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NOTA PALEONTOLÓGICA

A SPERM WHALE (CETACEA: PHYSETEROIDEA) FROM THE PARANÁ FORMATION (LATE MIOCENE) OF ENTRE RÍOS, ARGENTINA. ENVIRONMENT AND TAPHONOMY

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Palabras clave. Paraná Formation. Late Miocene. Entre Ríos. Cetacea. Physeteroidea.

Sperm whales (Physeteroidea) are known since the late Oligocene. They became very diverse during the middle and late Miocene (Bianucci and Landini, 2006). They are currently represented by only three species. Sperm whales have been reported in Argentina from the early Miocene Gaiman Formation [*Diaphorocetus pouchetti* Moreno, 1892, and *Idiorophus patagonicus* (Lydekker, 1893)], Gran Bajo del Gualicho Formation (*Preaulophyseter gualichensis* Caviglia and Jorge, 1980), the late Miocene Barranca Final Formation ("*Aulophyseter" rionegrensis* Gondar, 1975), and the late Miocene Paraná Formation (cf. *Aulophyseter* sp. by Agnolín and Lucero, 2004).

Unfortunately, there are very few published Miocene cetaceans with good stratigraphic and geographic provenance from central-eastern Argentina (*e.g.*, Balaenopteridae indet.; Noriega *et al.*, 2007). Recently, one of us (LMP) found a piece of carbonate rock with an embedded physeteroid tooth coming from upper levels of the Paraná Formation. The material was collected in the quarry known as "Cantera del Puerto Viejo" (GPS: 31°42′36″ S–60°33′10″W), close to the city of Paraná, Entre Ríos Province (Fig. 1). In this note, we describe the tooth, discuss the identification of another physeteroid tooth from the same stratigraphic unit, and compare them with different sperm whales. Additionally, we analyze the sedimentology and comment on the associated fauna and the taphonomic processes that acted on the fossil and the paleoenvironment.

STRATIGRAPHY

The continental and marine beds in the Paraná riverside cliffs in Entre Ríos (Argentina) have been scientifically known since 1827, when Alcide d'Orbigny visited the area (d'Orbigny, 1842). The relationships between them have been discussed for many years (cf. Aceñolaza, 2000). Two Miocene units are recognizable in the area: the mostly marine Paraná Formation and the overlying fluvial sequence of the Ituzaingó Formation. Several younger continental units overlie the Miocene sequence. The outcropping sections of the Paraná Formation are mainly constituted by green mudstones, variously colored sandstones, carbonate rocks, and several oyster levels (Aceñolaza, 1976, 2000). The Paraná Formation was deposited during the widespread marine trangression that covered the Chacopampean region during the middle Miocene and part of the late Miocene ("Mid Transgressive Onlap Sequence"; Uliana and Biddle, 1988; Cione *et al.*, 2000, 2005). The exposed beds of the Paraná Formation are considered late Miocene in age (Cione *et al.*, 2000). Mammals occurring in the basal part of the overlying Ituzaingó Formation are Huayquerian in age according to the South American local chronology (Cione *et al.*, 2000; Cione and Tonni, 2005). The Huayquerian Age ranges from about 8 to about 6 Ma (Tortonian–Messinian, late Miocene; Cione *et al.*, 2000, 2005; Cione and Tonni, 2005; Woodburne *et al.*, 2006).

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MATERIAL AND METHODS

The studied material comprises an almost complete tooth, MAS Pv 1361, and a fragmentary tooth, MACN Pv 8926, from the Paraná Formation. Additional fossil specimens of Physeteroidea examined: *Diaphorocetus poucheti*, MLP 5-6; *Idiorophus patagonicus*, MLP 76-VI-9-1/6; "*Aulophyseter*" *rionegrensis*, MLP 62-XII-19-1 and MLP 62-XII-18-1, cranium and isolated teeth, Barranca Final Formation; *Preaulophyseter gualichensis*, MLP 76-IX-5-1, periotic and two teeth, Gran Bajo del Gualicho Formation. Recent material examined: *Physeter macrocephalus* Linnaeus, 1758, many specimens in the MACN.

Transversal and longitudinal tooth thin sections were prepared to compare microscopic structures in fossil and recent teeth.

For the analysis of the rock containing the fossil, we used the techniques of thin sections of rock and XRD in whole rock. The thin sections were analyzed with a petrographic microscope Nikon Eclipse E200® and X-ray diffraction analysis was performed with a diffractometer Phillips®.

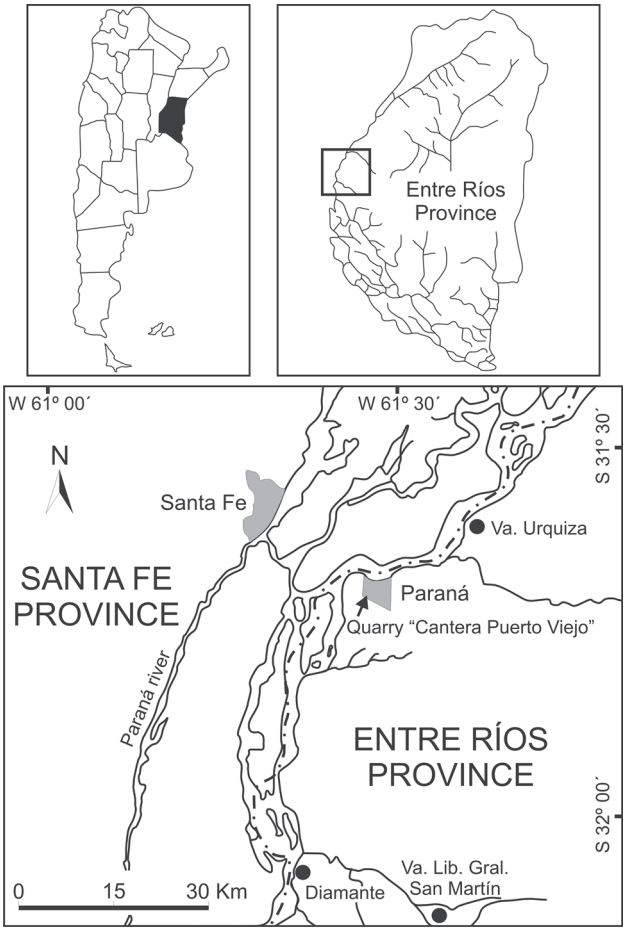

Figure 1. Geographical location of the "Cantera del Puerto Viejo" quarry/ *mapa de ubicación geográfica de la "Cantera del Puerto Viejo".*

Institutional abbreviations. **MACN**, Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Buenos Aires, Argentina; **MAS**, Museo de Ciencias Naturales y Antropología "Prof. Antonio Serrano," Paraná, Argentina; **MLP**, Museo de La Plata, La Plata, Argentina.

Anatomical abbreviations. **MAW**, maximum anteroposterior width; **MCT**, maximum cement thickness; **MLF**, maximum length of the fossil; **MTW**, maximum transversal width; **PC**, pulp cavity.

SYSTEMATIC PALEONTOLOGY

Order Cetacea Brisson, 1762

Suborder Odontoceti Flower, 1867

Superfamily Physeteroidea Gray, 1821

Physeteroidea indet.

Figures 2.1–3 and 3.1–3

Material. MAS Pv 1361, almost complete tooth, embedded in a bioclastic grainstone; "Cantera del Puerto Viejo" near the city of Paraná, Paraná Formation. MACN Pv 8926, fragmentary tooth lacking a large part of the distal end and most of the cement; indeterminate stratigraphic and geographic location in the Paraná area.

Macroscopic description. Teeth relatively robust, conical, and gently curved; cross-section of teeth oval; base with widely open pulp cavity (Figs. 2.3–4); root not swollen as in some other physeterids; tip missing in both teeth; MAS Pv 1361 much more complete (Fig. 2.1) and with apparently thiner, worn or entirely lacking enamel; no sign of a band corresponding to gingival or alveolar margin; greater part of teeth made up of dentine covered by relatively thin layer of cement (Figs. 2.1–3, 3.2); surface of cement smooth; where dentine exposed, ornamentation consisting in basoapical ridges and striae, with transversal ridges (Fig. 2.1), corresponding to growth layers.

Microscopic description. Tooth thin sections of MAS Pv 1361, the Miocene "*Aulophyseter*" *rionegrensis*, and the recent *Physeter macrocephalus* show the following characters: dentine with radially oriented dentine tubules (Fig. 3.1–2); cement with cementocyte lacunare visible; and transition ring between cement and dentine.

Measurements. MAS Pv 1361: MLF, 167 mm; MAW, 53 mm; MTW, 42 mm; PC, 104 mm; MCT, 1.12 mm. MACN Pv 8926: MLF, 120 mm; MAW, 40 mm; MTW, 31 mm; PC, 83 mm; MCT, 4 mm.

DISCUSSION

MACN Pv 8926 was previously identified as cf. *Aulophyseter* sp. by Agnolín and Lucero (2004). They mistakenly described dentine as enamel. We consider that the material can only be identified as Physeteroidea indet. It strongly resembles MAS Pv 1361 (Fig. 2). Both differ from the living *Kogia* spp., "*Aulophyseter" rionegrensis* (this species was referred to an unpublished new genus by Cozzuol, 1993), *Ferecetotherium* Mchedlidze, 1970, *Idiorophus* Kellogg, 1925, *Orycterocetus* Leidy, 1853 (*cf.* Bianucci *et al.*, 2004), and *Preaulophyseter* Caviglia and Jorge, 1980, because of their larger size. From *Livyiatan* (Lambert *et al.*, 2010b) (see Lambert *et al.,* 2010a) they differ because of their smaller size. They can be separated from *Scaldicetus*, *Physeterula* Van

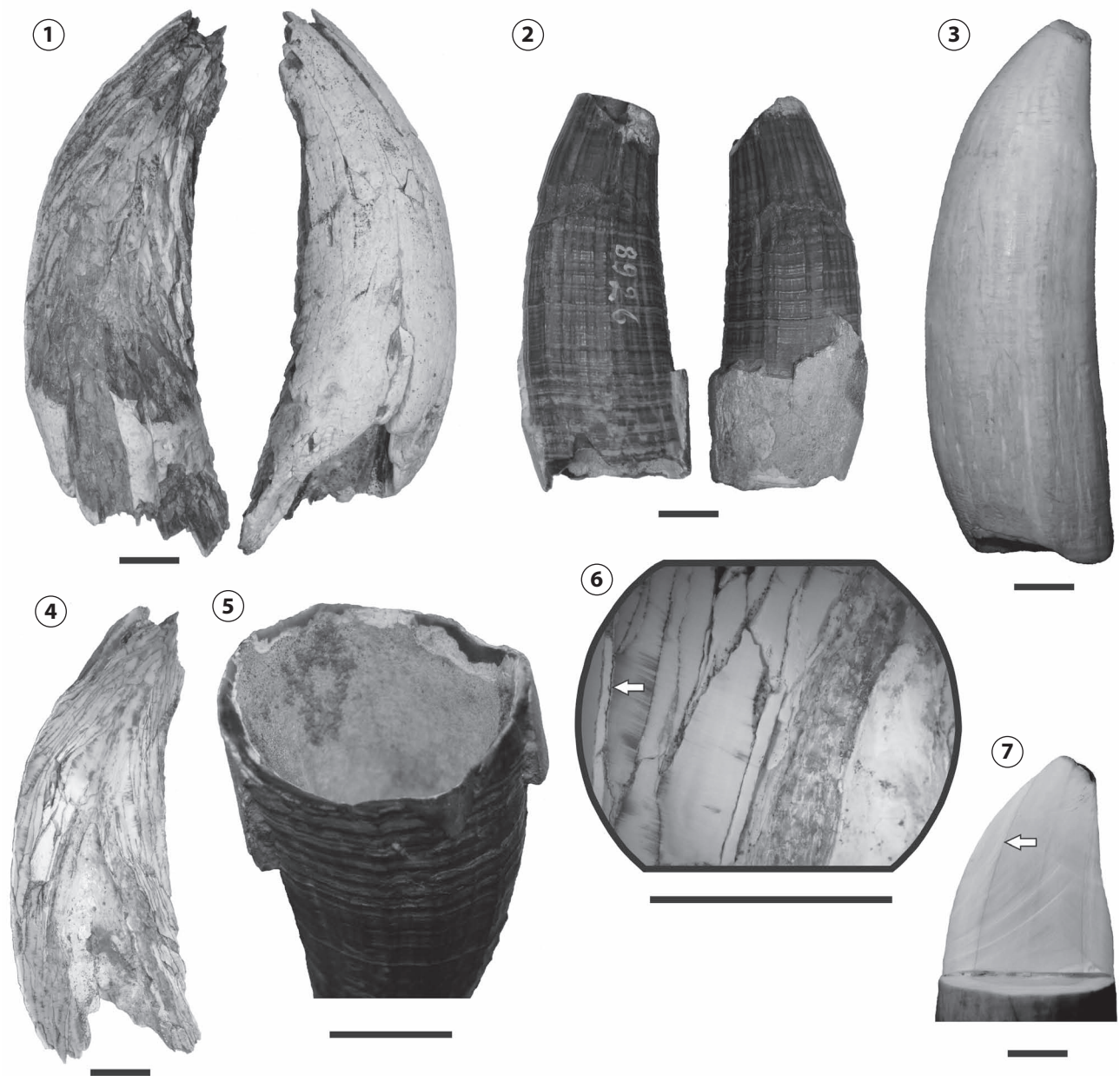

Figure 2. **1**. Physeteroidea indet. MAS Pv 1361, lateral view/ *vista lateral*. **2**. MACN Pv 8926, lateral view/ *vista lateral*. **3**. ***Physeter macrocephalus*** tooth MACN 29.768, lateral view/ *vista lateral.* **4**. Physeteroidea indet. MAS Pv 1361, lateral view of the polished tooth/ *vista lateral del diente pulido*. **5**. Physeteroidea indet. MACN Pv 8926 view of the large basal pulp cavity/ *vista de la gran cavidad pulpar basal*. **6**. Physeteroidea indet. MAS Pv 1361, detail of polished tip/ *detalle de la punta pulida*. **7**. ***Physeter macrocephalus*** MACN 29.768, details of the polished apical area of the recent tooth/ *detalle del área apical pulida del diente actual*. Arrows in 5 and 6 indicate the boundary between dentine and cement/ *las flechas en 5 y 6 indican el límite entre la dentina y el cemento.* Scale bar/ *escala* = 2 cm.

Beneden, 1877, *Hoplocetus* Gervais, 1848, *Zygophyseter* Bianucci and Landini, 2006, *Acrophyseter* Lambert *et al.*, 2008, and *Livyatan* because they lack fusiform roots (Bianucci *et al.*, 2004; Hampe, 2006). Lastly, they can be distinguished from *Placoziphius* Van Beneden, 1869 (at least from a specimen from the Miocene of Austria, Kazár, 2002 *fide* Bianucci *et al.*, 2004) because they lack the peculiar vertical deep furrows on the root surface (Fig. 4). Other physeteroids such as *Hoplocetus* Gervais, 1848, and *Scaldicetus* du Bus, 1867 (see Hampe, 2006), are not considered herein because they are based on undiagnostic material (Bianucci and Landini, 2006; Lambert *et al.*, 2008), or because our material is missing the tooth-tip.

The Paraná teeth resemble most closely those of the stem Physeteroidea genus *Orycterocetus* and the Physeteridae *Physeter* in shape, apparent absence of enamel cap, and the large basal pulp cavity (Figs. 2, 4). The last character is typical of juveniles. However, the relatively large size strongly suggests that the Paraná teeth correspond to adults, being similar to those of *Physeter*.

Environment

The outcrops of the Paraná Formation in the "Cantera del Puerto Viejo" area include the bed yielding MAS Pv 1361. It is a shell-bed approximately 2 m thick and exposed laterally for several hundred meters forming a chenier-like deposit. This shell-bed represents part of the topmost regressive sequence of the Paraná Formation. A sedimentological analysis of the bearing rock was performed in order to obtain palaeoenvironmental and taphonomic information. Macroscopically, the rock (Fig. 3.3) is a bioclastic grainstone *sensu* Dunham (1962), or a rudstone *sensu* Embry and Klovan (1972). Remnants of partially dissolved oysters and other molluscs were observed. Additionally, thin sections were prepared, in which not only partially but also completely dis-

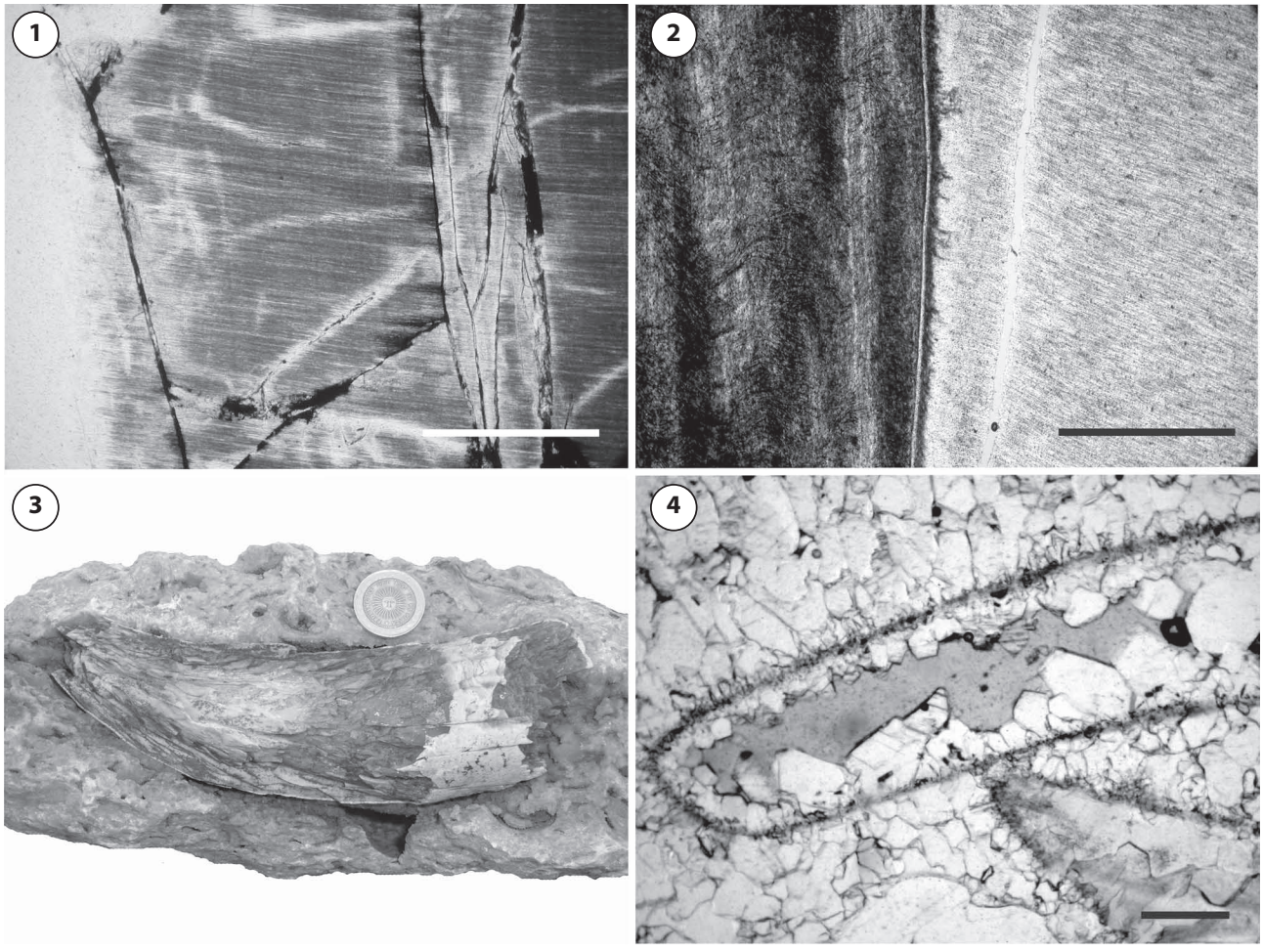

Figure 3. **1–2**. Longitudinal thin sections of physeteroid teeth/ *cortes delgados longitudinales de dientes de fisetéridos.* **1**. Physeteroidea indet. MAS Pv 1361; **2**. ***Physeter macrocephalus*** MACN 29.768; **3**, Physeteroidea indet. MAS Pv 1361 tooth as it was found in the rock/ *diente tal como fue hallado en la roca;* **4**. Rock thin section/ *corte delgado de roca*. Scale bar/ *escala* 1–2 = 1 cm; 4 = 500 µm.

solved mollusk shells are present. Where cement has not infilled the intraskeletal pore spaces completely, the space created by shell dissolution presents a drusy mosaic calcite (Fig. 3.4). There are two accompanying siliciclastic components, *i.e.*, angular quartz-clasts with clear and wavy extinction (of metamorphic origin) and microcline feldspar-clasts. Analysis using X-ray diffraction showed a prevalence of 99.9% calcite, with traces of quartz components contributed by the siliciclastic components.

Both macroscopic and petrographic analyses suggest that the sedimentation environment would correspond to a coastal shoreface. The malacofauna of the Paraná Formation indicates a warm-temperate to tropical sea (del Río, 1990, 1991); some taxa of this malacological association include Arcidae, Veneridae, Nuculanidae, and large pectinids (Pérez *et al.*, 2011). The ichthyofauna suggests the presence of a warm-temperate sea (Cione, 1978; Cione *et al.*, 2005). Fish taxa occurring in the same beds as the teeth described in this study include neoselachians and bony fishes, *i.e.*, lamniforms of the families Otodontidae, Lamnidae, and Odontaspididae; carcharhiniforms of the families Carcharhinidae, Sphyrnidae, and Hemigaleidae; heterodontiforms of the family Heterodontidae; squatiniforms of the family Squatinidae; batomorphs of the families Dasyatidae, Myliobatidae, and Rajidae; holocephalans; perciforms of the families Sciaenidae and Sparidae; and siluriforms of the Family Ariidae (Cione *et al.*, 2000, 2005, in press).

The predominance of calcium carbonate over the siliciclastic components indicates low terrigenous input and marine biogenic precipitation and accumulation. The lack of compactation, coupled with the blocky and drusy mosaic structures, indicate that the rock was subject to early meteoric diagenesis. The stability of crystalline calcite above that of aragonite explains the preservation of oyster calcitic shells and the differential dissolution of the rest of mollusks with shells composed of the two polymorphs. In this context, biostratinomic processes allowed the preservation of the physeteroid teeth, which are composed of phosphate (fluorapatite)—which is highly resistant to the corrosion of acidic meteoric water.

CONCLUSIONS

The material described —from the top of the regressive sequences of the Paraná Formation— corresponds to physeteroid teeth similar to those of the genus *Physeter*. Tooth MAS Pv 1361 from "Cantera del Puerto Viejo" is the only physeteroid remain with good stratigraphic and geographic data from the late Miocene of the Atlantic side of South America north of Patagonia. We discard the occurrence of the genus *Aulophyseter* in the Miocene of Paraná, the specimen MACN Pv 8926 being identified just as Physeteroidea indet.

The sedimentary paleoenvironment appears to correspond to a coastal shoreface in a warm-temperate sea. This hypothesis is based on biological, sedimentological, and petrological evidence. There was a low terrigenous input, while marine biogenic precipitation and accumulation predominated. The

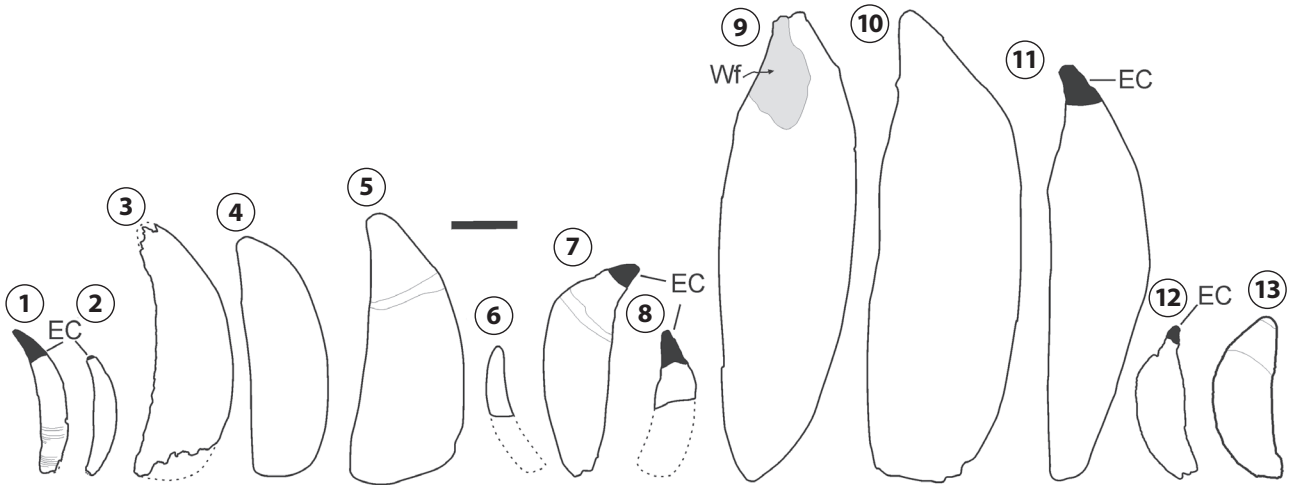

Figure 4. Diagrams of Physeteroidea teeth/ *diagramas de los dientes de Physeteroidea*. **EC**, enamel cap/ *capuchón de esmalte*. **1**. ***Preaulophyseter gualichensis*** MLP 76-IX-2-1. **2**. ***"Aulophyseter" rionegrensis*** MLP 62-XII-19-1. **3**. Physeteroidea indet. MAS Pv 1361. **4**. ***Physeter macrocephalus*** MACN 29.768. **5**. ***Physeter macrocephalus*** (modified from Lambert *et al*. 2010, fig. 1h). **6**. ***Orycterocetus*** (modified from Bianucci *et al*. 2004, fig. 3). **7**. ***Zygophyseter valorai*** (modified from Bianucci and Landini, 2006, fig. 9f). **8**. ***Acrophyseter deinodon*** (modified from Lambert *et al*., 2008, fig. 1f). **9–11**. ***Livyatan melvillei*** (modified from Lambert *et al*., 2010, fig. 1 e–g). **12–13**. ***Hoplocetus ritzi*** (modified from Hampe, 2006, fig. 4 e and g). Scale bar/ *escala* = 5 cm.

rock containing the teeth described was subject to early meteoric diagenesis, as suggested by the lack of compactation, coupled with the blocky and drusy mosaic structures.

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