# The Use of CT Scans and 3D Modeling as a Powerful Tool to Assist Fossil Vertebrate Taxonomy

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**Abstract.** 3D scans and 3D modeling are used to assist the taxonomy of a new unique fossil specimen of an elephant maxilla with molars heavily eroded by coastal sea waves, encrusted in extremely hard sediment, making the preparation and measurements with classical digital calipers impossible. The elephant fossil has been collected north of Poros on the coast at SE Kephallenia in consolidated fan- conglomerates and sands. The elephant maxilla is the first significant elephant fossil from Kephallenia and all the Ionian Islands. According to its dimensions and characteristics it is attributed to a new endemic island species, *Elephas cephallonicus* that lived isolated from the mainland 104.2 ± 18.5 ka ago. The existence of an island endemic specimen at this period in Kephallenia is in full accordance with the palaeogeographic evolution of the Ionian Islands, which is strongly indicated by the natural climatic changes during the last hundred thousand years. The *Elephas cephallonicus* became extinct possibly during the last ice age.

**Keywords:** CT scans and 3D modeling · Kephallenia · Greece
*Elephas cephallonicus* n. sp

## 1 Introduction

In the last centuries, palaeontologists have documented occurrences of Upper Pleistocene Proboscideans all over Greece in more than a hundred localities [2]. These finds can be divided in three general categories.

- Continental forms of mainland Greece.
- Island endemic forms on numerous Greek islands and Cyprus (and other Mediterranean Islands, Sicily, Malta, Sardinia etc.).


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- Island finds not easily attributed to mainland or island forms. These forms are in reality new endemic species that represent the first stages of dwarfism. Up to now the best Greek example is the *Elephas (Palaeoloxodon) chaniensis* [2, 14].

Typical island endemics are quite small and clearly shorter than their mainland relatives. They belong to isolated populations that migrated to the island by swimming during periods of low sea level. It is documented that even on islands with endemic forms the first arrivals belong to mainland forms. The study of these forms is quite demanding since they represent types in transition from mainland to insular forms. Some authors accept that mainland types are encountered on Crete, but so far the documentation of undisputable mainland forms in Crete is still unsatisfactory. The study of the largest elephants of Crete revealed a population with members smaller than the mainland forms. This population was attributed to *Elephas (Palaeoloxodon) chaniensis* from finds *c*ollected in the submerged cave at the area of Vamos near Chania. The fact that Cyrpus, Tilos, Rhodos, Naxos [1, 13, 16, 19, 27] for example, were never connected to the mainland during the Upper Pleistocene, even at periods of very low sea level, is reasonably cogent with the occurrence of small endemic forms on the respective islands.

## 2 The Kephallenia Fossil Vertebrates

In the case of the Ionian Islands, Zante and Kephallenia, we need to consider first the palaeogeography. These islands were located close to the mainland and it is conceivable that at periods of low sea level elephants and hippos and possibly deer could have easily migrated there, in more than one migration events, even if these islands were never connected to the mainland by a land bridge. The available fauna composition cannot help, because it is hardly evidenced. It is known that there are no mainland Pleistocene Carnivora, Bovidae and Suidae, documented for these islands up to now, while it is difficult to infer the existence of land bridges at least for the last 120.000 years [3].

Up to now there is a serious lack of adequate palaeontological studies on this island to elucidate its Pleistocene fauna. In the recent past, we had the opportunity to discuss an elephant molar fragment from the sea bed near Minies, the coastal stretch close to the airport of Kephallenia. In addition, on the Island of Zante, trace footprints in aeolianites can be attributed to elephants [9].

Up to this day, an old paper [11] mentions the occurrence of mainland hippopotamus on Kephallenia near Mantzavinata. New hippopotamus material is not yet available and the old specimen has to be studied again systematically for the sake of updating our assessment regarding its taxonomic status. Our own research during the last decade did not provide any information on elephant remains on Kephallenia or other Ionian islands. One exception is to be found on the island of Zante. In both cases, on Zante and on Kephallenia, field survey failed to yield satisfactory and adequate specimens to assist a good taxonomical determination (Fig. 1).

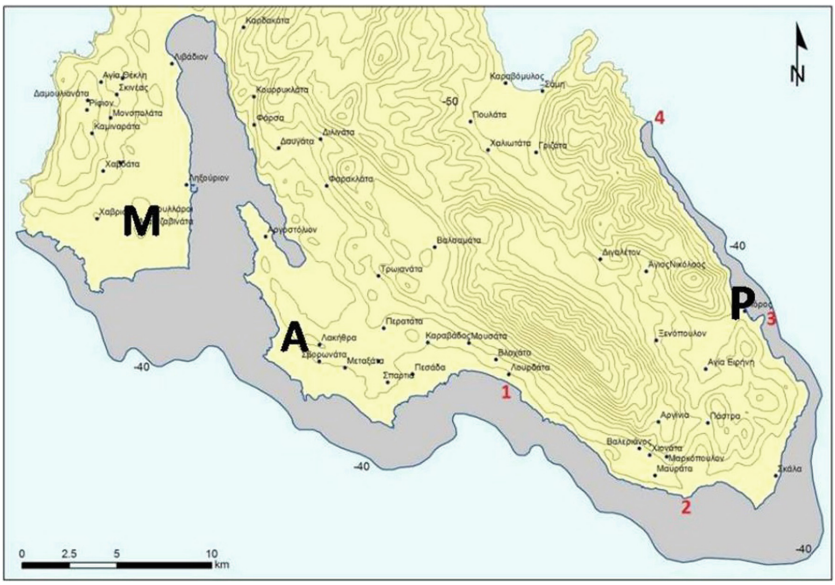


**Fig. 1.** The Kephallenia elephant and hippopotamus sites. Actual fossils of Elephants were located in the coast of greater Poros (this paper) and all on the sea bed of Minies, close to the Kephallenia airport [9]. The existence of 3 interesting vertebrate localities in Kephallenia (from left to right, **M**antzavinata, **A**irport beach at Minies and the coast of **P**oros) together with the footprint locality on Zante opens up new horizons for the study of Quaternary fossil vertebrates in the Ionian Islands, unpublished project report [26], the *A.Sho.Re.* Study area stretching along *nos* 1–4).

## 3 The Material

A unique fossil elephant specimen (Stored at, Athens Museum of Palaeontology and Geology, Code AMPG 900) was collected during summer 2015 from Quaternary coastal river conglomerate deposits in the area of Poros, SE Kephallenia. The specimen was at first glance quite large to be a typical endemic dwarf form, but also rather small to represent a typical mainland type. Did it belong to an undisputable mainland form or to an endemic large form? The specimen, being heavily eroded by sea water, proved impossible to measure with sufficient accuracy by means of digital calipers for classical measurements. Consequently, we decided to use the new powerful tool of CT scanning and modeling to find the correct answers by taking the correct and adequate measurements directly on the computer screen. The fossil elephant maxilla fragment, is the only fossil vertebrate yielded by the Archaeological Shoreline Research Project (*A.Sho.Re.*) conducted along the SE coastline of Kephallenia, the largest of the Ionian Sea island complex. *A.Sho.Re*. Introduces a geoarchaeological platform of investigation aiming at the understanding of geological and historical evolution of coasts in the long term through the systematic and extensive documentation of the available evidence [25, 26].

E. Bassiakos and E. Yiannouli provided G. Theodorou with the first photo of the find *in situ* and invited him for further collaboration. Direct inspection ascertained that the find, encrusted in very hard consolidated conglomerate of coastal river deposits, belonged to the maxilla of a Quaternary elephant. Significant fragments of the molars survived on both sides of the Maxilla. G. Theodorou organized its removal with power tools, after protecting the find carefully with a plaster case of gypsum. It was impossible to use hand tools to remove the extremely hard consolidated sediment or apply methods of extraction using ordinary hand tools. Being a unique find, the specimen had to be removed *ad hoc* to secure its efficient protection and preservation. The lamellae of the available molars were to our disappointment heavily eroded and substantial parts were missing. This fact arrested all efforts to complete any typical measurement or accurate description on the spot, and also later in the lab, with the aid of digital calipers. Only the enamel width could be measured by the standard digital instruments. Extremely bad state pf preservation could easily lead to the total destruction of the find. The eroded and broken lamellae could easily fall apart during the removal process of the extremely hard crust covering and supporting the molars. The specimen was taken to Athens University and later to the Agia Olga Hospital for a CT scan, which was carried out with the help of the Head of CT and interventional Department, Dr. P. Maniatis. The maxilla revealed easily its internal morphological details on the computer screen. That is the number of molars available on each side, the angle among the long axis of the $M^2$ sin and $M^2$ dext. the lamellar frequency, the enamel thickness and the maximum height, etc. Only after having these measurements and data in hand, did it become possible to retrieve the correct answers. We thence had to compare available data with published data from mainland or island endemic types of Quaternary elephants. This very powerful technology was used by us *for the first time in order to assist the taxonomical study* of a Greek fossil, where all other methods failed.

In the past, we had the opportunity to describe *Elephas (Palaeoloxodon) tiliensis* [10] based on scans made by hospital CT equipment. In that case, the analysis of the available CT scans proved inadequate to yield all the detailed internal micro morphology of the bone.

Theodorou et al. [17] worked further on skeletal proportions and morphology based on CT and Laser scans and, shortly afterwards, Theodorou *et al.* [18] proposed the comparison of overlapping 3D scans for comparative studies of morphological data of 3D models of fossils (Thalis project MIS 380135). In the following years, Liakopoulou [5] and Liakopoulou *et al.* [6, 7] used Micro CT scan for the *Elephas (Palaeoloxodon) tiliensis* petrosum and *Phanourios minor* petrosum As far as the members of the NKUA excavation team are concerned, this is the first time to use CT scanning for pure taxonomic purposes, where external measurements with calipers could not be easily applied. This new powerful tool is now available to vertebrate.

## 4 Methodology

High resolution computed tomography was used to observe the sample. The method of predilection was chosen, owing to its non-invasive/non-destructive nature. Also, due to the fact that during the last years it proved to be the most appropriate to study a large

number of palaeontological specimens. The extensive use of CT scanning provides high-resolution images that are treated with advanced imaging software (e.g. Avizo 8.1, Mimics). The CT data are processed to provide the digital reconstructions of the sample, allowing for an internal view of the samples and exposing internal structures for further analysis. Consequently, this approach supports all digital measurements, volumetric and linear ones, as 3D models will be the key for exploring the differences in the proboscidean dentition, as with the Kephallenia case. More specifically, access was gained to a Philips CT 64-slice tomographer, located in the Konstantopouleio General Hospital "Agia Olga". The calibrations of the machines for optimal imaging were carried out and a series of 906 slices was acquired with an interslice spacing of 1 mm.

The digital reconstruction of the sample was made using Avizo 8.1 imaging software. The slices produced by the CT-scanning were loaded and the contrast was fixed for better depiction of the lamellae of the molars. Since the fossil is characterized by a poor preservation state, higher contrast was needed. Once satisfactory contrast was achieved, the 3D models were rotated in such position so that the molars were in a perpendicular view to the observing plane in order to be measured.

The linear and angular measurements include the Basic Elephant molar measurements for taxonomic purposes that follow:

- **Molar Length** - It is usually the longest available measurement of the molar. **Molar Width**-The available measurement parallel to the occlusal surface.
- **Lammellar Frequency** - The number of Lamellae along an axis of 10 cm taken parallel to the masticating surface. This measurement varies with wear in all specimens.
- **Angle** of the longest axes of the molar series.
- **Lamellae height** - The largest available height of any lamellae. This measurement was applied at the highest available lamellae of $M\underline{^2}$ sin.
- **Enamel width** - This measurement could be taken also by digital calipers.
- A usual question in studying molars of elephants has to do with the **number and status of the available molars**, eroded or not or just being ready to erupt from alveoli.

## 5 Results and Discussion

In the past, X-rays were used [14] for the study of an elephant lower mandible from Crete. It was our first attempt to look at the inner morphology of a fossil. In the present case of the Kephallenia specimen, it became easy to document a series of 3 molars on the left side. An erupting molar ($M\underline{^3}$ sin) where only 3 lamellae were present, a complete $M\underline{^2}$ sin made up by 11 lamellae and an eroded with heavy wear molar $M\underline{^1}$ sin. On the right side of the maxilla are available part of the root of $M\underline{^1}$ dext, $M\underline{^2}$ dext and two lamellae from the erupting $M\underline{^3}$. The 3 molars on the left side belong to $M\underline{^1}$, $M\underline{^2}$ and the erupting lamellae to $M\underline{^3}$. It has so far been established that it is almost impossible to exclude the possibility that sin $PM\underline{^4}$, $M\underline{^1}$, $M\underline{^2}$ are present as opposed to $M\underline{^1}$, $M\underline{^2}$ and $M\underline{^3}$.

In either case, however, our final conclusions would be convergent, since all comparisons in both cases point to a large, but not a typically endemic form.

**Table 1.** Basic measurements of available molars from the Kephallenia specimen. On the right side only lamellae measurements. LF, and L width were available (Figs. 2 and 3).

| | |
|---|---|
| $M^2$ sin length | 20 cm - 11 Lamellae available |
| Molar width (sin) | 70–72 mm near the occlusal surface |
| Enamel average width – (Sin. and dext.) | 3.3 to 4.0 mm |
| Lamellar Frequency – (Sin. and dext.) | 5.5 to 6.5 |
| Angle of molars ($M^2$ sin. – $M^2$ dext.) | 20–23° |
| Max Lamellar height of sin. $M^2$ sin. | 155 mm |

The critical question to be answered in studying molars of elephants relates to the number and status of the available molars, eroded or not, or just waiting to erupt from molar alveoli. On Kephallenia, all available data point to the existence of an elephant of

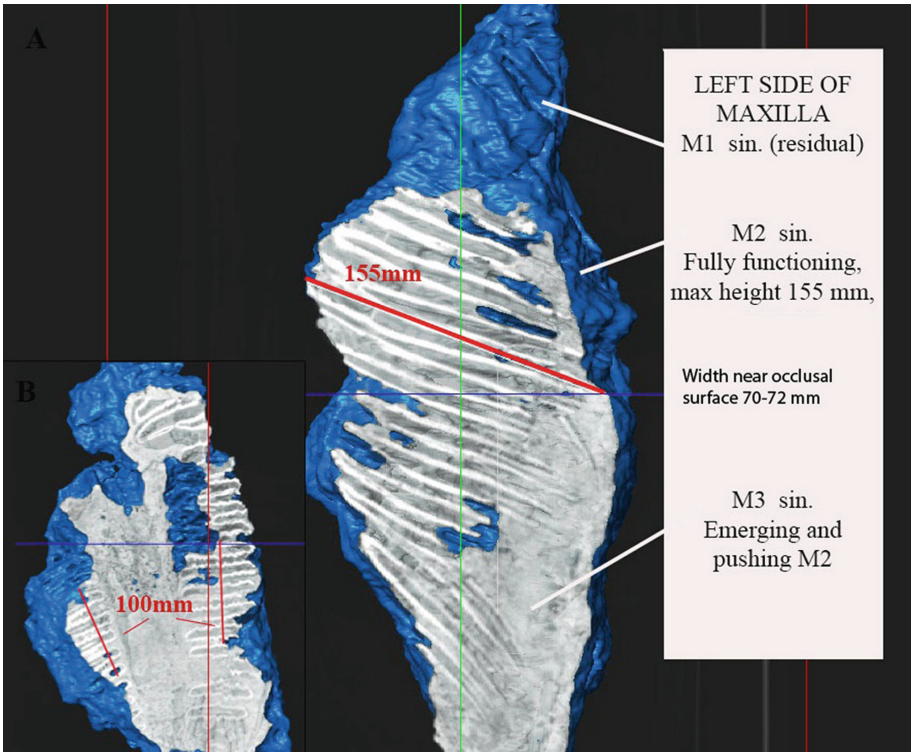


**Fig. 2.** Best possible section parallel to the occlusal surface of $M^2$ sin and $M^2$ dext. Arrows across the sin, and dext. $M^2$have a length of 10 cm, allowing for a good Lamellar Frequency view. It is well known that LF is influenced by the curvature of the molar and the relative position of the lamellae and the wear. Width of $M^2$ near occlusal surface 70–72 mm.

medium size that is not typical for a small endemic elephant. Its lamellar frequency, varying from 5.5 to 6.5 and the maximum lamellar width 71–72 mm close to the occlusal surface, point to an elephant of intermediate size. Such value is very small for a typical mainland type [4, 12]. This value (Lamellae width) is, however, larger if taken away from the occlusal surface, being also influenced by the stage of wear and the shape of cross section of molars [21]. The size range of continental *P. antiquus* upper molars is statistically not known. And it has no meaning to use a mean value based on different North European localities.

The richest biometrical data collection for Greece relates to the endemic elephant *Elephas (Palaeoloxodon) tiliensis* [15, 19]. Comparison with Sicily or Cyprus cannot help, since *Elephas falconeri* and *E. Cypriotes* and *Elephas xylofagou* are smaller [1]. Tilos specimens are smaller to about 30% in relation to the Kephallenia new specimen [15]. The Kephallenia specimen has dimensions very close to *Elephas. creutzbugi* from Rethymno area or *Elephas mnaidrensis* from Malta [12, compare Table 1, p. 34]. In addition, quite large values of typical mainland *P. antiquus* exist for specimens of Grevena area [23] or for specimens of Megalopolis [8], and new finds to study by Theodorou, *pers. communication*,). Therefore, the evidence from the available comparanda impels us to accept that the Kephallenia specimen belongs to an *endemic island form of a middle size as large as E. creutzburgi from Crete* and smaller than a typical mainland *Elephas (Palaeoloxodon) antiquus* [8, 23, 24].

## 6 Biogeography and Absolute Dating

Understanding the palaeoenvironment, along with the coastal formation processes, is a basic concern of the *A.Sho.Re*. Project and a central issue of work. However, the significance of a unique find, such as the identification of a fossil vertebrate in SE Kephallenia and indeed the Ionian Sea, reasonably begs the question. Were Kephallenia elephants separated from the mainland for some period? If Kephallenia was connected to the mainland at the time of the deposition of the conglomerates, no endemic elephant could be present. To understand the palaeodistribution of *Elephas (Palaeoloxodon) antiquus* and its descendants on the Ionian Islands we need the absolute dating of the fossiliferous formation. That is, it is necessary to know if the Kephallenia elephants at the time of deposition were isolated from the mainland or not. Ferentinos *et al*. [3] document that Kephallenia was an island at about 110 and 35 ka BP.

During the *A.Sho.Re.* campaign sediment samples were selected for determining their absolute date. A sediment sample, belonging to the relevant fossiliferous layer, was dated at the Luminescence Dating Laboratory, of the National Centre for Scientific Research (NCSR) «Demokritos» . The Infrared Optically Stimulated Luminescence of feldspar (IRSL) [20, 22] was employed for dating the sediment sample containing the elephant maxilla. Using IRSL an age of 104.2 ± 18.5 ka was obtained. The Infrared Optically Stimulated Luminescence of feldspar (IRSL) [20, 22] was employed for dating the sediment with the elephant maxilla. This chronology proves that the Kephallenia elephant lived at a period of a high sea level that was followed by the last

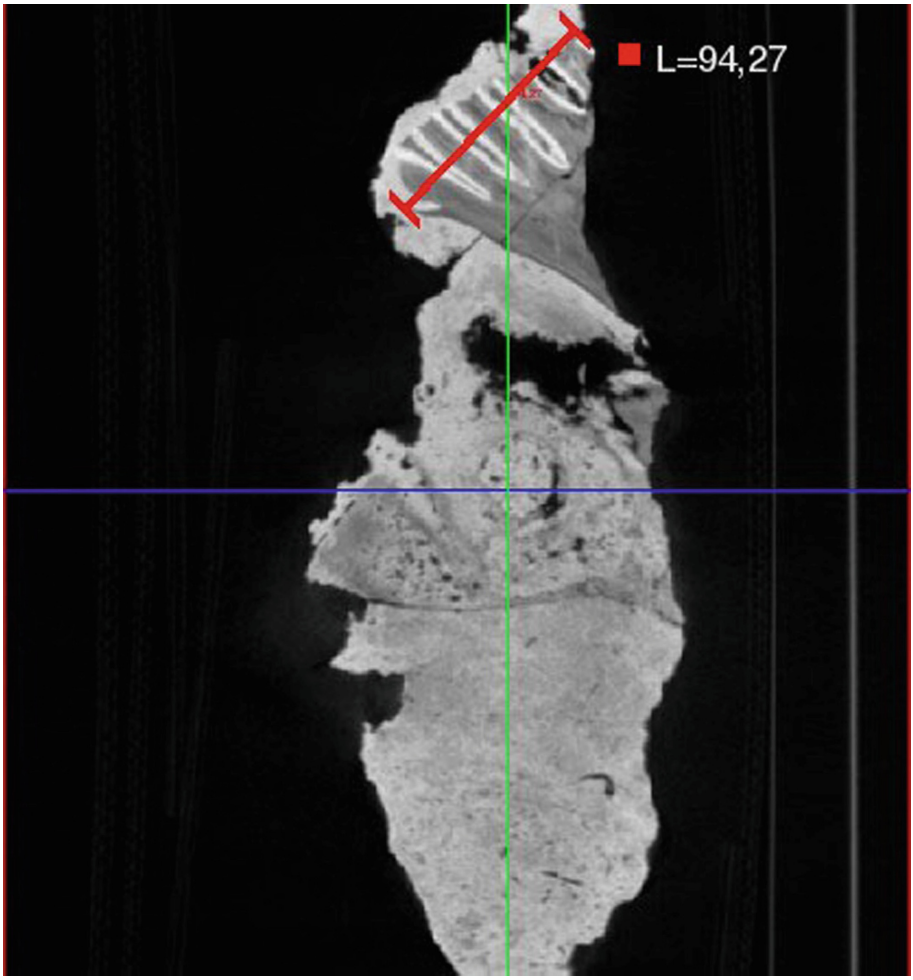


**Fig. 3.** Left side of maxilla. L of $M^1$ = 94, 27 (=94,3 Residual)

major ice period. During high sea level periods the possibility of isolation was significant and a corresponding reduction of size could have occurred quite fast. Since it is well documented that around 110 to 35 ka Kephallenia was insular [3], we cannot reject the hypothesis that the available data point to the existence of an endemic, isolated species with a first degree of endemism. The Kephallenia endemic elephants were smaller than mainland Quaternary elephants, but they were not as small as other endemic species as those of Tilos [15, 19], Cyprus [1] etc. whose high degree of endemism is due to an isolation for long periods. All these facts compel us to describe a new endemic species for Kephallenia.

## *SYSTEMATICS*

| | |
|---|---|
| ***Ordo –*** | **Proboscidea, Illiger, 1811** |
| ***Family-*** | Elephantidae, Gray, 1821 |
| ***Genus-*** | *Elephas* Linnaeus, 1758 |
| ***(Subgenus)*** | *(Palaeoloxodon Matsumoto, 1924)* |
| ***Species*** | *cephallonicus* |
| | *Elephas (Palaeoloxodon) cephallonicus* n. sp. |
| ***Holotype*** | *Fragment of Maxilla with heavily eroded molars on both sides. Code AMPG 900. Available are* $M^{\underline{2}}$ *dext.,* $M^{\underline{1}}$ *sin,* $M^{\underline{2}}$ *sin,* $M^{\underline{3}}$ *sin (errupting).* |
| ***Basic Synonym catalog*** | *Elephas*, Milan *et all,* 2015 |
| ***Etymology*** | *after the Ionian Island of Kephallenia* |
| ***Type locality*** | *Rocky, north coast of Poros, SE Kephallenia* |
| ***Stratigraphy*** | |

Quaternary, fan- coastal conglomerates, overlying uncomormably the alpine basement. Fossiliferous layer along the coast overlies small costal shelters created after the deposition of the conglomerates. These shelters, possibly similar to the available small coastal caves, are correlated with a phase of coastal marine erosion.

***Absolute date*** 104.2 ± 18.5 ka.

***Diagnosis and differential diagnosis.*** A dwarf endemic middle size species of the Elephantidae Family. Molars are larger than those of *Elephas tiliensis* and close to those *of Elephas creutzburgi* and *Elephas mnaidriensis*. These two forms are smaller than *Elephas chaniensis,* whose fossils are larger generally larger than *Elephas creutzburgi* and smaller than *Elephas (Palaeoloxodon) antiquus.* The $M^2$ sin from Kephallonia has 11 lamellae (all in situ), maximum width (close to the occlusal surface) 71-72 mm. and total length about 21 cm. Lamellar Frequency 5.5- 6.5 and maximum Lamellar height about 15 cm. Angle between left and right $M^2$ is 20-22 degrees.

***Geographic distribution:*** The Greek island of Kephallenia, the Ionian Sea.

***Extinction time.*** Not known with accuracy**.** During the last Ice Age

***Possible Extinction cause.*** Climatic changes and flora and fauna turn over during Quaternary. Human interaction cannot be excluded.

***Taphonomic rema*rks on the site.** The very hard conglomerate did not allow for any taphonomic study. It is obvious that other fossil elephant parts are still in situ, but they cannot be extracted in an appropriate way to facilitate taphonomic studies.

## 7 Conclusions

The new fossil elephant specimen from the coast of Poros, SE Kephallenia, belongs to a new island endemic species the *Elephas cephalonicus* n.sp, that lived isolated on the island in 104.2 ± 18.4 Ka. For the first time, the NKUA team employed CT scans and 3D modeling to assist the taxonomic study of a Greek vertebrate fossil. Its size is closer to *Elephas creutzburgi* from Rethymno, Crete. It became extinct during the last Ice

Age. Possible causes for its extinction is change of flora due to natural climatic changes and interaction with humans on the island during the last 100 Ka.

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