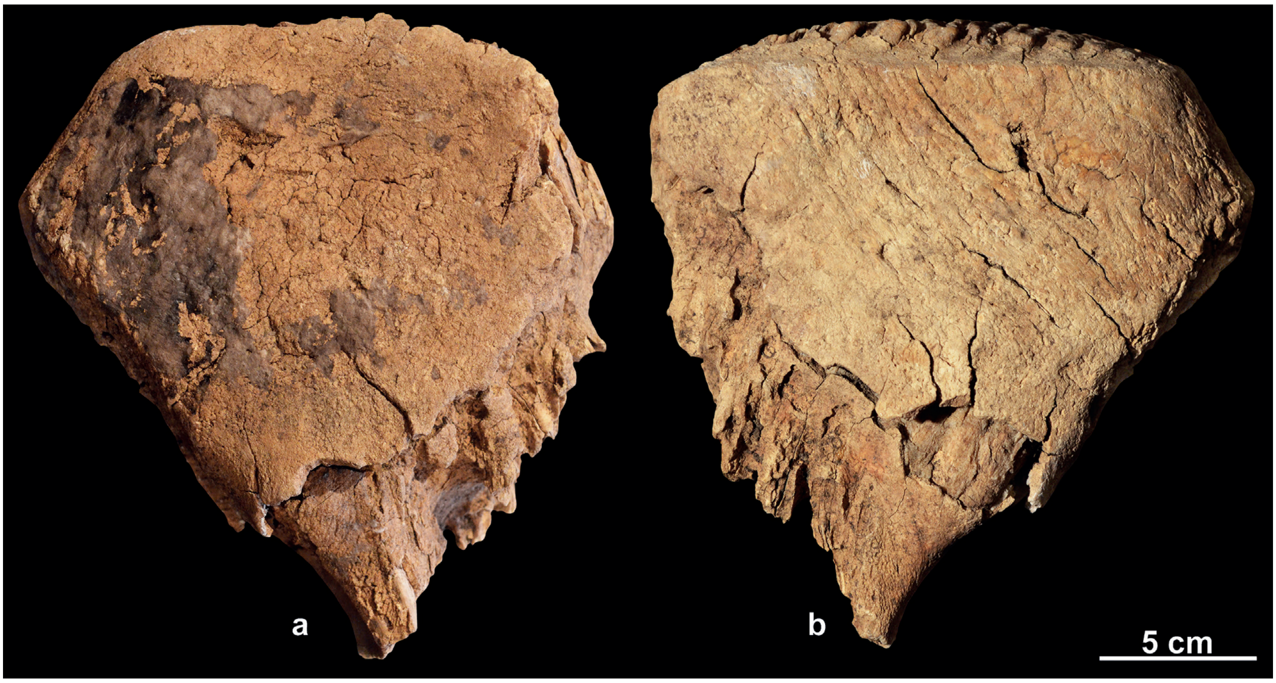


Fig. 5 - *Mammuthus* sp.: penultimate right upper molar stored at the Ozieri's Civic Archeological Museum, in vestibular (a) and lingual view (b).

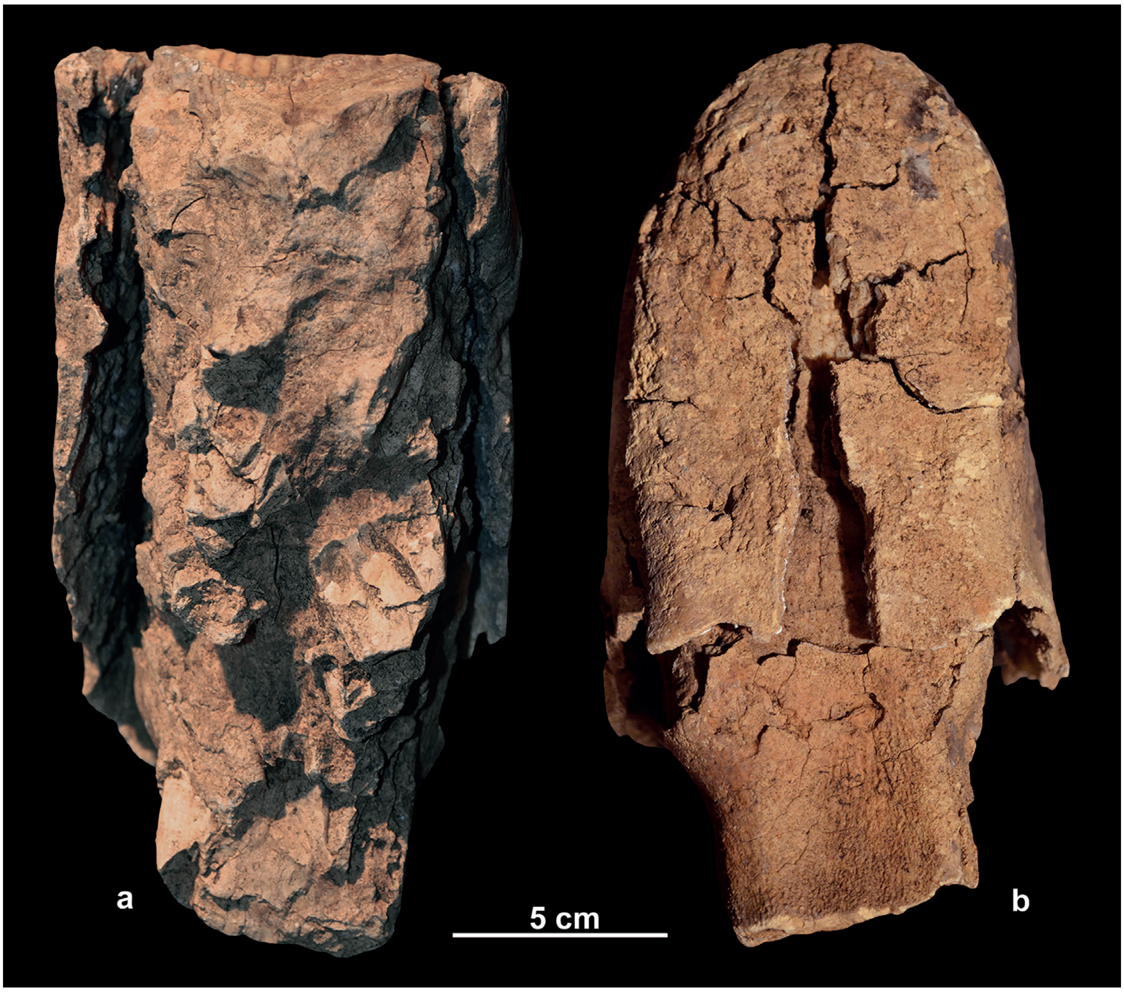


Fig. 6 - *Mammuthus* sp.: penultimate right upper molar stored at the Ozieri's Civic Archeological Museum, in ventral (a), and posterior (b) view.

distal plate (Fig. 4, Tab. 1). The breakage of the mesial side of the molar prevents knowing the original number of plates. Their number could be estimated if the first unpaired root can be individuated. Sher and Garutt (1985, 1987) evidenced that, in the second and third molars of *Mammuthus*, the first unpaired root is followed by a space (inter-root notch) especially visible on the convex side of the crown. Behind the inter-root notch, a set of 'paired' roots is present. Sher and Garutt (1987) termed "marker" the plate corresponding to the first paired root. The first paired roots are generally located under the fourth or fifth plate in M3 of *M. trogontherii,* and in front of them, there are 3 or 4 plates, while in *M. meridionalis* the number varies from 2 to 3 (Lister and Sher, 2015). Albayrak and Lister (2012) noted that two or three plates converge to the first root in most upper and lower last molars of British *P. antiquus*. The personal observations of one of us (MRP) roughly confirm the latter conclusion.

The roots of the Oz molar are broken at different heights. The root basal part is increasingly missing from the posterior to the anterior tooth's side, with most mesial roots broken till the tooth's crown. At the front of the tooth, the crown base is severely damaged, preventing a compelling check of whether the first root is present or not, as it seems probable. Assuming that the first root was effectively missing, the molar could lack two or three plates, and the total plate number could be 15 or 16. The estimate is, however, hypothetical, and the actual number is unknown.

3.2.2. Morphometry

The Oz molar is slightly elongated in shape, oval, and moderately wide but narrowing posteriorly as more commonly occurs in m3 *Palaeoloxodon* molars, and high-crowned (Fig. 4). The crown height is measurable at the nearly unworn most posterior plate, enabling us to calculate HI (Tab. 1). Indeed, the central portion of *Mammuthus* molariform teeth corresponds to a "zone of maximum crown height" (Sher and Garutt, 1987), where the height of unworn or little-worn plates provides a good indication of maximum crown height. The same occurs in the majority of *Palaeoloxodon* molars (MRP personal observations).

On the occlusal surface, the shape of the lamellar enamel figures varies from nearly uncurving in the less worn ones to weakly undulate in the moderately worn and to markedly concave towards the posterior side in the 2nd and 3rd plates, in which the middle line is laterally displaced. It is challenging to hypothesize whether or not such deformation might be caused by the pressure exerted by the molar during some overthrust on the first molar, as the deformation of the basal crown may suggest (Fig. 5).

The enamel is quite thin with small and rather packed folds except for the mesial half of the second and third plates, where it is rather thicker and coarsely folded. On the occlusal surface, the parasagittal zone of moderately worn lamellae enlarges in a small ring, showing a quasi-tripartite structure with a central circular enlargement flanked on each side by elongated ovals. This framework is more evident in the 5th, and 6th, and less in the 7th and 8th preserved plates. In the early wear plates, the enamel figures show four sub-equal small loops or rings (Fig. 4).

In the Oz tooth, some dimensional data (i.e., F, PlT, and e) (Tab. 2) are closer to those of *M. trogontherii* M2 (Tab. 2) than to those of the Italian *P. antiquus* ones (Palombo and Ferretti, 2005; Palombo unpublished data), whilst W, HI, and perhaps L fall in the overlapping range of the two species. Considering the Oz data on the whole, they fall in the variation ranges of the M2 of the advanced and primitive European *M. trogontherii* samples taken in comparison. Conversely, in the *M. trogontherii*-like M2 from Sinyaya Balka, the minimum value of L and W is higher, while the maximum value of F is inferior to those resulting for Oz molar.

4.2. TAXONOMIC IDENTIFICATION AND RELATED ISSUES

The first candidate elephant genus for the Oz molar could be *Mammuthus* because the elephant specimens reported to date in the late Middle and Late Pleistocene of Sardinia are endemic dwarf mammoths. However, a hypothetical presence of *Palaeoloxodon* has to be considered because the genus colonized several Mediterranean islands and *P. antiquus* is the most common Elephantini species in the Middle and Late Pleistocene of the Italian peninsula (e.g., Palombo and Ferretti, 2005; Palombo, 2014 and references therein).

M. meridionalis and *P. antiquus* differ clearly in molariform tooth general shape, number of plates, and hypsodonty, while *M. trogontherii* and *P. antiquus* have a similar number of plates and both show a high crown. However, the *Mammuthus* molariform teeth, especially M1/m1 to M3/m3, are relatively wider than the *P. antiquus* molars, which are more elongated as the Oz molar is.

In *P. antiquus*, the enamel on average folds shows larger and more prominent than in *Mammuthus*. The folds vary in amplitude and are particularly evident on the middle part of the enamel laminar figures. The enamel shows larger and more prominent folds than in *Mammuthus,* especially in the moderately worn plates. The later, rather often, are mesially and distally expanded, giving the lamella a rhombic 'loxodont' form. The lamellar large anterior and posterior expansions along the midline of the tooth are frequently flanked by distinct subsidiary folds lateral and medial to these. The laminar shape varies from an ellipse (cigar-shaped plates) to a rhombus. Moreover, the lamellar figures of the plates in early wear are formed by two short lateral and a single long medial ring (the so-called dot-dash-dot arrangement). All these features are absent in the Oz molar.

In *Mammuthus,* the plates in early wear are divided into subequal, frequently four that tend to fuse into lateral long and a single central short loop as the wear increases (the so-called dash-dot-dash form). In Oz M2, the less worn plates are divided into four subequal rings, while a sort of dash-dot-dash form is present in the plate in moderate wear, where a circular expansion is present in the middle of the lamellar figure.

All things considered, an assignment of the Oz M2 to *Mammuthus* rather than to *Palaeoloxodon* is the most reasonable, although its morphology fails to fully match those of typical *M. trogontherii*. The identification is based on the high lamellar frequency, the rather tinny enamel, and the presumed total number of plates, as well as by quadripartition in four circles of the enamel figures of the less worn laminae and the presence of enamel figures with two lingual and vestibular long ovals, merging in a central circle, observed in the moderately worn plates.

3.3. QUANTITATIVE ANALYSIS: RESULTS

3.3.1. Box plots

We used the explanatory data analysis diagrams (box plots) for comparing PlT, F, e, and HI, which have a particularly diagnostic value, of Oz M2 with the minimum, maximum, and average values, which synthetically represent the sample variation range, of the European *M. trogontherii* samples listed in table 2.

The box plot obtained comparing M2 data, the F, e, and HI data (Fig. 7) underlines the substantial separation between *M. trogontherii* and *M. meridionalis* scores, whereas such subdivision is slightly less evident in the score setting of PlT and e, respectively. All score distribution indicates some asymmetry of the Gaussian curves, less marked for F scores. In particular, the curves of PlT and HI are right-tailed (positive asymmetry), while those of F and e are left-tailed (negative asymmetry). M2 scores always fall within the range of *M. trogontherii.* The number of plates counted for this incomplete molar and the inferred total number fall in the highest part of the box (25-75% quartiles) and above the box (fourth quartile), respectively, matching the position of the average value reported for the primitive *M. trogontherii.* F and HI scores fall above the box among the highest steppe mammoth values (fourth quartile). The *M. trogontherii* e scores are mainly distributed below the box, where also the M2 score is, but the Süssenborn score falls in the box above the median line, confirming some enamel thickness variability in *M. trogontherii*.

We extended the analysis also to M3 to include in the comparison the dwarf mammoth Sardinian specimens and explore once more the dimensional relationships between the Sardinian species and the two continental

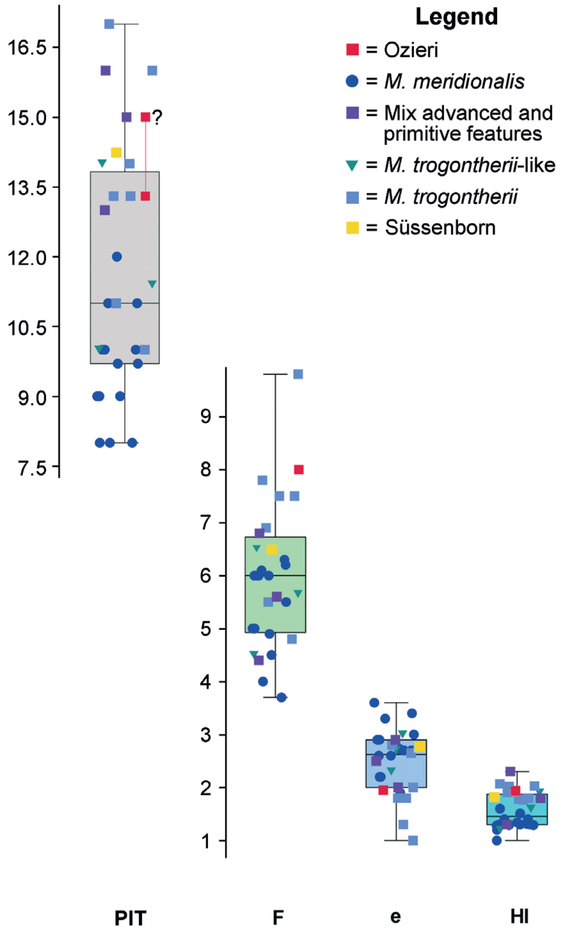


Fig. 7 - Box plot illustrating the variation range of the dimensions of molar stored at the Ozieri's Civic Archeological Museum and the dimensional minimum, average, and maximum values of *Mammuthus* M2 samples from some European sites. Abbreviations: PlT = number of plates, F = average lamellar frequency, e = average enamel thickness, HI = hypsodonty index.

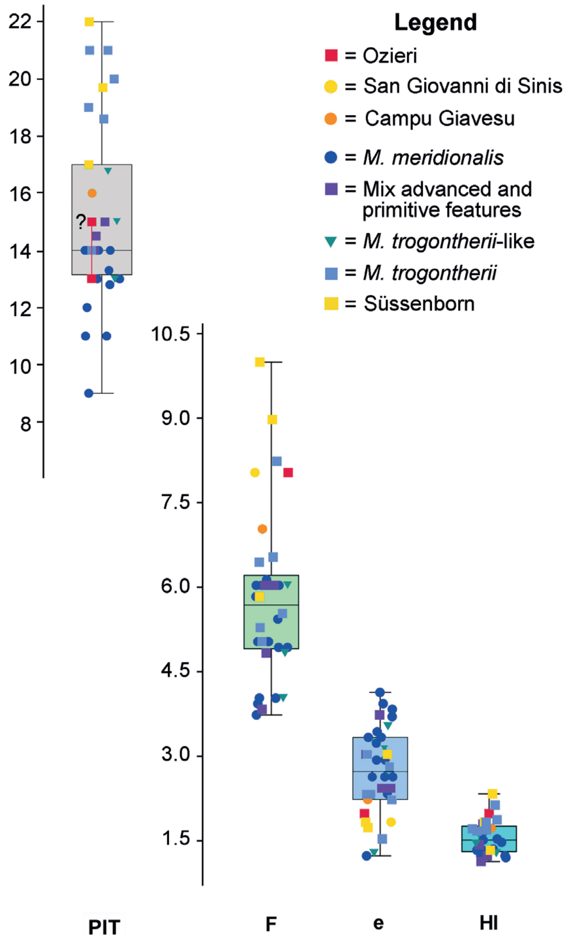


Fig. 8 - Box plot illustrating the variation range of the dimensions of molar stored at the Ozieri's Civic Archeological Museum and the dimensional minimum, average, and maximum values of *Mammuthus* M3 samples from some European sites. Abbreviations as in figure 7.

species (cfr. Palombo et al., 2024).

The PlT, F, e, and HI score distribution in the box plots resulting from the statistical analysis of tooth penultimate molars, the scores' setting of the *Mammuthus* upper last molars from Sardinia, and of samples from selected European sites largely confirms the results obtained for M2 data, showing, in particular, the substantial separation between the F, e, and HI scores of *M. trogontherii* and *M. meridionalis* samples (Fig. 8). The positive asymmetry is still marked for PlT data distribution but less for e data. The HI values have a quasi-normal distribution because those exceeding the modal value are fewer, thus the right tail is shorter. As expected, the scores of SG and CG M3 fall within the range of *M. trogontherii,* in agreement with the results already obtained by Palombo et al. (2024). The Oz HI score falls above the box in a higher position than the two Sardinian molars, which are less hypsodont even in the case of the moderately worn specimen from CG. The e position within the first quartile indicates that tooth enamel is thinner and thicker than that the SG and CG molars, respectively. The PlT of the latter is inferior to those of *M. trogontherii* but higher than the plate average number of the *M. trogontherii*-like M3 from Sinyaya Balka. Since second molars (M2) count a lower number of plates than M3, the position of Pl scores of the incomplete M2 fall below the box, but the hypothetical PlT fall within the box, above the median line, sharing the position with the average PlT scores of the Sinyaya Balka M3 sample and that of M3, showing a mix of primitive and advanced characters.

3.3.2. Similarity analysis

We performed the cluster analysis in two steps. First, we run the analysis considering the minimum, maximum, and average values of all the variables using as cases the samples for which these variables were all available (Figs. 9, 11). Second, we refined the analysis, limiting it to the most compelling variables (PlT, F, e, and HI) and selecting cases following the same criterion used in the first analysis. For the Oz molar, we used the inferred number of PlT (Figs. 10, 11).

In the dendrogram resulting from the analysis of M2 samples using all the variables (Fig. 9), two well-

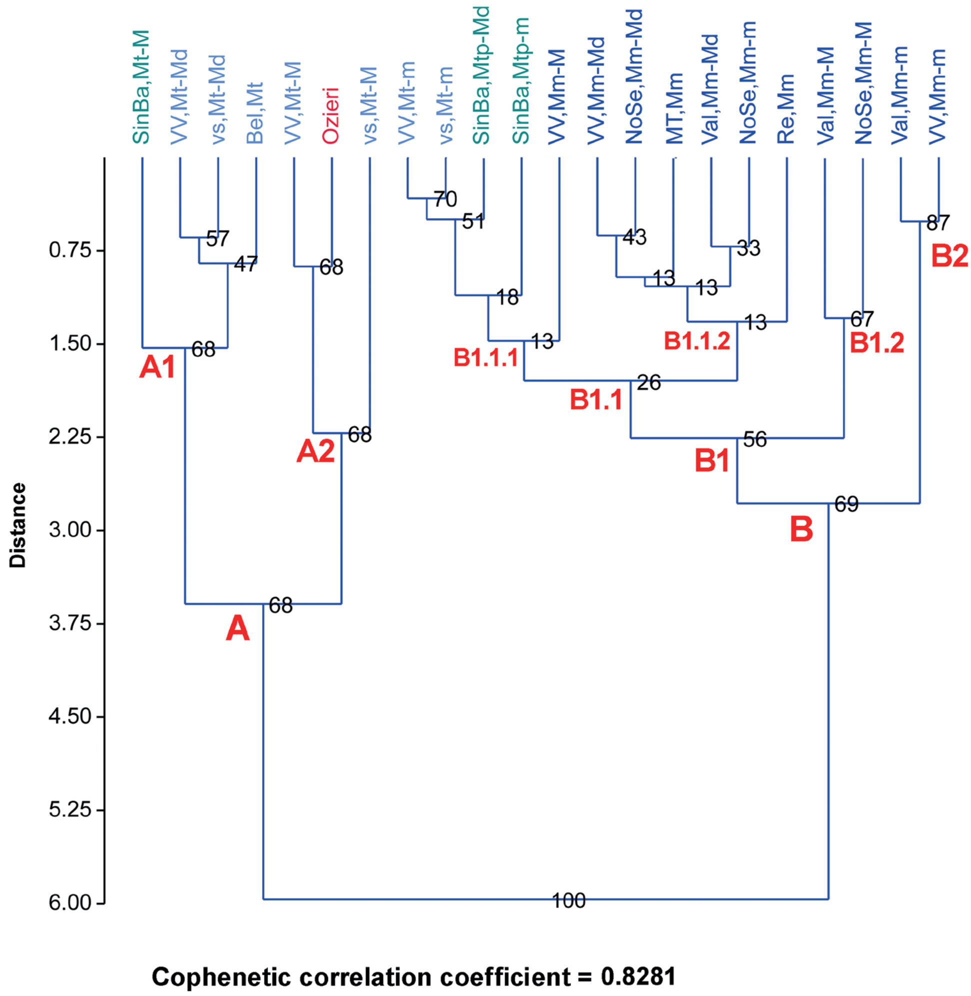


Fig. 9 - Q-mode dendrogram showing how the molar stored at the Ozieri's Civic Archeological Museum and the dimensional minimum, average, and maximum values of *Mammuthus* M2 samples from some European sites cluster using the all the dimensional variables (i.e., PlT = number of plates; F = average lamellar frequency, e = average enamel thickness; HI = hypsodonty index; L = crown length; W = crown width; H = crown height; ? = estimated total number of plates). Abbreviations: M = maximum; m = minimum; Md = mean; Mm = *Mammuthus meridionalis*; Mt = *Mammuthus trogontherii*; Mtp = *M. trogontherii*-like; Bel = Belchatów; MT = Monte Tenda; NoSe = North Sea; Re = Redicicoli; Val = Valdarno; vs = various Russian sites; Vv = various sites.

separated clusters are detectable, the large cluster A and the small cluster B. A includes *M. trogontherii*-like, and a couple of *M. trogontherii* samples grouped into a large sister cluster (A1.2) and a very small one (A1.1), which includes only two *M. meridionalis* cases. The minimum values of the sample, including various sites (Garutt and Foronova, 1976) (Tab. 2) form a separate branch. Oz M2 falls on the B cluster, together with most *M. trogontherii.* A and B show a low similarity. The cophenetic correlation coefficient (CCC hereinafter) is rater low (= 0.7384), thus, the dendrogram does not faithfully preserve the pairwise distance between the original unmodeled data. In the dendrogram obtained using the PlT, F, e, and HI variables (Fig. 10), CCC is higher (= 0.8281) and the separation between the cluster gathering most of *M. trogontherii* (A), which includes the Oz molar, and *M. meridionalis* (B) samples is clearer. In cluster B, the minimum vales of the steppe mammoth reported by Maglio (1973) and Garutt and Foronova (1976) from various sites (Tab. 2) form a small group together with the minimum and average values of *M. trogontherii*-like samples from Sinyaya Balka.

In the dendrogram resulting from the analysis of M3, the split into the two groups of *M. meridionalis* and *M. trogontherii* s.l. samples is rather well-defined even using all the variables even if their distance is rather low and similarity is moderate. The two groups (A1 and A2), indeed, are sister clusters within the large cluster A (Fig. 11). A1 encompasses nearly all the *M. meridionalis* samples as well as samples of the minimum and average values of the *Mammuthus* molars that show a mix of advanced and primitive characters (i.e., molar from Saint Prest) (Tab. 2). The only steppe mammoth samples gathering with *M. meridionalis* is that from the Turkish site of Amasya-Suluova, with a rather tick enamel (Tab. 2). All other *M. trogontherii* samples group together in A2, where also the Sardinian CG M3 falls.

Removing the L, W, and H variables from the analysis,

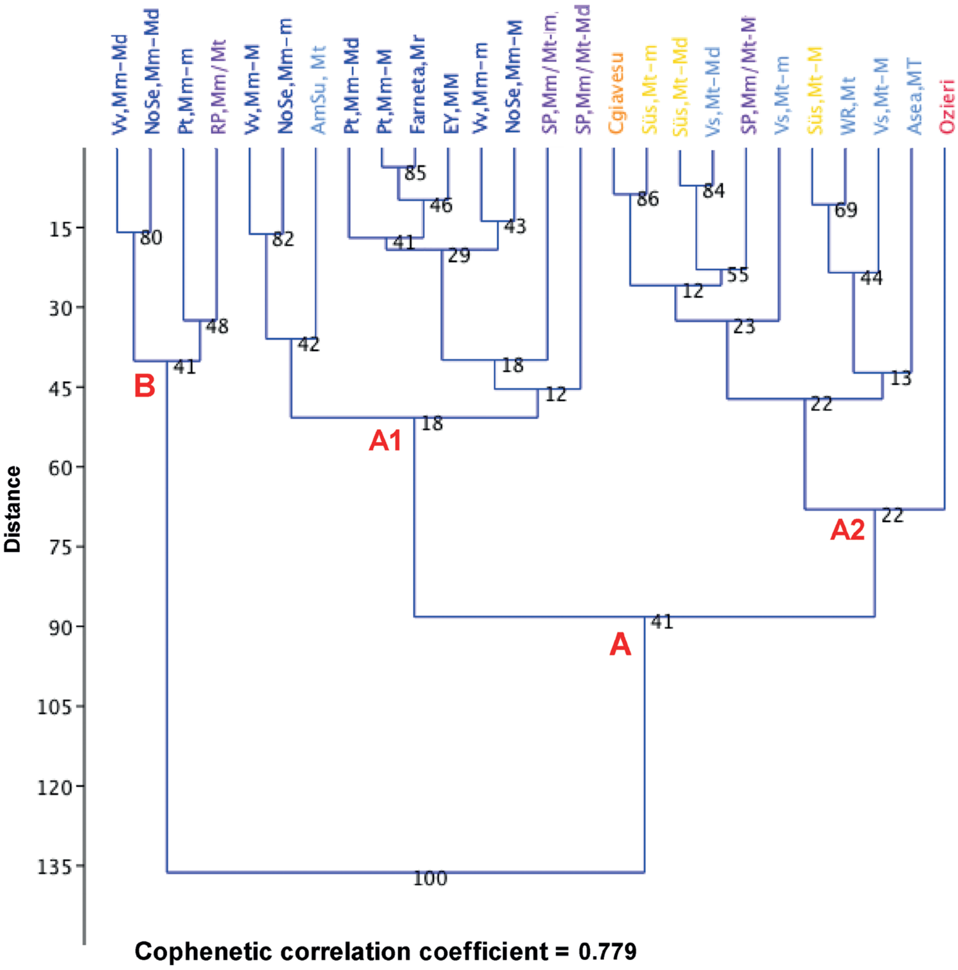


Fig. 10 - Q-mode dendrogram showing how the molar stored at the Ozieri's Civic Archeological Museum and the dimensional minimum, average, and maximum values of *Mammuthus* M2 samples from some European sites cluster using selected dimensional variables (PlT, F, R, and HI). Abbreviations as in figure 9.

M. meridionalis and *M. trogontherii* samples gather in two well-distinct clusters (A and B) (Fig. 12). The Sardinian M3 from CG and even Oz M2 gather together with the minimum data values of M3 from Süssenborn, forming a small sister group (A2.1) of the group A2.2 that includes most of *M. trogontherii* samples, whilst three other clusters in A2 and the sample of the minimum data values of M3 from various former Soviet Union sites (Garutt and Foronova, 1976) gather in the large cluster B with *M. meridionalis,* mammoth M3 with a mix of advanced and primitive characters, and *M. trogontherii*-like samples.

3.3.2. Principal Component Analysis

We executed the principal component analysis to further confirm the affinity between the Oz molar and European steppe mammoths. First, we run the analysis using all the variables and cases to extend the comparison to all the available dimensional data (Figs. 13, 15). Then, we limit the analysis to the most compelling variables (PlT, F, e, and HI) (Figs. 14, 16). We analyzed both the M2 and M3 samples for including in the comparison the Sardinian small rather large M3 from SG and CG.

In the PCA biplots (Figs. 13-16), the scores arrange themselves according to their basic morphobiometric characters. The dispersion areas (biplot geographic area) of *M. meridionalis* and *M. trogontherii* little overlap in the scatter biplots resulting from the analysis of all the original variables, while they are separate if L, W, and H are removed from variables. The scores of the molar samples from the French Saint Prest (M2 and M3) and Italian Pratola Peligna (M3) sites fall among the *M. meridionalis* scores or, occasionally, below their dispersion area, or fall in the *M. trogontherii* one, while those of *M. trogontherii*-like M2 and M3 from Sinyaya Balka sites mainly set between the two dispersion areas. The dominant principal component (PC hereinafter) is always the first (PC1) that captures a variance percentage ranging from 78.235% to 89.151%, running PCA on M2 using all and the selected variables, respectively. The percentage of variance captured by PC2 (from 16.142% to 7.074%) and PC3 (from 5,253% to 3.382%) are increasing lower, while those of other PC is negligible, and the latter can be considered as constant. The variables that most

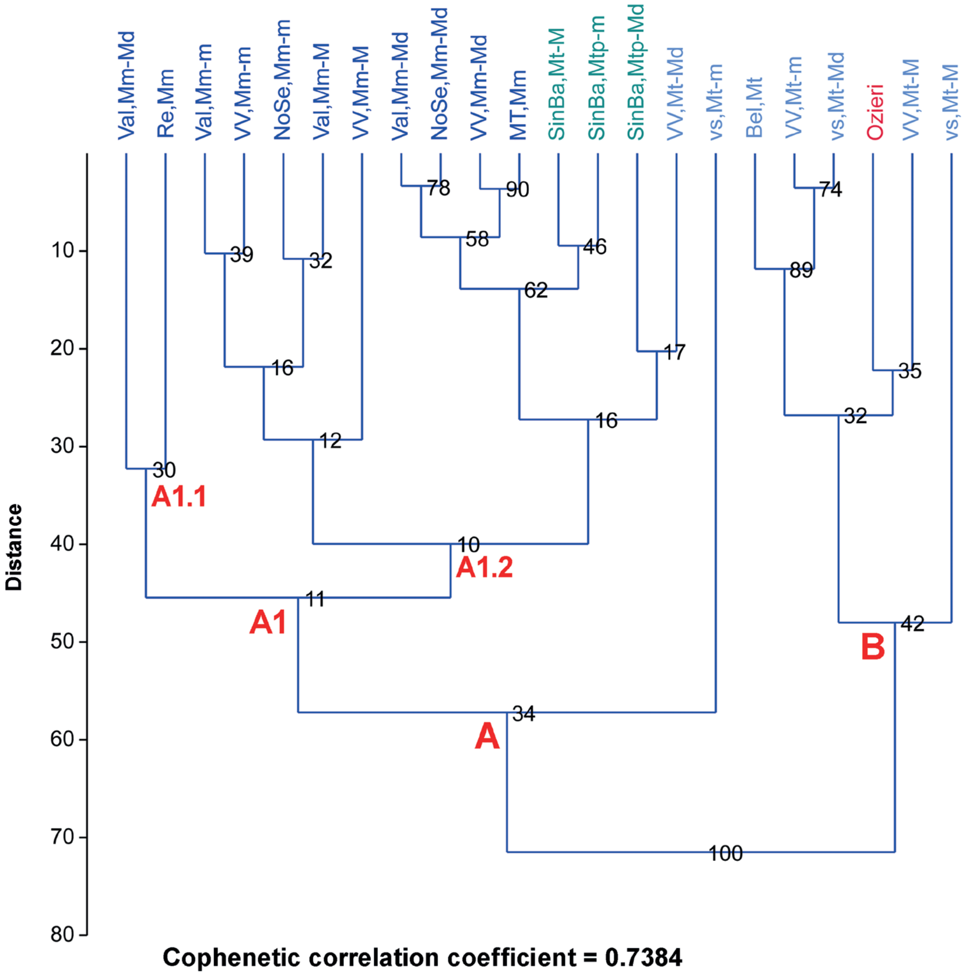


Fig. 11 - Q-mode dendrogram showing how the molar stored at the Ozieri's Civic Archeological Museum and the dimensional minimum, average, and maximum values of *Mammuthus* M3 samples from some European sites cluster using the all the dimensional variables. Abbreviations: M = maximum; m = minimum; Md = mean; Mm = *Mammuthus meridionalis*; Mt = *Mammuthus trogontherii*; Mtp = *M. trogontherii*-like; AmSu = Amasya-Suluova; EY = Eskişehire Yukarısögütön; NoSe = North Sea; Pt = Pietrafitta; RP = Rio Pradella; SP = Saint Prest; Süs = Süssenborn; Val = Valdarno; Vs = various Russian sites; Vv = various sites.

influence (positively) PC1 are L and PlT in the biplots obtained using both all and selected variables. In the same biplots, H and F positively dominate PC2, and W and e are the most influential for PC3.

The Oz M2 score falls in the area of *M. trogontherii* M2 scores, most precisely in the second and quadrants in the biplot resulting from the analysis of all and select variables, by the moderate length (underestimated) and hypsodonty, the inferred number of laminae, and the high lamellar frequency (Figs. 13, 14). As expected, in the M3 biplots, the Oz score sets outside of the distribution area of the European mammoth scores. The score of the CG M3 falls into or close to the *M. trogontherii* scores, while that of the small SG molar sets far from the steppe mammoth area but in the same quadrants (Figs. 15, 16).

3.4. REMARKS

To discriminate between first and second elephantid molars may not be easy in the case of isolated, incomplete, and not well-preserved teeth because of the impossibility of correctly measuring all key dimensions some of which could be only estimated. As regards Oz M2, we have presumed that it could be a second molar based on its crown width, presumably larger than those commonly found in *P. antiquus* and mammoth M1 as reported in the literature.

There are a few uncertainties also about the Oz molar identification increases because some morphological features are not compelling enough for confirming without any doubt its identification as a mammoth representative. For instance, the two European Pleistocene genera, *Mammuthus* and *Palaeoloxodon,* differ in terms of gross proportions, being in general the straight-tusked elephant molars rather longer and narrower crowned. The shape of Oz upper molar is less oval than that characterizing not only mammoth but also some *P. antiquus,* with which it shares the coarse folding of some large folds on the vestibular side of the first plates (Fig. 4). Nevertheless, some pivotal morphometric characters (quadripartition in four circles

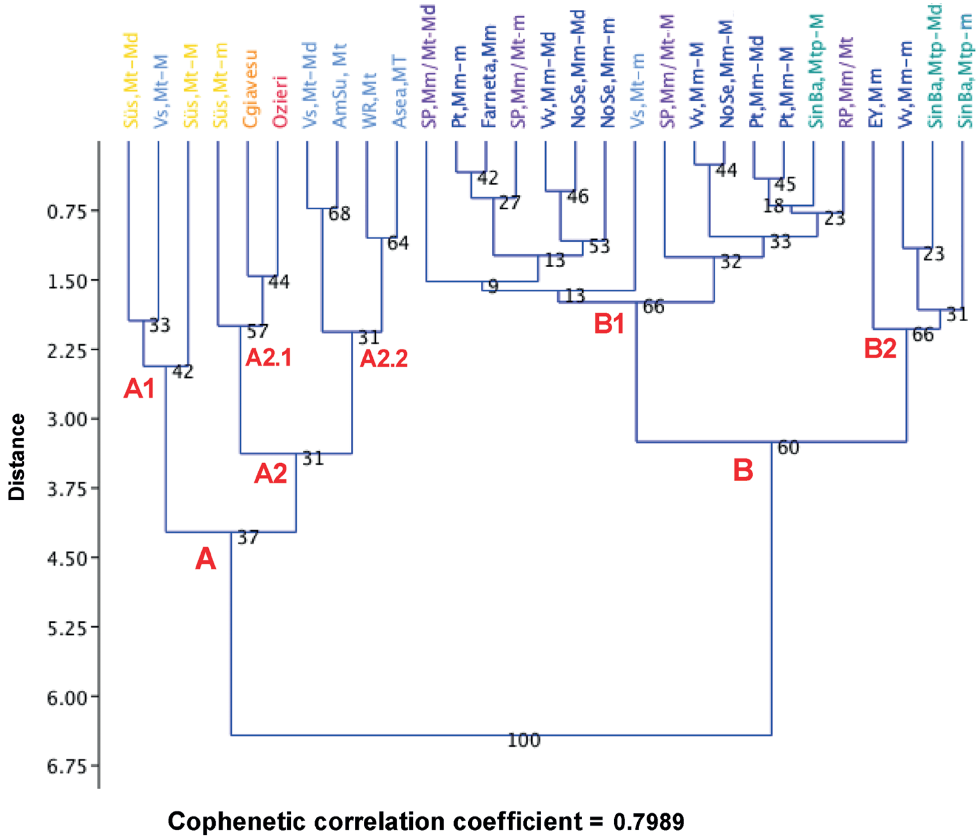
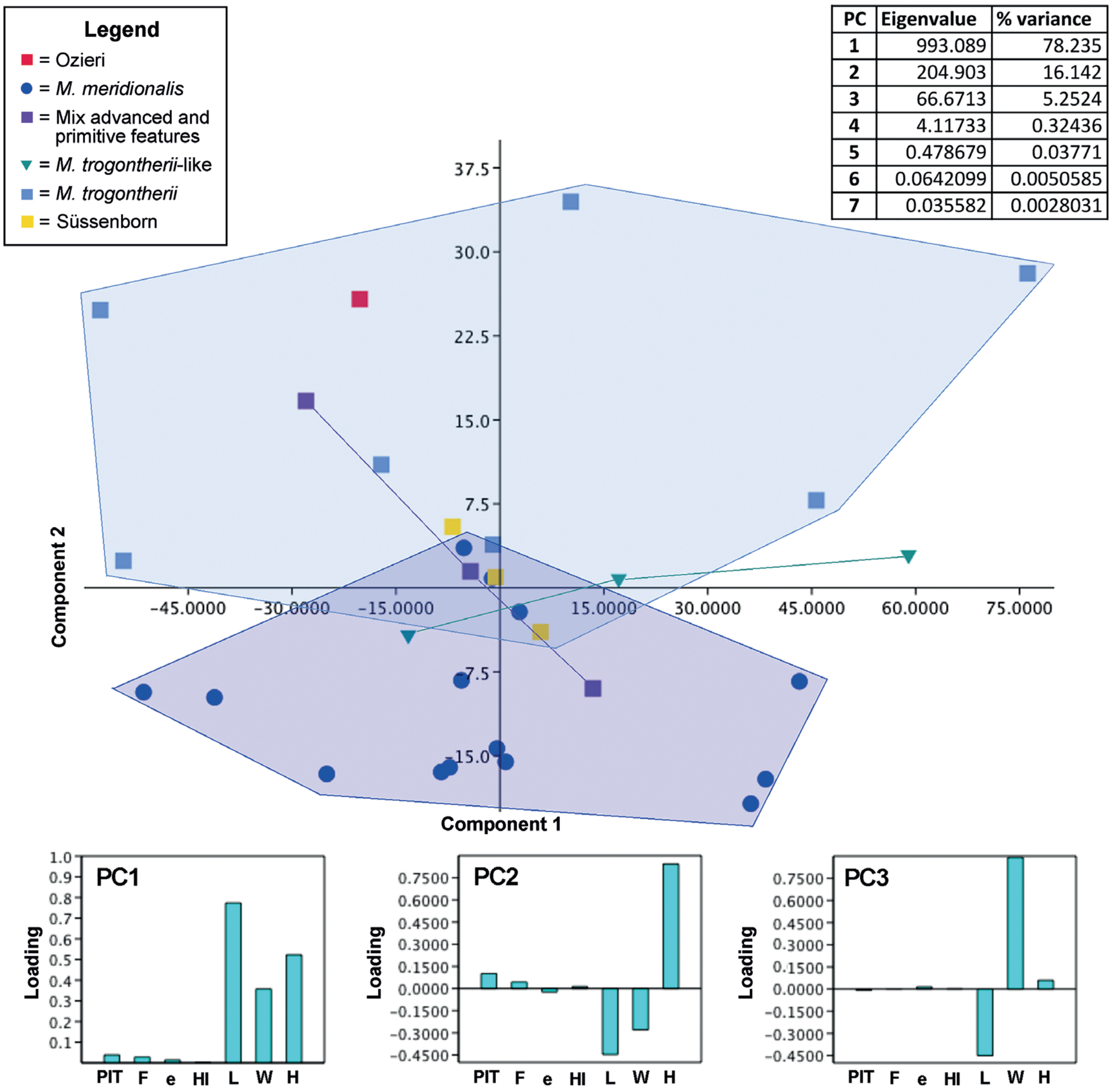


Fig. 12 - Q-mode dendrogram showing how the molar stored at the Ozieri's Civic Archeological Museum and the dimensional minimum, average, and maximum values of *Mammuthus* M3 samples from some European sites cluster using selected dimensional variables (PlT, F, R, and HI). Abbreviations as in figure 11.

of the enamel figures of the less worn laminae; presence of enamel figures with two lingual and vestibular long ovals, merging in a central circle observed in the moderately worn plates; high lamellar frequency; and averagely rather thin enamel) suggest that the Oz upper molar likely belongs to *Mammuthus* rather than to *Palaeoloxodon*. The results of the quantitative analyses support the taxonomic assignment, indicating a greater affinity with *M. trogontherii* than with *M. meridionalis*.

4. DISCUSSION AND CONCLUSION

The history of the Sardinian elephants has been a matter of long debate, and researchers are still far from clearly understanding the intricate issues related to their evolutionary dynamics. Most uncertainties depend on the scanty fossil record. The number of known elephant specimens reported thus far from a few Sardinian localities is extremely low: an incomplete skeleton; four isolated molariform teeth, a tusk fragment, a largely incomplete tibia, and some footprints (Acconci, 1881; Comaschi Caria, 1965; Maxia and Pecorini, 1968; Palombo et al., 2005, 2012, 2017; Pillola and Zoboli, 2017). All these remains have been assigned to the genus *Mammuthus* on the basis of the morphometric characters and to the dwarf endemic species *M. lamarmorai* mainly basing on the size of the incomplete skeleton from the Guardia Pisano Hill (cfr. Palombo et al., 2012 for the identification of the discovery's place). The skeleton is the holotype on which C. Forsyth Major created the new species "*Elephas lamarmorae*" (recte *Mammuthus lamarmorai)* (Major, 1883). The chronology of remains is only roughly outlined, indeed, in some cases the depositional context was inferred or it is unknown: Moreover, the putative occurrence of some size dissimilarities among Sardinian mammoth populations are merely based on the dimensional differences between the last upper molars from SG and CG (see Palombo et al., 2024 for more information). Therefore, it is hardly conceivable knowing the chronological sequence of mammoth remains and whether the dimensional variation in size may have some significance or not. Moreover, it remains undetermined what the potential scaling between the dimensions of skeletal bones and teeth (which in insular mammals reduce their size at a slower pace than bones) should have been because no teeth have been found associated with postcranial bones. Two molars were discovered together with the incomplete skeleton discovered by the end of 19th century at the Guardia Pisano Hill, during the construction of a new railway, but the German engineer, who coordinated the construction works, sent them to Germany, where they likely became part of a



PC	Eigenvalue	% variance
1	993.089	78.235
2	204.903	16.142
3	66.6713	5.2524
4	4.11733	0.32436
5	0.478679	0.03771
6	0.0642099	0.0050585
7	0.035582	0.0028031

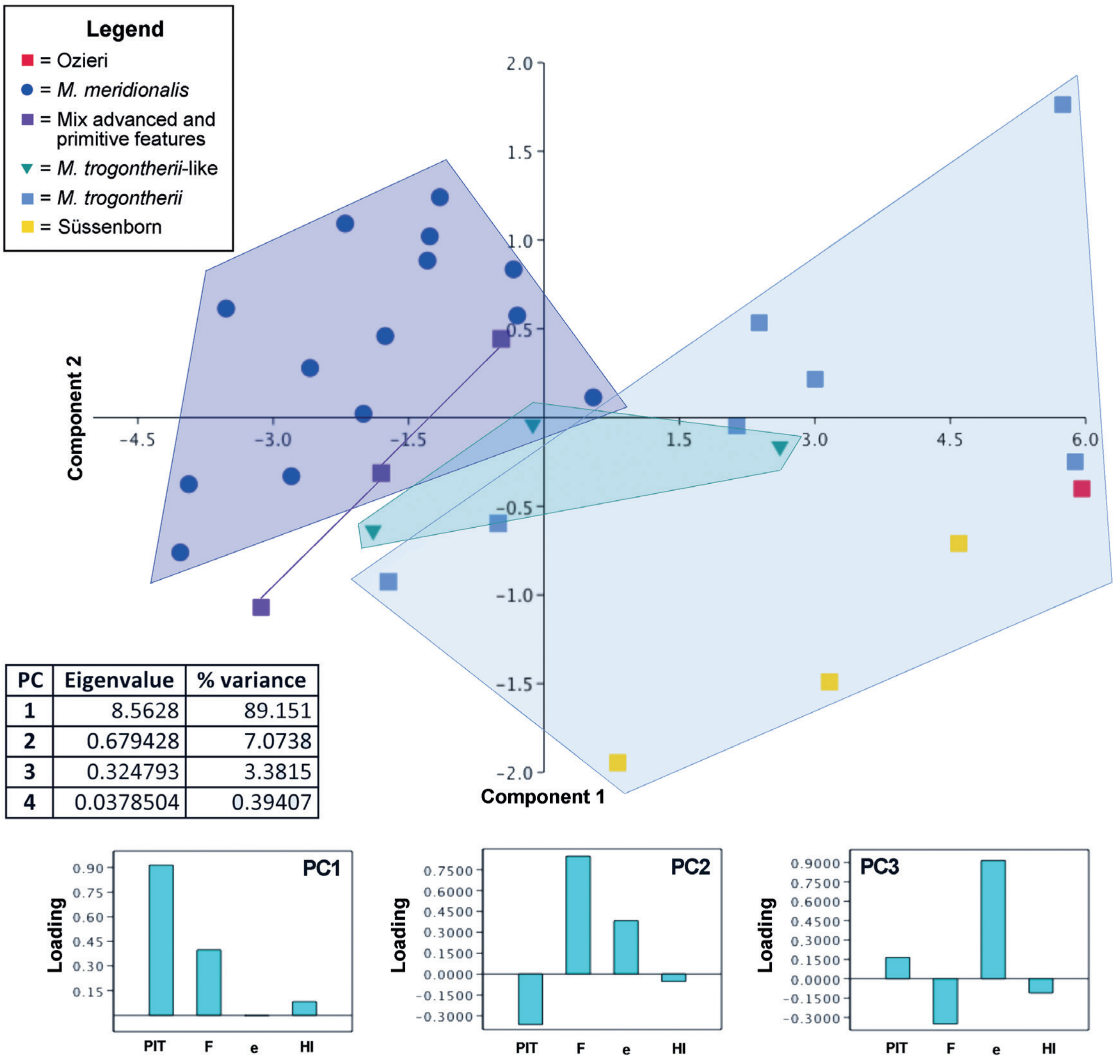
Fig. 13 - Biplot diagram produced by the principal components analysis (PCA) using as variables the minimum, maximum, and average values of M2 dimensions and, as cases, the tooth stored and the *Mammuthus* M2 samples from some selected European sites, for which all variables were available. The component loadings (below) show the degree to which the different original variables enter into the tree components capturing a percentage of variance of some significance (PC1, PC2, and PC3). Abbreviations: PlT = number of plates; F = average lamellar frequency, e = average enamel thickness; HI = hypsodonty index.

private collection (see Palombo et al., 2024 and references therein).

Only the SG and the lost Tramariglio molars were discovered during systematic geological surveys (Palombo et al., 2024 and references therein), while some elephant and most mammals' remains were found incidentally by local people, who gave notice of the discovery to researchers or unprofessional scholars interested in archeology, paleontology, and related matters. The hypothesis that some people collected them merely for curiosity without understanding the authentic significance of the findings and giving notice of their discovery cannot be entirely rejected.

Recently, Palombo et al. (2024) clarified some of the questions related to the Sardinian dwarf mammoth, such as the chronological ranges of remains spanning from about 200 ka (MIS 7a) to about 30 ka (MIS 3) (Fig. 17), the phyletic relationships between continental species and Sardinian mammoth that originated from the continental *M. trogontherii,* and the chronological period in which the dwarf mammoth's ancestor may have entered the island during one or more dispersal events. However, the scanty and poorly known fossil record and some uncertainties about the exact chronology of most remains hamper unraveling several questions that remain unaddressed (e.g., what could be the real meaning of the alleged dimensional differences and if the differences fit or not the intra- and inter-population variability, how many elephant species inhabited Sardinia, how many times the putative ancestor entered Sardinia, whether the hypothetical subspecies or species derived from an anagenetic or radiative evolutionary process and how long each population or species persisted on the island).

Hence, even a single new specimen may theoretically

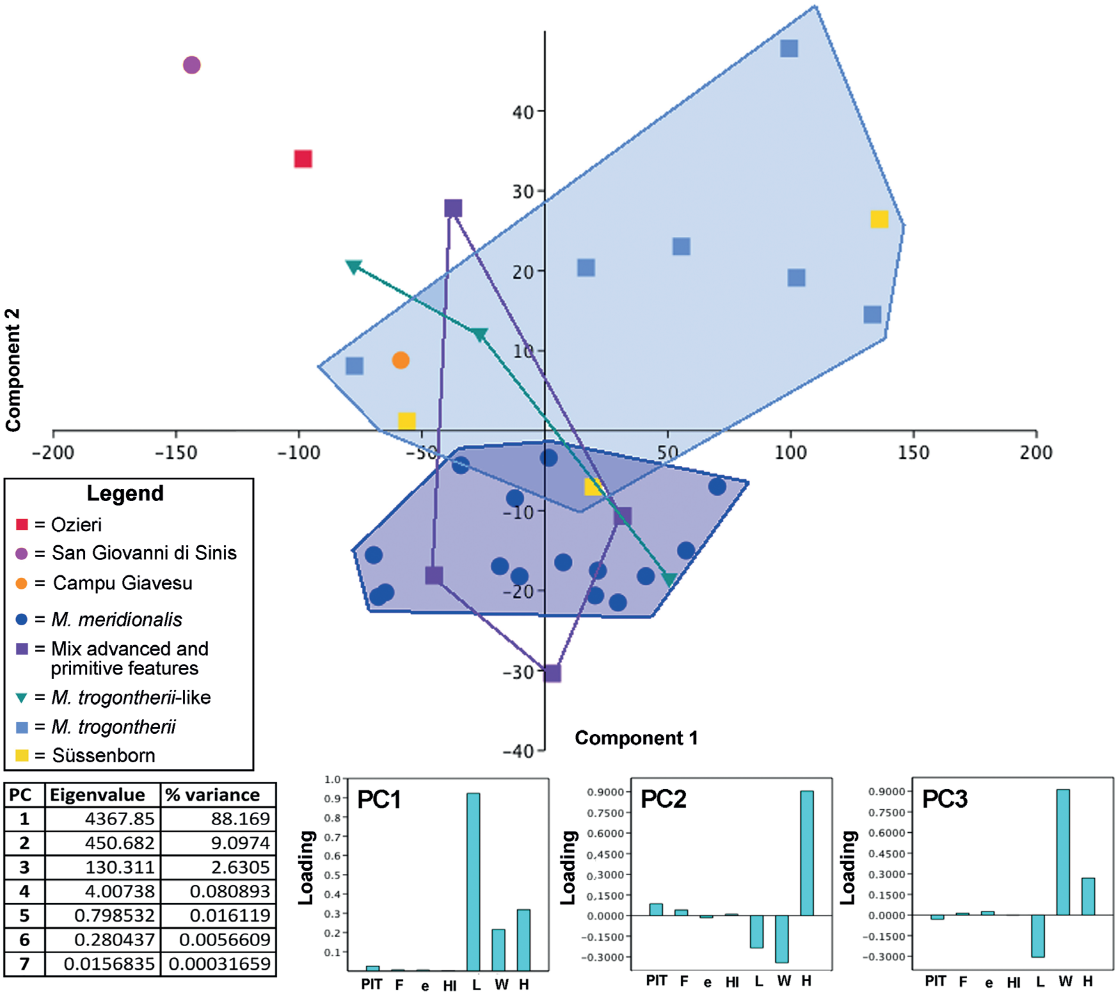


PC	Eigenvalue	% variance
1	8.5628	89.151
2	0.679428	7.0738
3	0.324793	3.3815
4	0.0378504	0.39407

Fig. 14 - Biplot diagram produced by the principal components analysis (PCA) using the most compelling variables (PIT, F, e, and HI) of the tooth stored at Ozieri's Civic Archeological Museum and of and the *Mammuthus* M2 samples from the selected European sites, for which all variables were available. The component loadings (below) show the degree to which the different original variables enter into the tree components capturing a percentage of variance of some significance (PC1, PC2, and PC3). Abbreviations as in figure 13.

provide a piece of interesting information, increasing our knowledge. Unfortunately, this was not the case for the CH lost elephant tooth and the Oz mammoth, whatever they should be the same specimen or not. Although the morphometric characteristics of Oz molar give some support to the phyletic link between Sardinian mammoth and *M. trogontherii,* several other crucial points remain unaddressed. For instance, the exact place of CH discovery is vaguely known, and there is no information about the place and the level from which the Oz was retrieved. Consequently, they provide no new data useful for chronologically ordering the mammoth remains and, in turn, for knowing whether some differences shown by the molars fall within the intra- and inter-population variation of the morphometric characters or not. Besides, the dimensions of Oz tooth are rather large for a moderately dwarfed mammoth as those of CG M3 are. For instance, W of both molars is comparable with the minimum values of European *M. trogontherii* samples (Tab. 2). Hypothetically, Oz and CG molars might represent the rather primitive stage within a theoretical anagenetic evolutionary process of the Sardinian mammoth lineage. Even this supposition remains merely speculative without the support of sound data and evidence. Furthermore, CG molar might be slightly more advanced than Oz according to the plate morphology, but other morphometric data fail to support the hypothesis.

Finally, the lack of any information about the morphology of CH molar reopens the debate about the putative presence of straight-tusked elephants in Sardinia. Indeed, in the central and eastern large Mediterranean area, Sardinia and Corsica, which connected each other during the last glacial severe sea lowering, are the only islands, whose Pleistocene endemic faunas do not include *P. antiquus* remains. The latter were extremely common in the fauna known on islands that were interested in large mammal dispersals by the end of the Early and during the



PC	Eigenvalue	% variance
1	4367.85	88.169
2	450.682	9.0974
3	130.311	2.6305
4	4.00738	0.080893
5	0.798532	0.016119
6	0.280437	0.0056609
7	0.0156835	0.00031659

Fig. 15 - Biplot diagram produced by the principal components analysis (PCA) using as variables the minimum, maximum, and average values of the M2 stored at Ozieri's Civic Archeological Museum, the Sardinian M3 from San Giovanni di Sinis and Campu Giavesu, and the *Mammuthus* M3 samples from the selected European sites, for which all variables were available. The component loadings (below) show the degree to which the different original variables enter into the tree components capturing a percentage of variance of some significance (PC1, PC2, and PC3). Abbreviations as in figure 13.

Middle and Late Pleistocene (e.g., Palombo, 2018; van der Geer et al., 2021).

In the current state of knowledge, the few and fragmentary available data prevent any attempt to arrange the few pieces of information in some framework depicting the evolutionary dynamics of Sardinia mammoth lineage. Without the discovery of new remains able to give at least sound and detailed information about the fossiliferous level that yielded the finding (e.g., the level's stratigraphic context and its chronology, exhaustive data about the fossil depositional framework and as much information as possible useful for deciphering biostratinomic and taphonomic signature) several unclear points will persist, obscuring the peopling and the intriguing evolutionary history of Sardinian elephant populations.

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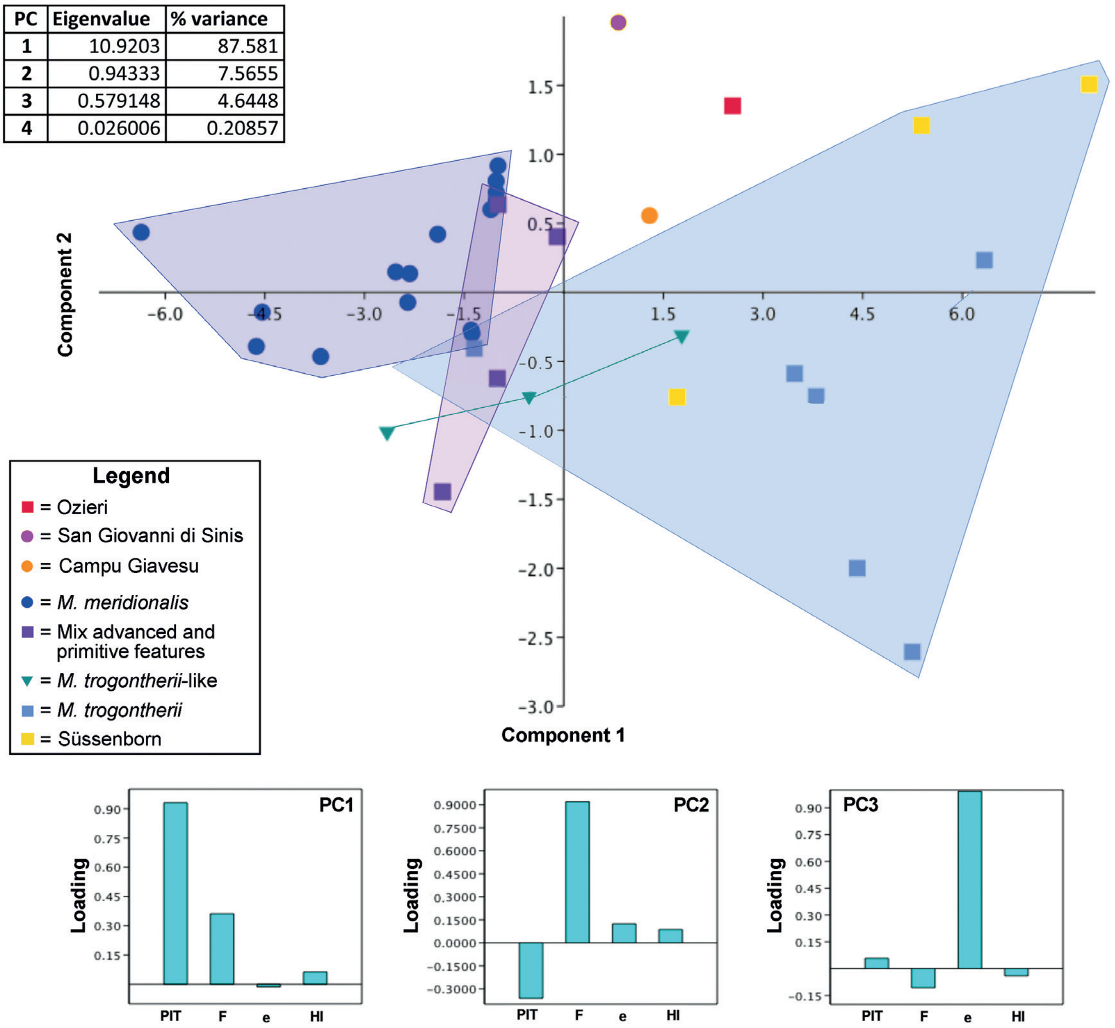
Conflicts of Interest

The author declares no conflict of interest.

Authors' contribution

MRP conceived the manuscript and wrote the text with the substantial contribution of MZ and DZ; MZ and DZ collected and critically revised the information about the elephant molars from Chiaramonti and that stored at the Civico Museo Archeologico di Ozieri; MRP analyzed morphometric data and compared the Ozieris's molar to selected continental *Mammuthus* samples, run the quantitative analysis, and wrote the



PC	Eigenvalue	% variance
1	10.9203	87.581
2	0.94333	7.5655
3	0.579148	4.6448
4	0.026006	0.20857

Fig. 16- Biplot diagram produced by the principal components analysis (PCA) using the most compelling variables (PlT, F, e, and HI) of the M2 stored at Ozieri's Civic Archeological Museum, the Sardinian M3 from San Giovanni di Sinis and Campu Giavesu, and the *Mammuthus* M3 samples from the selected European sites, for which all variables were available. The component loadings (below) show the degree to which the different original variables enter into the tree components capturing a percentage of variance of some significance (PC1, PC2, and PC3). Abbreviations as in figure 13.

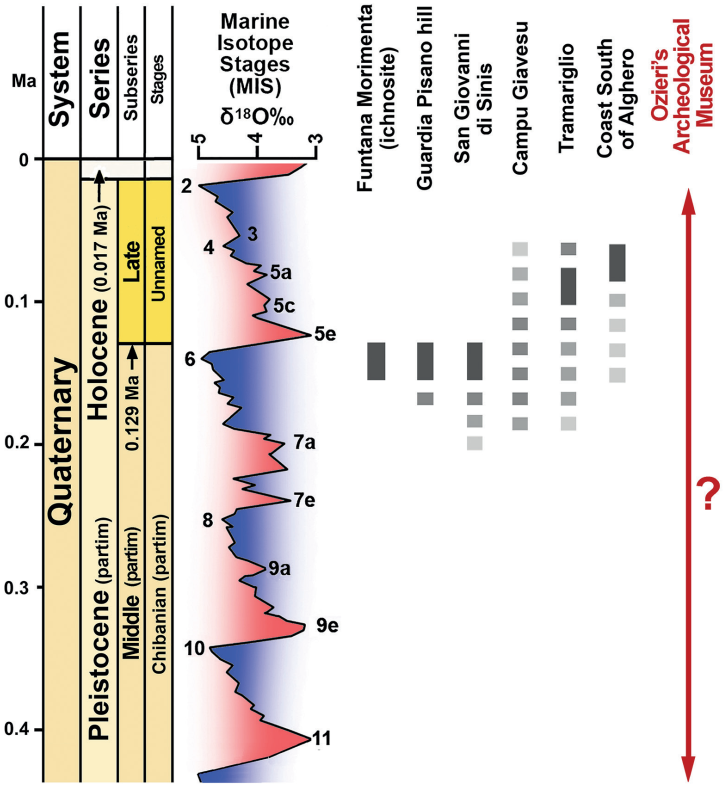


Fig. 17- Chronological range of the Middle and Late Pleistocene dwarf mammoth remains recorded in Sardinia. Dark grey = almost certain chronological range; light grey = possible but unproved chronological range. The red line indicates the time span in which could fall the unknown chronology of the Ozieri's molar.

related sections; MZ measured the mammoth molar at the Civico Museo Archeologico di Ozieri.

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