Dentary of *Masracetus markgrafi,* Archaeocete in the north of Lake Qaroun, Fayoum Egypt

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Abstract: This paper describes for the first time the dentary of *Masracetus markgrafi* collected from sediments of the Late Middle Eocene (Late Bartonian) Gehannam Formation at Qaret umm Regl section, north of Lake Qaroun, Fayoum, Egypt. The specimen teeth were found as isolated, well preserved elements amongst and beneath remnants of eroded and deformed vertebrae, ribs and other elements of the *Masracetus markgrafi* skeleton, in a calcareous mudstone layer. These teeth are similar in shape and ornamentation to those of Basilosauridae, particularly *Basilosaurus isis* and *Dorudon atrox*, but differ in their sizes. The specimens represent upper and lower incisor, canine, premolar and molar teeth. The internal structure of the teeth was studied by thin section of the crown portion of a lower incisor and is described in this paper.
[Gebely A. Abu El-kheir , Mohammed I. El Anbaawy Sobhi A. Helal, Susan Gibbs. **Dentary of *Masracetus markgrafi* in the north of Lake Qaroun, Fayoum Egypt.** *J Am Sci* 2013;9(12): 459-469]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 63

Keywords: Archaeocetes, Basilosauridae, *Masracetus markgrafi*, Middle Eocene, Bartonian, north of Lake Qaroun, Fayoum, Egypt.

1. Introduction

Fayoum province is an important area, for vertebrate fossils from the Eocene and Oligocene sequences. Wadi El-Hitan and Gebel Qatrani areas (fig. 1) contain many mammal fossils, including marine mammals such as Cetacea and Sirenia, and terrestrial mammals including Probocideans, and Anthracotheridae, also Primates (Beadnell, 1905, Simons et al., 1968, Fleagle et al,. 1986, Simons et al. 1990, Gingerich, 1992, Andrews, 1901, Dolson et al., 2002, Abu El-Kheir et al., 2010). The Middle and Upper Eocene strata contain marine vertebrates that inhabited the Tethyan Sea (Gingerich et al., 1990). In addition to marine mammals other marine vertebrates including Selachians, Teleosts, and reptiles have been discovered there (Stromer, 1903, Andrews, 1906). The marine mammals appear to be concentrated in the Wadi El Hitan area and the northern side of Lake Qaroun.

The majority of whale and sea cow fossils are situated in the Gehannam Formation (Middle to Late Eocene), with others in the Birket Qaroun Formation (Late Eocene), (Abu El-Kheir et al., 2010). The whale species from the Middle and Late Eocene in Fayoum have been identified as *Basilosaurus isis* (Gingerich, 1990, Dolson et al., 2002), *Dorudon atrox* (Uhen, 1992), *Saghacetus osoris* (Gingerich, 1992), *Anclacetus simonsi* (Gingerich et al., 1996) and *Masracetus markgrafi* (Gingerich, 2007). Gingerich (2007) distinguished *Masracetus markgrafi* from the other whales by the relative dimensions of the centra of the lumbar vertebrae, being shorter in width and height than those of. *Basilosaurus isis*.

A poorly preserved *Masracetus markgrafi* fossil skeleton was found on the northern side of Lake Qaroun, in grayish white, calcareous mudstone of the Gehannam Formation in 2010. This was during a one day expedition by P. Gingerich and others from the University of Michigan. Most of these vertebrae centra were squeezed and deformed, and the zygapophyses and neural arches were missing. Well preserved teeth were found amongst the vertebrae and other skeletal elements.

Distribution of Masracetus markgrafi in the Eocene Fayoum layers

The first vertebral column of *Masracetus markgrafi* was discovered by Markgraf in 1904 at the northern end of Lake Qaroun near Dimeh (Dimeh: N: 29° 32' 07.8, E: 30° 40' 07.31"). This specimen was situated in a yellow sandstone layer (Stromer, 1908). The specimen was found in the Birket Qaroun Formation of the early Priabonian period (Kellogg, 1936). Gingerich (2007) identified that specimen as *Masracetus markgrafi*, and noted that all *Masracetus markgrafi* specimens had been found in the Birket Qaroun Formation (early Priabonian). Recently, in 2010, a partial skeleton of *Masracetus markgrafi* was discovered in the lower layers of the Birket Qaroun Formation.

Numerous specimens of *Masracetus Markgrafi* have been reported from the exposed layers of Gehannam Formation (Late Bartonian) and Birket Qaroun Formation (early Priabonian) on the northern side of Lake Qaroun**.** Partial, badly preserved skeletons and isolated vertebrae of *Masracetus markgrafi* were found in the calcareous mudstone layers of the Gehannam Formation at the western end of Lake Qaroun, Qaret Umm Regl and Qaret Mizar on the north western side of Lake Qaroun. Some isolated vertebrae have been found east of Dimeh and in the Qum Oshim area, north east of Lake Qaroun (fig. 1).

The present study describes the teeth of *Masracetus markgrafi* for the first time in the literature. The specimens described were found in the middle portion of exposed layer of Gehannam Formation in grayish white, calcareous mudstone near the Qaret Umm Regl section.

2. Materials and methods

Sixteen specimens of *Masracetus markgrafi* teeth were examined. These were collected from grayish white, calcareous mudstone in the mid part of an exposed layer of Gehannam Formation near Qaret Umm Regl. The well preserved teeth were found amongst thoracic and lumbar vertebrae that were squeezed and deformed by geological processes, and broken pieces of ribs.

The internal microstructure of the teeth was examined by transverse thin section of a lower incisor, taken from the crown portion of the tooth.

The specimen teeth are currently housed in the Lake Qaroun Protectorate Office, Shakshouk, Abshawi, Fayoum.

3. Results and Discussion

Stratigraphic setting

The majority of whale fossils are exposed in three main formations in the southwest and northern Fayoum depression. From the base to the uppermost, these formations are: Gehannam Formation (Middle to Late Eocene), Birket Qaroun Formation (Late Eocene) and Qaser El Sagha Formation (Late Eocene).

The tooth specimens in the present study were found near the western end of Lake Qaroun, (fig. 2 and 3). Here the Gehannam, Birket Qaroun and Qaser El Sagha formations are all well exposed.

The Gehannam Formation: Formed of about 25 m of gray to grayish white mudstone and argillaceous limestone of the shallow shelf facies. These strata contain various species of whales and sea cows skeletons in good preservation state.

The Birket Qaroun Formation (Priabonian): Exposed as a stand cliff form, it is formed of about 11 m yellow fine calcareous sandstone and 10 m of dark gray and brown laminated shale, with gypsum intercalated by fine calcareous yellow sandstone. These deposits have previously been interpreted as an offshore barrier sand bar complex (Gingerich, 1992, Abu El-Kheir et al., 2010). The upper portion of the Birket Qaroun Formation is approximately 2 m of sandstone and shale intercalation, which may have been deposited in an ancient estuarine environment.

The Qaser El Sagha formation (Priabonian)*:* The uppermost section of the Qaser El Sagha Formation is composed of shale and oyster banks. It has previously been interpreted as a lagoonal environment (Gingerich, 1992, Abu El-Kheir et al., 2010).

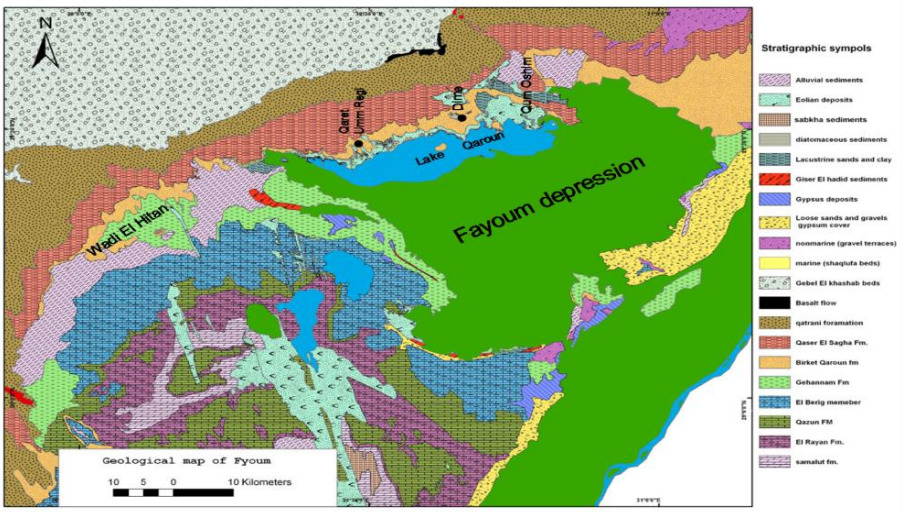

Fig. 1. Geological map of Fayoum, Qaret Umm Regl is to the north of Lake Qaroun (modified after Swedan, 1986, Abu El-Kheir *et al.* 2010).

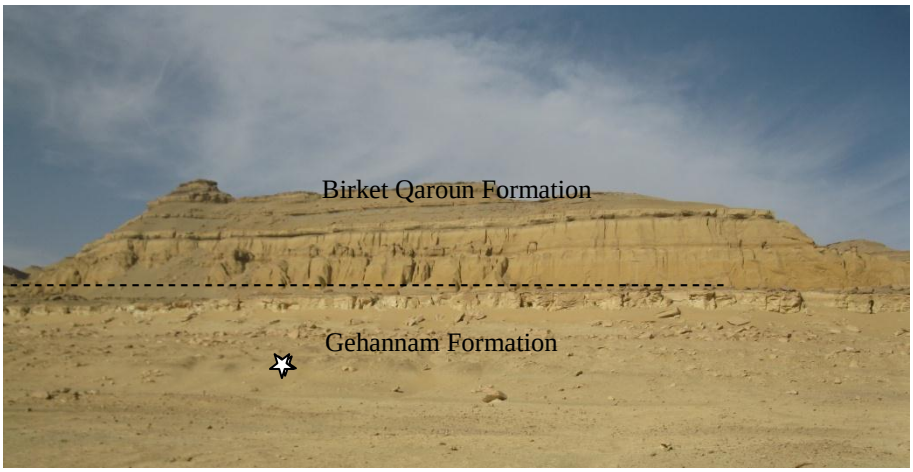

Fig. 2. General view of the middle and upper Eocene sequence in the Qaret umm Regl section, north of Lake Qaroun. The star indicates the location of the study specimen.

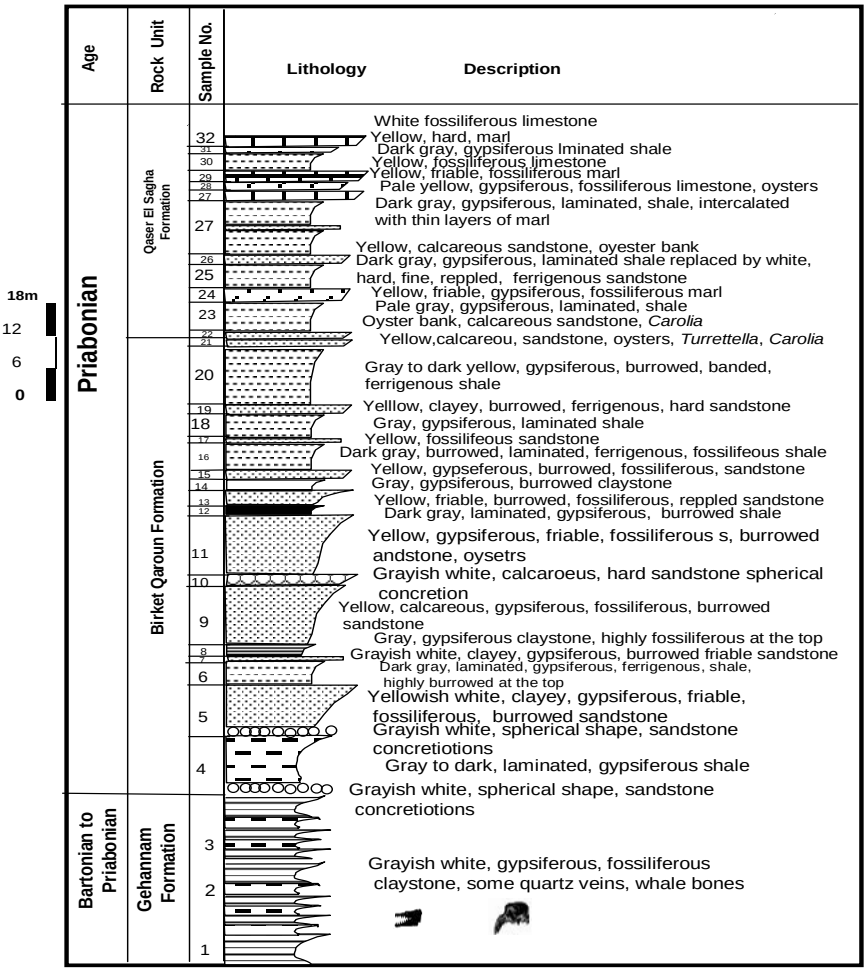

Fig. 3. Lithostratigraphy of the Middle and Late Eocene at Qaret Umm Regl.

Foraminiferal Biozones

Previous studies of the foraminiferal faunal content in the Qaret Umm Regl and Qaret Mizar (one km east of Qaret Umm Regl) stratigraphic sections identified two planktonic foraminiferal biozones, a) *Globigerinatheka semiinvoluta* Zone (Bolli 1957; Blow 1979; Berggren 1988) and Late Eocene, Priabonian (Berggren et al. 1995); and, b) the *Turborotalia pseudoampliapertura* Zone (Late Bartonian) (Haggag 1989; 1990; Haggag et al. 1995).

Figure 3 shows the stratigraphic succession of the section. The details of the recorded planktonic foraminiferal faunal content will be discussed in a separate forthcoming paper and is used here for biozonation and age assignment of the whale bone bearing beds.

In the Qaret Mizar section, the lower part of the Gehannam Formation (samples 1-9) yielded a faunal association belonging to the *Turborotalia pseudoampliapertura* Zone (Late Bartonian). Whereas the upper part of the Gehannam Formation (samples 9-16) in Qaret Mizar and the exposed part of Gehannam Formation of Qaret Umm Regl (samples 1-3) and the hole Birket Qarun Formation of Qaret Mizar (samples 17-40) and Qaret Umm Regl (samples 4-21) yielded a faunal association belonging to the *Globigerinatheka semiinvoluta* Zone (Late Eocene, Priabonian).

Systematic paleontology of Archeocetes in the study area.

Order:
Cetacea (Brisson, 1762).
Suborder:
Archaeoceti (Flower, 1883).
Super Family:
Basilsauroidea (Mitchell, 1989).
Family:
Basilosauridae (Cope, 1868).
Subfamily:
Bsilosaurinae (Cope, 1868).
Genus:
Masracetus (Gingerich, 2007).
Species:
Masracetus markgrafi (Gingerich, 2007).

Species found in the study area include:

Zeuglodon isis (partial) (Stromer, 1908).
Zeuglodon cf. brachyspondylus (in part) (Stromer, 1908).
Prozeuglodon isis (partial) (Kellogg, 1936)
Zeuglodon cfr. brachyspondylus (Kellogg, 1936).
Zeuglodon brachyspondylus (partial) (Slijper, 1936).
Masracetus markgrafi (Gingerich, 2007).

Fig. 4. Fossilised fragmented bone elements that were found with the tooth specimens of *Masracetus markgraphi.*

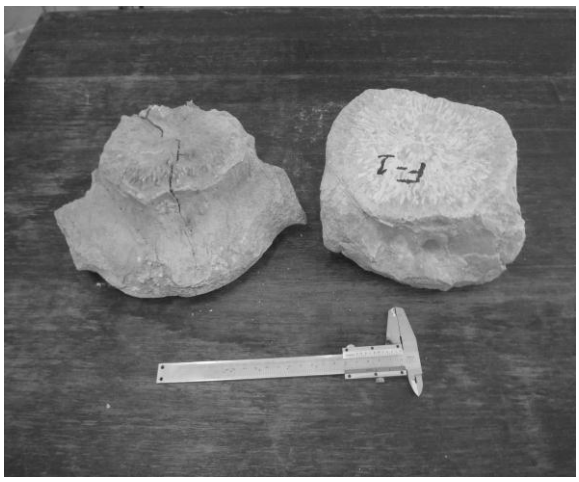

Fig. 5. Fossilised vertebrae of M*asracetus markgraphi* that have been squeezed and deformed by geological processes.

Morphological description of the study teeth.

The teeth of *Masracetus markgrafi* are smaller than those of *Basilosaurus isis* and larger than *Dorudon atrox* (fig. 5A and B). Tooth measurements are shown in Table 1.

The first lower incisor (I_1): Smallest of the incisors (Plates 1 and 2). The crown is conical and curved distally projecting mesially and slightly buccally. The enamel is slightly rugose. The crown is terminated by a pointed apex, extended anteriorly by a sharp ridge or crista and posteriorly by delicate ridge. The first lower incisor has a long and very gentle sloped single root directed to the mesial side, it is bucco-lingually compressed and less wide than the crown of the tooth. It is oval shaped in cross section.

The second and third lower incisors (I_2): These are smaller than the lower canine. They project mesially and slightly buccally. There are no denticle accessories. There is a midline ridge running up the mesial face and down the distal face of the crown. The enamel of the base of the crown is slightly rugose with the rugosity better developed on the lingual side. The incisor has a long and very gentle slope root as in the first incisor, directed to the mesial side, it also bucco-lingually compressed, it is oval shaped in cross section.

The lower canine (C_1): Is a conical tooth, slightly curved distally and single rooted. The crown tapers from its base to the tip and it has no accessory denticles. The mesial side has a midline ridge to the tip of the tooth and on the distal face of the tooth. The enamel is slightly rugose at the base of the crown. It is fractured and partially damaged. The root is mesio-distally long and bucco-lingually compressed, and is less wide than the crown. The lower canine is larger than the lower incisors in all dimensions.

The first lower premolar (P_1): The first lower premolar is double rooted and bucco-lingually compressed. It is triangular in the lateral view. The mesial edge has two small denticle accessories, in addition to a well developed mesial cingulum. The mesial denticles are smaller than the distal denticles. The mesial side has a midline ridge going up the central cusp, and going down the distal edge. There are three accessory denticles on the distal edge of the tooth. The mesial root is larger than the distal root. The two roots are meeting at the center of the crown and are less wide than the crown. Specimens include left and right first premolars.

The second lower premolar (P_2): Is buccally compressed and double rooted. The crown is triangular and has lingual projection over the root. The central cusp is the largest of P_2. It is located directly over the division between the roots. There are small denticle accessories on the mesial edge and three accessory denticles on the distal edge. The mesial denticles are smaller than the distal denticles. There are well-developed rugosities on the enamel near the base of the crown on two sides. The lower part of the mesial root is broken.

The third lower premolar (P_3): Double rooted, and bucco-lingually compressed. The distal root is slightly larger than the mesial root. The crown is triangular in the lateral view. The central cusp is directly above the division between the two roots. The mesial edge has four accessory denticles that project mesially then upward.

The first denticle is on one of the edges of the crown immediately above the root junction. The mesial denticles are smaller than the distal denticles. The distal edge has five accessory denticles increasing in size from the distal to the mesial side. The distal denticles project distally then upward. The last denticle is short and arises from the well-defined cingulum, The two roots are nearly equal in length. The mesial root is less in wide than the distal root.

The fourth lower premolar (P_4) The fourth lower premolar is similar to the third lower premolar but is larger. It is double rooted and bucco-lingually compressed. The crown is triangular in lateral view. The mesial edge has four accessory denticles that project mesially. The first denticle is on the edge of the crown above the root junction. The distal edge has five accessory denticles increasing in size from the distal to mesial side and project distally. The mesial root is shorter than the distal root.

The second lower molar (M_2): Has four accessory denticles on the distal edge in addition to the protoconid. There are no serration accessories on the mesial side. The cingulum is well developed at the base of the crown. There is also a ridge on the buccal side of the groove with a cuspule at the base of the crown. The ridge of the lingual side of the groove has a well-developed cuspule at the base of the crown. Also a ridge on the buccal side of the groove with a cuspule at the base. The roots of the specimen are broken. The specimens include left and right second lower molars (M_2).

The third lower molar (M_3): Is smaller than M_2. It is partially broken on the distal side. There is no serration at the mesial side of the crown. There is a sharp ridge up the crown to the protoconid on the lingual side. The root is broken.

The upper incisors: Difficult to differentiate the left and right upper incisors as they were found as individually and detached. Wear on the sides of the teeth was used to indicate the tooth positions.

The first upper incisor (I^1): The smallest of the upper incisors. It has a single gently tapering root. The crown is a simple cone that curves distally and buccally. The mesial and distal surfaces of the crown have a midline.

The second upper incisor (I^2): Is distinguished from I^1 by a bulbous inflated root, the root is very expanded proximal to the base of the crown. The crown is similar in size and shape to that of I^1, being slightly curved buccally and distally. The specimen has slight rugosities near the base of the crown.

The third upper incisor (I^3): The crown is conical and larger than I^2. The root is similar to I^2 but is not expanded. The enamel of the crown has rugosity at the base of two sides.

The first upper premolar (P^1): Appears to be double root and smaller than the third upper premolar. It is damaged beyond further description.

The third upper premolar (M^3): Is buccaly compressed, and double rooted. The distal root is bucco-lingually significantly wider than the mesial root. The crown has lingual projection outer roots. The central cusp is the largest cusp of P^3. It is located directly below the division of the two roots. There are four accessory denticles on the mesial edge of the tooth. The mesial denticles project slightly mesially then upward. The mesial denticles are smaller than the distal denticles. There are five accessory denticles on the distal edge of the tooth, the last denticle arises from the short but well defined cingulum. The denticles increase in size from the distal to the mesial side.

The study specimens include left and right third upper premolars.

Table 1. Measurements of the teeth of *Masracetus markgrafi*

Tooth	Height (mm)	Crown length (mm)	Crown Width (mm)	Root Width (mm)		Complete tooth length (mm)	Preservation state
I1	33	18	14	11.7		87	complete
I2	41.5	24	12	12		101.2	complete
C1	50	32	19	13		87.4	Lower root section missing
P1	31	49.5	17.5	mesial: 100.5	distal: 104	89.4	complete
P_2	39	54	24	17.2	15	79.5	Lower root section missing
P_3	45.3	71.5	20.8	12.4	13.3	123.4	Lower root section missing
P_4	45.4	71.9	28	na	na	62.8	complete
M_1	30.8	30.7	16.3	na	na		Root missing
M_2	32.9	na	15.4	na	na	47.3	Lower root section missing
I^1	32.2	26.4	16.6	16.6		87	Complete
I^2	31.8	28.2	17.9	16.5		82.5	Complete
I^3	31.8	27.2	19	14		87	Complete
P^1	3.6	na	na	na	na		damaged
P^3	45.2	58.2	20.4	mesial: 19	distal: 19.8	122.2	Complete

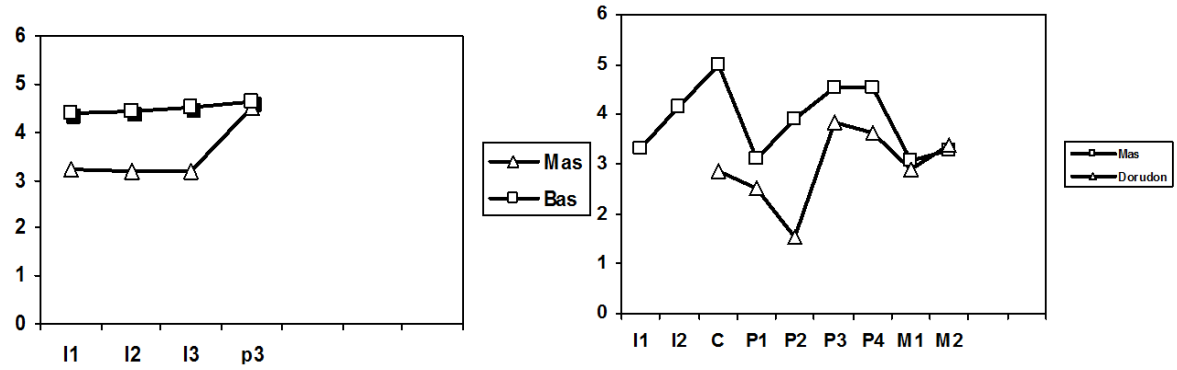

Fig. 5. Plots of the height of lower and upper teeth of *Masracetus markgrafi* (study specimen) and other species identified from the area. A (left) height (cm) of the upper teeth of *Masracetus markgrafi* and *Basilosaurus isis* (Abu El-Kheir, 2010); B (right) height (cm) of the lower teeth of *M. Markgrafi* and *Dorudon atrox* (Uhen, 2004).

Tooth Histological Structure

A mammal tooth has a crown extending above the gumline with one or more roots inserted through the gum into alveoli (Maas, 2002). A tooth is formed of layers including, pulp, dentine, enamel and cementum. The pulp cavity, within a tooth, is filled with a soft gelatineous tissue during life, which can be subdivided into a pulp chamber, inside the crown, and the root canal (Gartiner et al., 1997). The root canal extends downward to the end of the root. A layer of dentine surrounds the pulp cavity. The crown is capped with a thin layer of enamel which is the hardest material in the teeth. The root is covered by cementeum, which is similar in composition to bone, and helps anchor a tooth into the jaw (Maas, 2002).

Incisor internal tooth structure

A thin section of a fossilised lower incisor of *Masracetus markgrafi* revealed:

The pulp cavity

The pulp in the cavity in the center of the crown has been replaced by ferruginous, calcareous mudstone (fig. 7A). This has very fine elongated calcite grains in a ferruginous mud matrix formed during the fossilization process.

The dentin layer

The dentin layer surrounding the pulp layer is homogeneous tissue, formed of calcium hydroxyl apatite. This layer had many horizontal fractures filled by ferruginous sandstone. The dentin has fine Lines of Owen which are alternating regions of normal calcification and the hypocalcification (Gartiner et al. 1997, Uhen, 2004), which Very fine dentinal tubules extend from the pulp to the dento-enamel junction of the crown (fig. 7B).

The enamel layer

Enamel is the hardest substance of the tooth. It is a thin layer of large crystals of calcium hydroxyl apatite over the crown portion of the dentine. In the study specimen it is coloured dark yellow/brown. The enamel was not evident in the transverse thin section and may have been removed in the process of preparing the thin section. The enamel in the entire tooth is thick at the tip of the crown decreasing in thickness towards the base of the crown of the teeth (near gum insertion). The enamel is rugose in the majority of the study specimens.

Taphonomic Setting

The fossilised *Masracetus markgrafi*, containing the study tooth specimens was a poorly preserved partial skeleton, with fragmented ribs and vertebrae (figs. 4 and 5) deformed by the load of mudstone bearing layer above the fossils. The skull and the mandible were fragmented into small pieces. The well preserved teeth were found close to the anterior portion of the skeleton imbedded in the mudstone among and beneath fragmented elements of the skeleton. The skull was positioned with the dorsal surface orientated uppermost, thus the teeth were protected by the skull from weathering after death. The teeth were found in close proximity to each other, with some above others, as would be found in the mouth. This indicates that the skull remained in situ after the death of the animal, and while being covered by sediments. The presence of both upper and lower teeth suggests the lower mandibles were conjugated with the skull.

The study specimens were found as isolated teeth that were separated from the tooth alveoli in the maxilla and mandibles. The teeth were well preserved amongst and beneath remnants of eroded and deformed vertebrae, ribs and other elements of the *Masracetus markgrafi* skeleton. The position of the remnants suggests the carcass was relatively rapidly covered by sediments.

Where cusps were present, wear of the primary cusps and accessory denticles was not evident, perhaps suggesting a diet and/or feeding technique that causes little tooth wear. For example, tooth wear can occur when feeding in shallow environments or benthic feeding where abrasive substrates such as sand and rocks can erode teeth while feeding, conversely, suction feeding may minimize erosion. Alternatively, the specimen may have been a relatively young animal with minimal tooth erosion at the time of death. Further studies of this and other specimens are needed.

4. Conclusions

Masracetus markgrafi is a Basilosauridae, a fully aquatic extinct Archeocete. The teeth are characteristic of Basilosauridae, that is, triangular cheek teeth with multiple accessory cusps, and M^3 absent. The presence of many main cusps and accessory denticles suggest this whale may have been a predator.

The teeth in the present study were collected from the calcareous mudstone of the Gehannam Formation which indicates an open mildly warm shallow marine environment (inner neritic zone 50-100 m depth). Perhaps indicating *Masracetus markgrafi* inhabited shallow marine, near shore environments comparable to the environments of other Basilosaurids in the area, particularly *Basilosaurus isis* and *Dorudon atrox*.

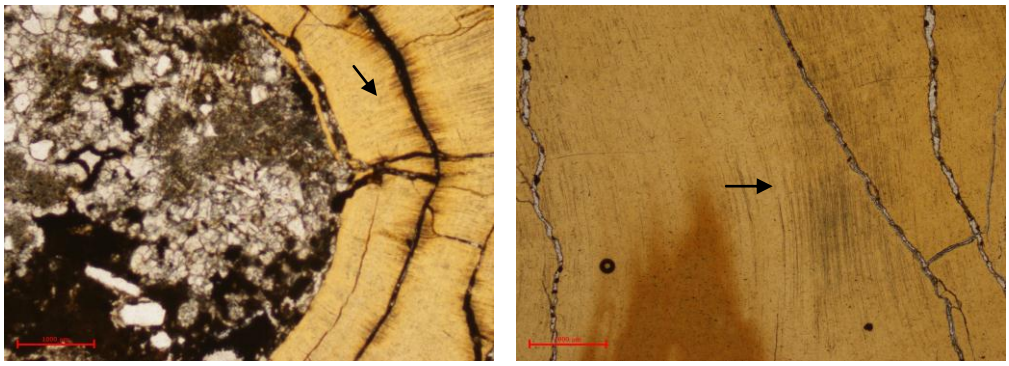

Fig. 7. Transverse thin section of a lower incisor of *M. markgrafi*, showing the internal structure in the crown. A (left): the internal pulp cavity filled by fine textured sediments of ferruginous, calcareous mudstone, surrounded by cracked, homogeneously texture dentin with very fine dential tubules (arrowed). B (right): dentin surrounding the pulp cavity, showing the fine Lines of Owen, alternating regions of calcifications (arrowed).

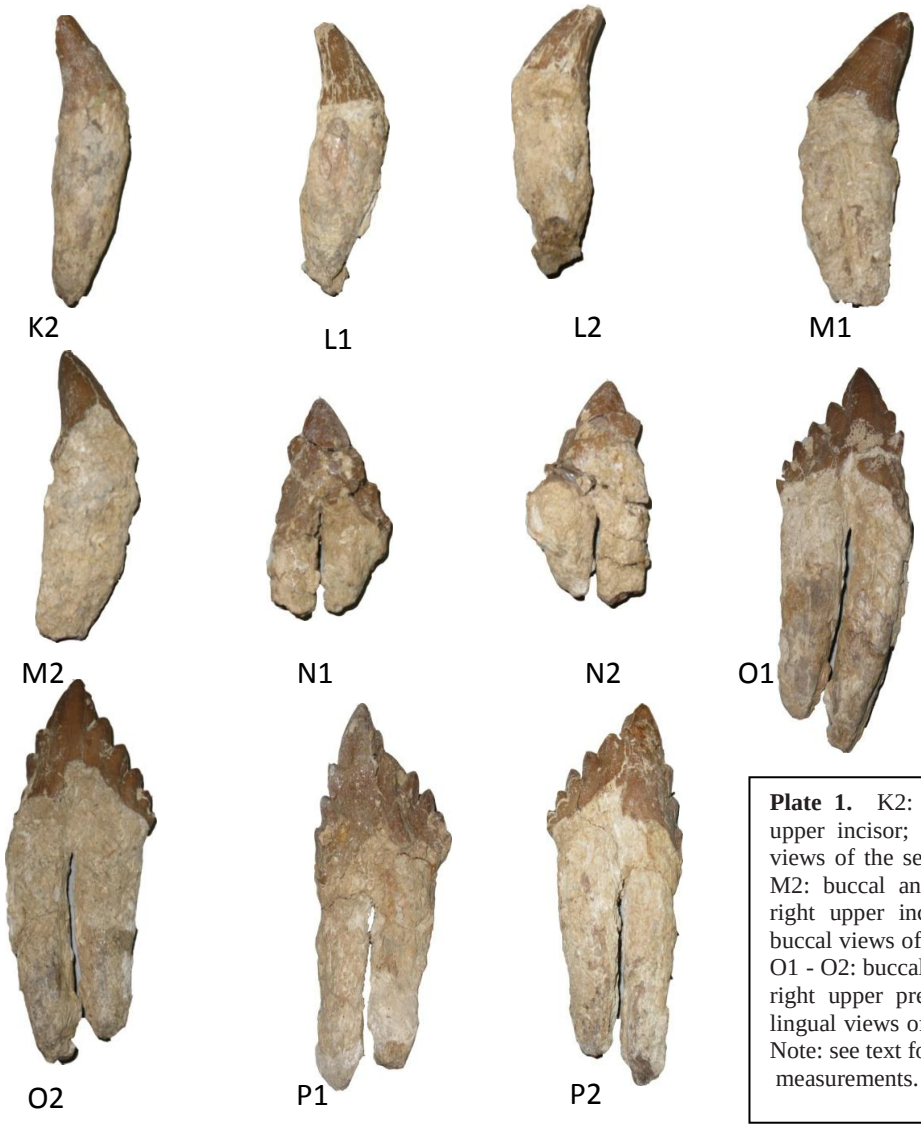

Plate 1. K2: lingual view of the first left upper incisor; L1 - L2: lingual and buccal views of the second left upper incisor; M1 - M2: buccal and lingual views of the third right upper incisor; N1 - N2: lingual and buccal views of the first right upper premolar; O1 - O2: buccal and lingual views of the third right upper premolar; P1 - P2: buccal and lingual views of the third left upper premolar. Note: see text for individual tooth. measurements.

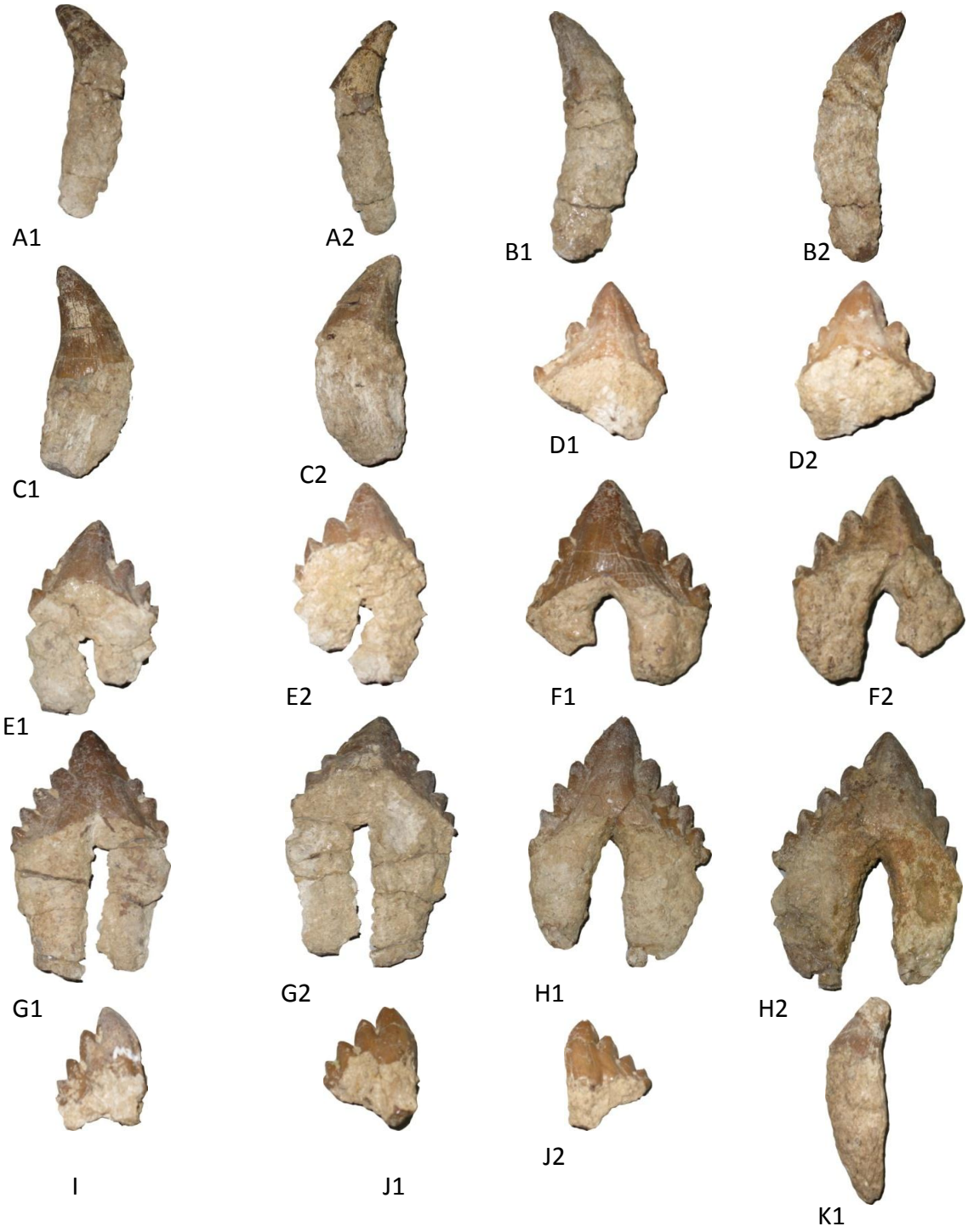

Plate 2 A1 - A2: buccal and lingual views of the first right lower incisor; B1 - B2: lingual and buccal views of the second or the third left lower incisor; C1 - C2: lingual and buccal views of the left lower canine; D1 - D2: lingual and buccal views of the first left lower premolar; E1 - E2: the lingual and buccal views of the first right lower premolar; F1 - F2: lingual and buccal views of the second right lower premolar; G1 - G2: lingual and buccal views of the third left lower premolar; H1 - H2: buccal and lingual views of the fourth left lower premolar; I: lingual view of the first left lower molar; J1 - J2: buccal and lingual views of the second right lower molar; K1: buccal view of the first left upper incisor. Note: See text for individual tooth measurements

5. Acknowledgments

We are very grateful to Dr Philip Gingerich, Director of the Geological Museum and Department of the Geological Science, University of Michigan and his expedition team, Christopher King, Charles Underwood and Divide Ward for their assitance in the field. We also thank very much Dr. Guda Isamiel Abd El Gawad, Beni Suef University, for comments on this article. We also thank the Rangers of Qaroun Protected Area and are grateful for their assistance during this work.

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