FOSSIL WHALES FROM THE AZORES

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ABSTRACT

The Azores are well-renowned for their rich fauna of living cetaceans. Less known, however, is the occurrence of Late Neogene fossils of whales in Santa Maria, the only island in this volcanic archipelago with a significant sedimentary record. This work reviews the scarce fossil record of cetaceans from Santa Maria, including both the historical occurrences long cited in the literature, and more recent ones, as yet unpublished. All 10 occurrences currently recognized originate from Touril Complex, an essentially marine sedimentary unit that has been dated, as a whole, from the Messinian-Zanclean (» 6.0-4.8 Ma). Apart from a few scrappy remains, tentatively assigned only to Cetacea indet., the more significant specimens belong to groups that are mostly pelagic and typical inhabitants of deep and open ocean waters (*Mesoplodon* sp. and ? Balaenopteridae indet.). Pending further discoveries, the Late Neogene cetaceans from the Azores may prove quite relevant in the establishment of palaeobiogeographic correlations within the North Atlantic, due both to the strategic mid-oceanic location of the archipelago and the rarity of cetacean associations known from the sampled interval in this region.

RESUMO

Os Açores são bem conhecidos pela sua rica fauna de cetáceos actuais. Menos conhecida, no entanto, é a ocorrência de fósseis de baleias do Neogénico superior em Santa Maria, a única ilha deste arquipélago vulcânico com registo sedimentar significativo. Este trabalho consiste numa revisão do escasso registo fóssil de cetáceos de Santa Maria, incluindo as ocorrências históricas há muito citadas na literatura, bem como outras mais recentes, ainda não publicadas. Todas as 10 ocorrências presentemente reconhecidas provêm do Complexo do Touril, uma unidade sedimentar essencialmente marinha que foi datada, no conjunto, do Messiniano-Zancliano (» 6.0-4.8 Ma). Além de alguns restos menos completos, tentativamente atribuídos apenas a Cetacea indet., os espécimes mais significativos pertencem a grupos maioritariamente pelágicos, que vivem tipicamente em águas oceânicas profundas e abertas (*Mesoplodon* sp. e ? Balaenopteridae indet.). Na iminência de mais descobertas, os cetáceos do Neogénico superior dos Açores podem vir a revelar-se bastante importantes no

estabelecimento de correlações paleobiogeográficas no âmbito do Atlântico Norte, quer devido à localização estratégica do arquipélago quer devido à raridade, nesta região, das associações de cetáceos conhecidas deste intervalo estratigráfico.

INTRODUCTION

The mid-North Atlantic Azores Archipelago is well-renowned for its rich fauna of living cetaceans (Reiner *et al.*, 1993), which makes these islands one of the most sought-after whale watching spots in the world (Silva *et al.*, 2003). Less known, both to the general public and the scientific community, is the occurrence of Late Neogene fossils of whales on Santa Maria, the only island in this volcanic archipelago with a significant sedimentary record. These fossils, nevertheless, have long been known by the local population, which commonly refers to them as "ossos de gigantes" [bones of giants].

The present work reviews the scarce fossil record of cetaceans from Santa Maria, including both the historical occurrences long cited in the literature (but not described), and more recent ones, as yet unpublished, based on specimens deposited in several institutions at the Azores and mainland Portugal (see below). It expands on a preliminary note presented at the 1st "*Atlantic Islands Neogene*", International Congress, held in June 2006 at Ponta Delgada, São Miguel Island (Estevens, 2006a), which was since updated with new information. In addition to a systematic synopsis of all the occurrences so far inventoried, it includes a first appraisal of the palaeoecological and palaeobiogeographical significance of the fossil cetacean record from the Azores within the framework of the Late Neogene from Portugal and the North Atlantic region.

INSTITUTIONAL ABBREVIATIONS

DBUA-F – Reference Collection of the Fossil Marine Molluscs of the Azores, Marine PalaeoBiogeography Working Group, Biology Department, University of the Azores, Ponta Delgada, São Miguel Island, Azores, PORTUGAL;

DTP – Private collection of Mr. Dalberto Teixeira Pombo, Vila do Porto, Santa Maria Island, Azores, PORTUGAL;

MCM – Carlos Machado Museum, Ponta Delgada, São Miguel Island, Azores, PORTUGAL;

MG/INETI – Geological Museum, National Institute of Engineering, Technology and Innovation, Lisbon, PORTUGAL;

MMRDC – King D. Carlos Sea Museum, Cascais, PORTUGAL.

HISTORY AND INVENTORY OF OCCURRENCES

Currently, the fossil cetacean record of Santa Maria consists only of 10 occurrences, herein identified with the notation SMI (Santa Maria Island) and numbered in approximate

TABLE 1. Inventory of fossil cetacean occurrences from Santa Maria Island (Azores, Portugal), with data on collection, relevant bibliographic references, geographic and stratigraphic provenance, repository, material and current taxonomic assignment.

Occurrence	Collection date	Collectors	Bibliographic references	Locality	Stratigraphy	Age	Catalogue number	Material	Taxonomy
ISM 1	Collection not certain	Collection not certain	Boid (1835) Bedemar (1837) Reiss (1862)	Ponta do Pesqueiro	Touril Complex	Messinian-Zanclean	Not located	1 (or more) undetermined (limb ?) bone(s)	? Mysticeti indet.
ISM 2	Late 19th century ?	Luiz Corte Real	Cotter (1888-92)	?	Touril Complex ?	Messinian-Zanclean ?	MG/INETI unnumbered	12 bone fragments (ribs, vertebrae and others)	? Mysticeti indet.
ISM 3	Early 20th century ?	Ernesto Ferreira ?	-	?	Touril Complex ?	Messinian-Zanclean ?	MCM 108	1 dentary portion + 2 rib fragments	? Balaenopteridae indet.
ISM 4	Early 20th century ?	Ernesto Ferreira ?	-	?	Touril Complex ?	Messinian-Zanclean ?	MCM 114	1 vertebra	? Balaenopteridae indet.
ISM 5	Late 20th century ?	Dalberto Pombo	-	Figueiral	Touril Complex	Messinian-Zanclean	DTP unnumbered	1 vertebra	? Mysticeti indet.
ISM 6	04-1984	Dalberto Pombo	-	Assumada	Touril Complex	Messinian-Zanclean	MMRDC-R/2003/02/0841	1 rostrum fragment	Mesoplodon sp.
ISM 7	26-07-2001	Sérgio Ávila + Rui Amen	-	Pedreira da Cré	Touril Complex	Messinian-Zanclean	DBUA-F 123-13	1 undetermined bone fragment	? Mysticeti indet.
ISM 8	25-06-2002	Adriano Quintela + Pedro Raposeiro + Rui Costa + Sérgio Ávila	-	Pedreira da Cré	Touril Complex	Messinian-Zanclean	DBUA-F 163	1 dentary portion	? Balaenopteridae indet.
	17-06-2006	F. Garcia-Talavera + Fabrizio Cecca + Sérgio Raffi + Mário Cachão + Pedro Monteiro + Patrícia Madeira + Nuno Mendes + Sérgio Ávila					DBUA-F 401	1 dentary portion	
ISM 9	22-05-2005	Sérgio Ávila	-	Pedreira da Cré	Touril Complex	Messinian-Zanclean	DBUA-F 194	1 rib fragment	? Mysticeti indet.
ISM 10	17-06-2006	F. Garcia-Talavera + Fabrizio Cecca + Sérgio Raffi + Patrícia Madeira + Nuno Mendes + Sérgio Ávila	-	Pedreira da Cré	Touril Complex	Messinian-Zanclean	DBUA-F 402	1 rib fragment	? Mysticeti indet.

chronological order of discovery (Table 1). A brief inventory of all these occurrences follows, complemented by a short review of their history.

Although the existence of fossil bones on Santa Maria has been seemingly known by the inhabitants of the island for a long time (according to popular knowledge), published references to their occurrence can only be first detected in the 19th century literature, and still, have remained scarce ever since. In fact, only two verified occurrences were previously mentioned in the literature, as the remaining reports are presently regarded as doubtful or clearly erroneous.

Apparently, the first published reference of fossil bones on this island (SMI 1) was reported by Captain E. Boid, an English navy man that, based on personal observations, wrote: "In a part of this schistose rock on the N.W. side scarcely accessible, is to be seen an immense fossil thigh-bone of some animal (by the inhabitants called that of a man), which has been, by the erosion of rain, partly freed from its bed, and is now seen projecting from the rock. I offered a considerable sum in order to obtain it, but without success." (Boid, 1835: 101). After visiting Santa Maria himself in 1836, the Danish author Carl Friedrich August Grosse (also known as Edouard Romeo, self-proclaimed Count of Vargas de Bedemar), stated for the first time: "que o grande osso antediluviano, que se dizia existir alli, era unicamente um osso de balea" [that the large antediluvian bone, that was said to exist there, was only a whale bone] (Bedemar, 1837: 4). Although inaccurate in several points (even in light of early 19th century knowledge), Bedemar's work was quite explicit in the assignment of these bones, for which the ironic criticism that received soon after (Anonymous, 1838: 374) seems rather unjustified. As demonstrated above, and contrary to what was then implied by this unknown author (possibly John White Webster), Bedemar did not regard these bones, erroneously referred to Madeira Island by the same anonymous source, to be the fossil remains of the ancient people of Atlantis. Bedemar's authority on these vertebrate remains would be subsequently cited in a work (Reiss, 1862: 14-15), that added some information about the geographic and stratigraphic provenance of this occurrence when it referred the presence of "Bruchstücke grosser zelliger Knochen" [fragments of large cellular bones] in some tuff blocks fallen at the base of "Ponta da Pescaria" cliffs, a locality on the northwestern coast of the island currently known as Ponta do Pesqueiro (Fig. 1). Later references to this occurrence include only posthumous reproductions of Bedemar's original work (Bedemar, 1889: 290; 1982: 290), and a citation based on Reiss's work (Zbyszewski & Ferreira, 1962a: 220). The whereabouts of these bones is presently unknown (Estevens, 2006b: 179) and, as suggested by Boid's remarks, may have never been collected at all.
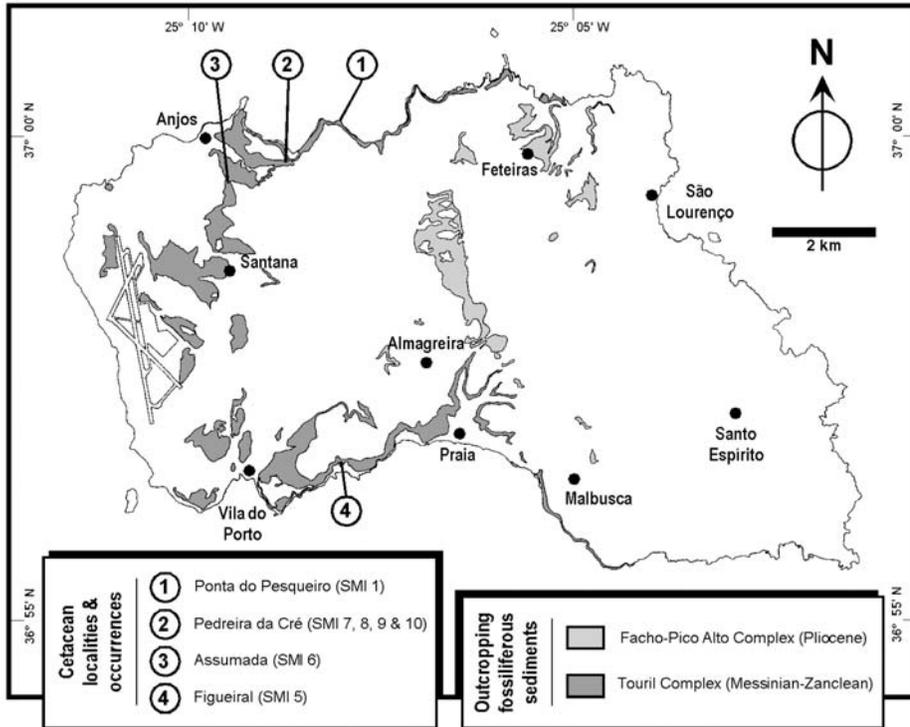
FIGURE 1. Location of fossil cetacean localities and occurrences in the Touril Complex (Messinian-Zanclean) of Santa Maria Island (Azores, Portugal).

The other published occurrence (SMI 2) relates to some "fragmentos de vertebras e costellas de cetaceo" [fragments of cetacean vertebrae and ribs], that were included in a collection of fossils from Santa Maria therein gathered by Luiz de Figueiredo Lemos do Canto Corte Real and donated to the Geological Survey of Portugal by José Julio Rodrigues (Cotter, 1888-92: 255, 283). According to the latter author, the fossils had no record of geographic provenance (p. 259) and the cetacean bones, in particular, had not been cited in previous lists of fossils from this island (p.

287), thus reasserting its identity as a separate occurrence. Based on this original reference, it would be cited repeatedly over the years, namely in Teixeira (1950: 212), Cotter (1953: 97, 101) (in a posthumous reproduction of the original work), Ferreira (1955: 15, 37), Zbyszewski & Ferreira (1962b: 288) and Estevens (1998: A161). The referred bones, with no number assigned, are still deposited in cupboard 67, tray 8, of the Stratigraphic Collection of the Geological Museum of this institution, now named the INETI (Estevens, 2006b: 180), and are par-

tially described and illustrated below for the first time.

Other historical bibliographic references to vertebrate remains found in the sedimentary rocks of Santa Maria Island could not be presently confirmed as belonging to cetaceans.

Some "Knochen-formige Kalk-konkretionen" [bone-shaped calcareous concretions], long noticed in a fossiliferous bed of the section at Pinheiros cliff (Reiss, 1862: 13), were later interpreted as constituting "ossos de cetáceos" [cetacean bones] (Zbyszewski *et al*., 1961: 11; Zbyszewski, 1962: 688), just to be soon again recognized as nothing more than "concrétions en forme d'ossements" [bone-shaped concretions] (Zbyszewski & Ferreira, 1962a: 218).

Although not specifically attributed to cetaceans, a few "fragmentos de pequenos ossos" [fragments of small bones] were also noted in a level of tuffs in the section between Almagreira and Praia, on a slope facing the southern coast (Zbyszewski *et al*., 1961: 10, 13; Zbyszewski, 1962: 691). Due to the reportedly small size of the bones, their assignment to Cetacea seems unlikely, although not completely impossible.

All remaining occurrences correspond to unpublished material housed in Portuguese institutions, some of which resulting from historic collecting (and only recently recognized among collections), whilst others were found during rather recent expeditions (Table 1).

Two of the historic findings are deposited at the Carlos Machado Museum, and were supposedly collected and donated by Priest Ernesto Ferreira, possibly during the early 20th century. One of the occurrences (SMI 3) consists of three separate fragments of bone (a larger rib portion and two smaller rib fragments of a mysticete whale), each of which partially encased in its own block of dark grey volcanic tuff, but all included under the same catalogue number (MCM 108). The other occurrence (SMI 4) corresponds to a large cetacean vertebra that has an attached block of light calcareous matrix (MCM 114). Both lack information about their provenance, but the rather different types of associated matrix suggest that the two occurrences may have come from distinct localities.

Two other occurrences were collected later in the 20th century by the same person, Mr. Dalberto Teixeira Pombo, but had different repository destinations (Table 1). One is a cetacean vertebra found in Figueiral (SMI 5), the only locality near the southern coast of the island (Fig. 1), that Mr. Pombo keeps in his private collection at Vila do Porto (personal communication of Patrícia Madeira). The other is an odontocete rostrum fragment collected in April 1984 at Assumada (SMI 6), a locality also in the northwestern part of the island, but further inland (Fig. 1). This rostrum is currently deposited at the King D. Carlos Sea Museum as specimen MMRDC-R/2003/02/0841, where it was originally catalogued as MMRDC 6260 (personal communication of Carlos Marques da Silva).

The last four fossil occurrences resulted from recent expeditions made to Santa Maria Island by the team of the Marine PalaeoBiogeography Working Group (MPB) and collaborators (Table 1), and are all deposited in the Reference Collection of the Fossil Marine Molluscs of the Azores (DBUA-F). All originate from Pedreira da Cré, a locality near Baía da Cré, on the northwestern coast of the island (Fig. 1). The first such occurrence (SMI 7) was collected in July 26, 2001 and consists of a rather eroded, undetermined small fragment of bone (DBUA-F 123-13). The second (SMI 8) is a large rib portion broken in two fragments, that were collected on two separate occasions. The first fragment, catalogued as DBUA-F 163, was discovered and excavated on June 25, 2002, during a visit framed within the 1st workshop "*Palaeontology in Atlantic Islands - Marine Fossils of the Azores: perspectives for the future*". The second fragment, numbered DBUA-F 401, was recovered from the same locality on June 17, 2006, during the "*Palaeontology in Atlantic Islands* 3rd International Workshop". Although not formally published, the original fragment was briefly mentioned in Estevens (2006b: 180). The third (SMI 9) and fourth (SMI 10) recent fossil occurrences both consist of small rib fragments, one discovered on May 22, 2005 (DBUA-F 194), and the other likewise collected on June 17, 2006, during the "*Palaeontology in Atlantic Islands* 3rd International Workshop" (DBUA-F 402).

Although not all could be definitely positioned geographically and/or stratigraphically, the 10 occurrences listed in Table 1 compose the currently known record of fossil whales in the Azores, and thus constitute the basis of this study.

STRATIGRAPHIC SETTING

The existence of fossiliferous sediments of Tertiary age on Santa Maria Island has been known for nearly 150 years, and was the object of study ever since (Hartung, 1860, 1864; Reiss, 1862).

These marine sedimentary rocks were traditionally regarded as belonging to a single Late Miocene stratigraphic unit, intercalated between eruptive volcanic complexes that underlie and overlie it (Agostinho, 1937; Teixeira, 1950). Based on its macrofaunal content, the sedimentary unit was broadly dated from the "Vindobonian" (Ferreira, 1955; Zbyszewski *et al.*, 1961; Zbyszewski, 1962), with a slight tendency towards the Tortonian (Zbyszewski & Ferreira, 1962a, 1962b). The study of the microfauna, namely the planktonic and benthonic foraminifera, pointed instead to a Late Miocene-Pliocene age (Krejci-Graf *et al.*, 1958), apparently corroborated by later radiometric dating of some lava beds lying below, above and amid the sediments, as a whole framed between 6-3 Ma (Abdel-Monem *et al.*, 1968, 1975; Feraud *et al.*, 1980, 1984).

Revision of the paleontological data, coupled with detailed stratigraphic field studies (Serralheiro & Madeira, 1993; Serralheiro, 2003), led to the recognition of two separate Neogene units containing fossiliferous marine strata: the oldest unit, named Touril Complex, is dated from the Messinian-Zanclean (6.0-4.8 Ma) and consists mostly of shallow marine sediments, with few intercalations of lava flows and pyroclastic materials; the youngest unit, designated Facho-Pico Alto Complex, is entirely assignable to the Pliocene (4.8-3.0 Ma) and contains fewer deposits of beach facies, for the most part subordinated to eruptive volcanic materials.

The confined distribution of the known cetacean localities to the western part of the island, where only Touril Complex marine sediments occur, restricts the provenance of most of the fossils herein described to this stratigraphic unit (Fig. 1). This hypothesis is further reinforced (and tentatively extended to the fossil remains of unknown origin) by the fact that the Touril Complex is the most fossiliferous rock unit on the island, and that the more restricted beach deposits of the Facho-Pico Alto Complex seem to constitute a less appropriate facies.

SYSTEMATICS

Class Mammalia Linnaeus, 1758
Order Cetacea Brisson, 1762
Suborder Odontoceti Flower, 1864
Superfamily Ziphioidea (Gray,
1865) Gray, 1868
Family Ziphiidae Gray, 1865
Subfamily Hyperoodontinae (Gray,
1866) Muizon, 1991
Genus *Mesoplodon* Gervais, 1850
Mesoplodon sp. (Figs. 2A-C)
Material. MMRDC-R/2003/02/0841 (formerly MMRDC 6260), a medial fragment of a ventral portion of rostrum (occurrence SMI 6).

Description. Short fragment of a worn medial section of an edentulous odontocete rostrum, that is transversely broken by a clean, sloping fracture throughout its entire length, thus lacking most of the dorsal region. As preserved, the fragment measures 193 mm in greatest length, 51 mm in greatest width (approximately at mid-length), and 32 mm in greatest height (at the proximal end).

The lack of the dorsal region makes it possible to see that the mesorostral canal is completely filled with extremely dense, osteosclerotic bone (Fig. 2A). This dense bone occupies most of the width of the rostrum in dorsal view, except for two narrow strips of nearly fused maxilla and premaxilla that lie adjacent to this medial, denser region on both sides. At the anterior end, only the medial denser ossification of the vomer remains, with the more cancellous bone of the maxilla and premaxilla greatly eroded. Vomer, maxilla and premaxilla seem to be mainly pachyostotic and fused throughout most of the fragment, thus suggesting that the specimen belonged to an adult male (Mead, 1989).

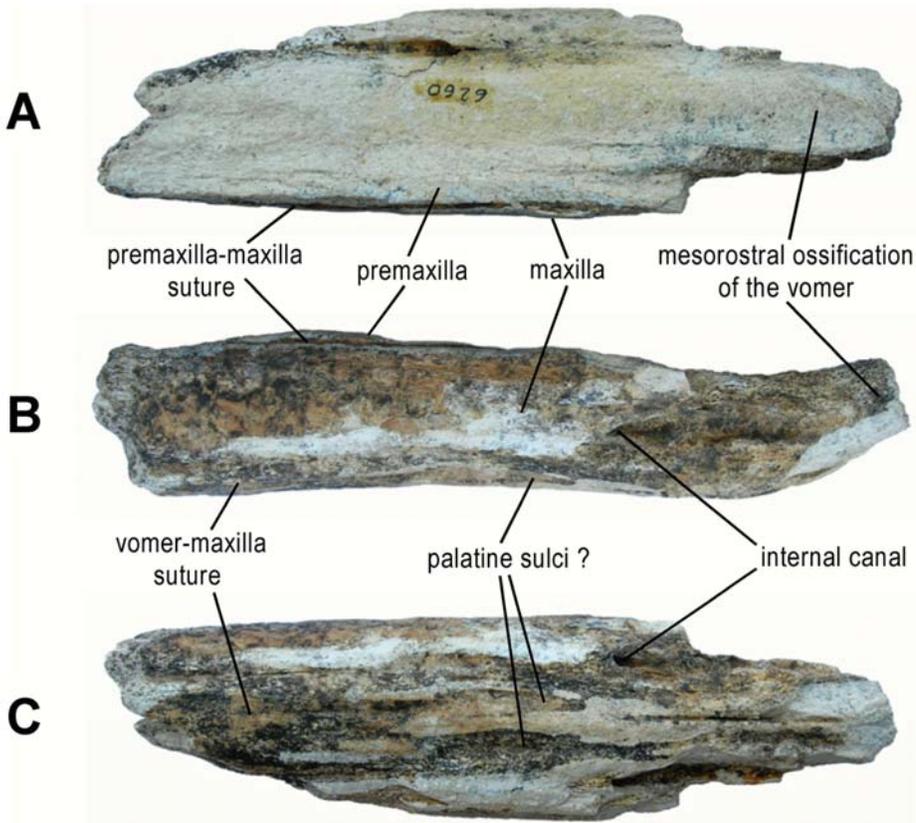Due to the inclination of the trans-

FIGURE 2. MMRDC-R/2003/02/0841 (formerly MMRDC 6260), a medial fragment of a ventral portion of rostrum assigned to *Mesoplodon* sp. (occurrence SMI 6). A – Dorsal view; B – Left lateral view; C – Ventral view. All ´ 0.5.

verse fracture of the fragment, the right side is comparatively more complete in lateral view (Fig. 2B). On this side, part of the anteriorly inclined premaxilla-maxilla suture can be faintly recognized. Most of the height of the fragment is thus consti-tuted by the maxilla. The ventral pro-file is slightly concave from end to end, possibly because of some degree of erosion at the medial portion of the ventral region. This concavity causes

the rostrum fragment to be lower at mid-length and higher at the proxi-mal and distal ends, with the latter apparently also curving dorsally (probably exaggerated due to erosion of this region).

Although also somewhat worn in the middle region (*i.e.*, possibly flatter than originally), the ventral surface is the better preserved region (Fig. 2C). The sutures between the vomer and the maxilla can barely be distin-

guished, but the ventral exposure of the vomer was surely wider near the proximal end (22 mm), narrower near the distal end (10 mm), and would widen again slightly towards the apex. Due to erosion of the antero-lateral margins, part of the paired canals that run through the inside of the rostrum are exposed on both sides at the anterior third of the fragment (26 mm apart). The left canal also pierces the fractured dorsal surface, indicating that the canals would incline noticeably to the ventral side towards the anterior region (the right canal reappears only at the proximal end of the fragment, due to the greater preserved height on this side). The only other recognizable structures on the ventral surface are two elongated shallow depressions located on both sides of the mid-line at mid-length of the fragment, which could represent the anterior ends of the palatine sulci.

As can be ascertained from the more complete proximal end, the rostrum would probably be elliptical to somewhat laterally compressed in cross section.

Discussion. The cylindrical to laterally compressed shape of the rostrum, together with the lack of dental alveoli and the strong mesorostral ossification of the vomer, readily identify MMRDC-R/2003/02/0841 as a portion of rostrum of Ziphiidae and, particularly, of the genus *Mesoplodon* Gervais, 1850.

A specific assignment is more difficult though, due to the fragmentary condition of the specimen. Isolated rostra are the most common fossils of Ziphiidae and, particularly, of *Mesoplodon* (Bianucci, 1997). Several species have been described based on incomplete rostra, most of which are not considered valid at present (see for instance Bianucci, 1997 about the numerous Italian specimens). A single fossil species, *M. longirostris* (Cuvier, 1823), has been consistently recognized by different authors in Neogene sediments exposed in several parts of the world: early Middle Miocene to Early Pliocene of Florida (Whitmore *et al.*, 1986; Morgan, 1994), the Early Pliocene of North Carolina (Whitmore, 1994), the Late Miocene (?) of Antwerp (not as frequently as thought by Abel, 1905, but surely present according to Lambert, 2005), the Pliocene of Italy (revised by Bianucci, 1997), and the Early Pliocene of Australia (Glaessner, 1947; Fordyce, 1982; Fitzgerald, 2004).

MMRDC-R/2003/02/0841 is similar to some of the specimens assigned to this extinct species in the referred literature (for instance Whitmore *et al.*, 1986 or Bianucci, 1997), namely in general dimensions, elliptical cross section, supposed elongation of rostrum, supposed exposure of vomer on dorsal surface and very pointed and anteriorly extending palatine sulci (if the paired depressions on the ventral surface do in fact correspond to those structures). However, due to its fragmentary condition, the Santa Maria rostrum can be safely assigned only to *Mesoplodon* sp., inasmuch as the taxon *M. longirostris* may also include more than one fossil species and constitute, in fact, a form species (Whitmore *et*

al., 1986; Morgan, 1994; Bianucci, 1997).

Suborder Mysticeti Flower, 1864
? Superfamily Balaenopteroidea (Gray, 1868) Mitchell, 1989
? Family Balaenopteridae Lacépède, 1804
Genus and species undetermined (Figs. 3A-D, 4A-B, 5A-F, 6A-B)

Material. MCM 108, a large medial portion of a right rib and two smaller fragments of ribs (occurrence SMI 3); MCM 114, a lumbar vertebra (occurrence SMI 4); and DBUA-F 163 and DBUA-F 401, two fragments of the same medial portion of a large rib (occurrence SMI 8).

Description. MCM 108 comprises a 137 mm long fragment of the medial region of a large right rib. At the proximal end, it measures 75 mm in greatest antero-posterior diameter and 42 mm in greatest transverse diameter. The fragment is partially encrusted in a block of matrix that
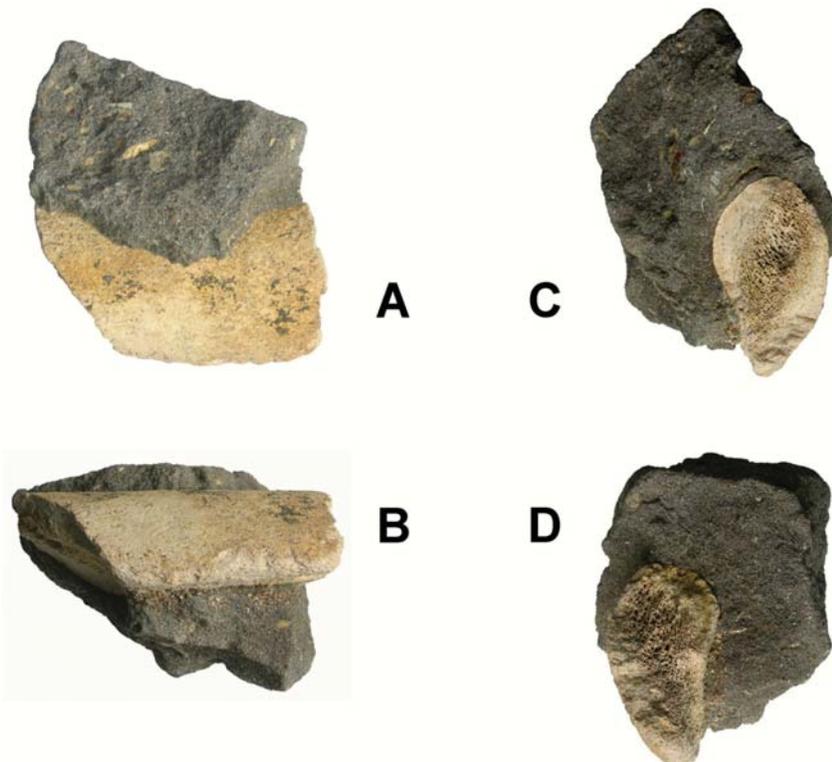
FIGURE 3. MCM 108, a medial portion of a large right rib assigned to ? Balaenopteridae indet. (occurrence SMI 3). A – Lateral view, B – Posterior view, C – Cross-section at proximal end, D – Cross-section at distal end. All ´ 0.25.
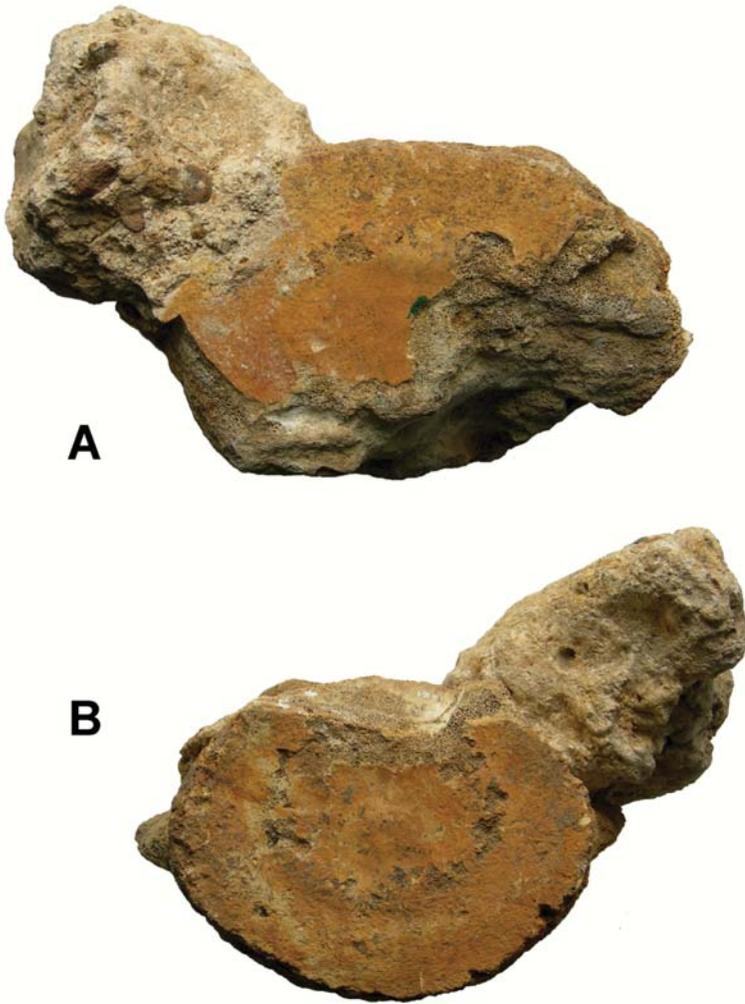
FIGURE 4. MCM 114, a lumbar vertebra assigned to ? Balaenopteridae indet. (occurrence SMI 4). A – Anterior view, B – Posterior view. All ´ 0.25.

covers most of its antero-medial surfaces, and is too short to allow the definite recognition of any longitudinal curvature (Fig. 3A-B). The shape of its cross-section changes somewhat from the proximal to the distal end. The proximal view shows a convex lateral surface and a concavo-convex medial surface, with the greatest diameter located near the anterior edge (Fig. 3C). The distal view also shows the greatest diameter nearer the anterior edge, but is more transversely compressed, with less convex

lateral and medial surfaces (Fig. 3D). Although eroded (Fig. 3B), the keel at the posterior edge is thus more acute than that at the anterior edge (Fig. 3C-D). The other two associated rib fragments of MCM 108 (smaller, more incomplete and not illustrated here) are also encrusted in blocks of matrix, and only partially exposed. Both have greatest measurable diameters between 40-42 mm, although the smallest is reduced to half of its diameter, showing the inner core of cancellous bone.

MCM 114 is a somewhat eroded, large-sized lumbar vertebra, which is essentially reduced to the centrum (Fig. 4A-B). As preserved, the main obtainable measurements are: 185 mm in greatest length and, at the pos-terior epiphysis, 180 mm in width and 125 mm in height (incomplete). Although too incomplete to be measured, as it lacks most of the left ven-tro-lateral region (Fig. 4A), the anteri-or epiphysis would be considerably larger than the better preserved pos-terior one, which maintains an ellipti-cal shape (Fig. 4B). Both are, however, fused to the centrum, thus indicating an adult individual. There is also a large block of matrix encrust-ing the right dorso-lateral surface of the vertebra, and covering most of the dorsal surface of the right trans-verse process. Both transverse processes are broken near their bases, barely projecting from the centrum. Otherwise, the vertebra is extensively eroded both on its dorsal and ventral
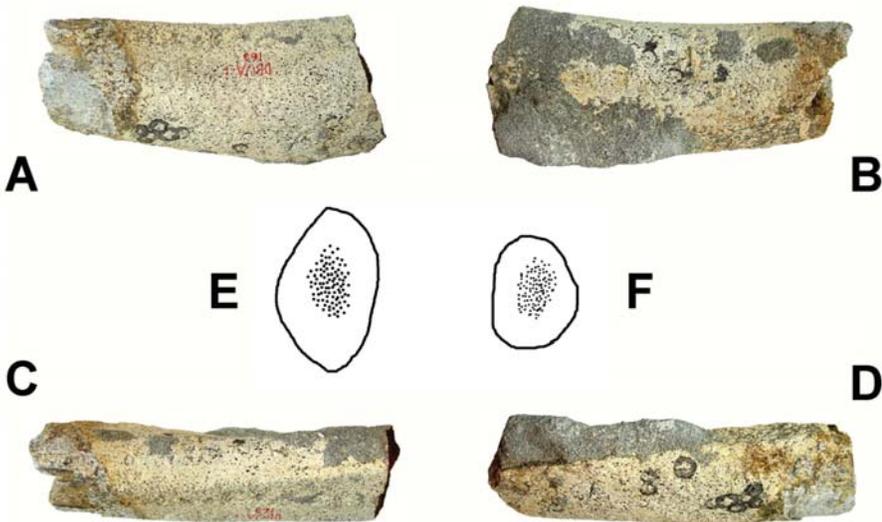

FIGURE 5. DBUA-F 163, the first recovered fragment of the large left rib assigned to ? Balaenopteridae indet. (part of occurrence SMI 8). A – Lateral view, B – Medial view, C – Anterior view, D – Posterior view, E – Schematic cross-section at proximal end, F – Schematic cross-section at distal end. All ´ 0.25.

surfaces, with no traces whatsoever of neither the neural arch nor the median keel.

DBUA-F 163 was the first fragment of the occurrence SMI 8 to be recovered, and seems to constitute a medio-distal portion of a large left rib. It measures approximately 196 mm in length, 84 mm in greatest antero-posterior diameter and 54 mm in greatest transverse diameter (both at the proximal end). The antero-posterior diameter tapers noticeably towards the distal end, mostly due to a strong curvature of the posterior edge (Fig. 5A-B). A gentle lateral bow is also noticeable in anterior or posterior views (Fig. 5C-D). Moderately acute keels run the whole length of both the anterior and posterior edges in a diagonal line, being somewhat more pronounced near the proximal end (Fig. 5C-D). The cross-section of the rib fragment changes in shape throughout its length, from fairly sigmoidal at the proximal end to approximately ovate at the distal end. (Fig. 5E-F). The surface of the fragment is somewhat corroded all over, and additionally covered by a great number of shallow, circular-shaped depressions, approximately 10 mm in diameter, that are most likely due to bioerosion.

DBUA-F 401 was the second fragment of the occurrence SMI 8 to be collected (Fig. 6A), and judging from its more robust cross-section (Fig. 6B), it seems to be the proximal continuation of DBUA-F 163. It is generally similar to the latter, even in the presence of the circular bioerosion markings, but shows an even more concavo-convex lateral and medial surfaces that, coupled with the different positions of the greatest convexities, further accentuates the sigmoidal shape of the cross-section (Fig. 6B).

Discussion. Both the large rib fragments and the isolated vertebra do not constitute significantly diagnostic elements, but at least a tentative familial assignment may be advanced. Although quite short, the rib portions MCM 108 and DBUA-F 163 + DBUA-F 401, as well as the MCM 114 vertebra, are all of considerable dimensions and would surely belong to some large-sized mysticete cetaceans. All are in fact compatible with the corresponding skeletal elements known for some members of the Balaenopteridae, a family with several fossil representatives in the North Atlantic region during the Messinian-Zanclean (see Deméré, 1986 and Deméré *et al.*, 2005). Consequently, only a familial and yet tentative assignment to ? Balaenopteridae indet. is here suggested for all three occurrences.

Cetacea indet.
Suborder undetermined (Figs. 7A-B, 8)
Material. Not located, some undetermined (limb?) bone(s) (occurrence SMI 1); MG/INETI unnumbered, 12 bone fragments, including some ribs, vertebrae? and other undetermined elements (occurrence SMI 2); DTP unnumbered, an undetermined vertebra (occurrence SMI 5); DBUA-F 123-13, an undetermined bone fragment (occurrence SMI 7); DBUA-F 194, a small rib fragment (occurrence SMI 9); and DBUA-F 402, a small rib fragment (occurrence SMI 10).

Description. The specimens listed above could either not be examined

FIGURE 6. DBUA-F 401, the second recovered fragment of the large left rib assigned to ? Balaenopteridae indet. (part of occurrence SMI 8), immediately after being collected. A – Lateral view, B – Cross-section at intermediate break. Scale given by handler's hands.

during this study or are too fragmentary and/or eroded to allow for detailed descriptions.

The material that corresponds to SMI 1 is impossible to locate (Estevens, 2006b), and thus can only be interpreted from the meagre information provided in the historic literature. Boid (1835) referred originally to an "immense fossil thigh-bone" and both Bedemar (1837) and Reiss (1862) reported that the bones, although not specified, were of large dimensions and had cancellous texture, descriptions also given by Zbyszewski & Ferreira (1962a). This, and the references to "whale" by Bedemar (1837) and Reiss (1862), suggest that these undetermined remains may have consisted of some large (limb?) cetacean bone (or bones?).

FIGURE 7. DBUA-F 194, a small rib fragment assigned to Cetacea indet. (occurrence SMI 9). A – Outer view, B – Inner view. All ´ 1.

The vertebra that constitutes the occurrence SMI 5 is deposited in a private collection (DTP) and could not be directly examined during this study, but according to indirect accounts (Patrícia Madeira) is of large dimensions and may be also assigned to a cetacean.

Specimens deposited in the DBUA-F collection are all too fragmentary and can only be superficially described. DBUA-F 194 and DBUA-F 402 can both be recognized as small fragments of ribs, reduced to about half of its width, where the inner core of cancellous bone may be distinguished from the more compact outer cortex (Fig. 7A-B). DBUA-F 123-13, on the other hand, is reduced to a mere fragment of rather cancellous, internal bone, not definitely assignable to any particular skeletal element.

Most of the bones grouped under MG/INETI unnumbered are quite eroded and reduced to rather small sizes (Fig. 8), and not all can be assigned to particular skeletal elements. Some seem to be small fragments of ribs (between 31 and 59 mm long), mostly preserving only the outer, denser cortical layer of bone, with little of the inner core of cancellous bone remaining (mid-upper row and middle row in Fig. 8). Others, although larger (60 to 97 mm in greatest length), are notably cancellous all over and essentially shapeless due to erosion (upper left and right corners in Fig. 8). Still, the presence of apparent foramina in one of them suggests that they could consist of eroded vertebral centra, which could be the basis for Cotter's (1888-92) reference
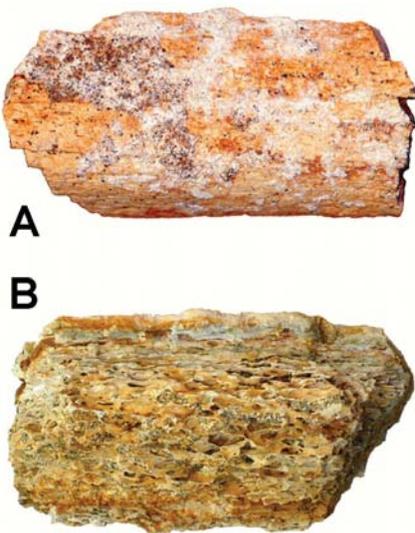
FIGURE 8. MG/INETI unnumbered, vertebral? and rib fragments assigned to Cetacea indet. (occurrence SMI 2). Scale bar = 10 cm.

to both "ribs and vertebrae" among this association. The larger and most important element is a somewhat eroded medial portion of a rib, diagonally fractured in two separate fragments (lower row in Fig. 8). This 200 mm long portion of rib is noticeably curved longitudinally and slightly compressed transversely, with greater and lesser preserved diameters at mid-length of 40 mm and 32 mm, respectively. Most notable, and quite the opposite of the remaining rib fragments, this specimen shows a comparatively more cancellous cortical layer (5 mm in width), surrounding a noticeably osteosclerotic inner core of bone with few macroscopically visible canals throughout its entire

preserved length. Such features of the ribs, most likely responsible for the better preservation of this fragment, have previously been recorded among cetaceans only in some Eocene archaeocetes and a few Oligocene archaic mysticetes (summarized in Fordyce & Watson, 1998), with no definite records among post-Paleogene cetaceans and, even less, Late Neogene ones.

Discussion. Such fragmentary material obviously lacks the diagnostic characters that may allow detailed classification, but the overall cancellous nature of most of the bones (with the notable exception of the osteosclerotic rib fragment in MG/INETI

unnumbered), and the inferred large size of several elements, suggests a most probable assignment to Cetacea indet.

PALEOECOLOGICAL AND PALEOBIOGEOGRAPHICAL CONSIDERATIONS

Albeit limited, the fossils from Santa Maria provide an opportunity to draw some preliminary considerations, regarding the palaeoecology of the Messinian-Zanclean seas of this region and the palaeobiogeographic relationships of its cetacean faunas.

Regarding palaeoecological conditions, it is noteworthy that the most significant fossil occurrences belong to groups whose living representatives are mostly pelagic, such as large baleen and beaked whales (mostly Balaenopteridae and Ziphiidae), all typical inhabitants of deep and open ocean waters (Fordyce & Muizon, 2001) and still present around the Azores today (Reiner *et al*., 1993). This suggests that the Late Neogene Azorean seas, much like today, were well separated from the continental shelf, thus allowing for these pelagic species to come rather close to the island coast.

Although meagre, the Azorean fossil record also increases our knowledge of Late Neogene (8-3 Ma) eastern mid-Atlantic cetaceans, and builds on the correlative record known from the Portuguese mainland, which consist only of fragmentary remains of undetermined odontocetes and mysticetes (Estevens, 2006b, 2006c).

Regarding palaeobiogeographic relationships, the Azorean fossil fauna may prove to be quite relevant in the establishment of correlations within the North Atlantic realm, mostly due to the strategic mid-oceanic location of the archipelago. At the moment, and pending further discoveries, tentative comparisons may be established with such approximately contemporaneous (Messinian-Zanclean) faunas as those from the Eastover (» 7.2-6.1 Ma) and Yorktown (» 4.8-3.0 Ma) formations from the Middle Atlantic Coastal Plain (Gottfried *et al*., 1994; Whitmore, 1994); the Palmetto Fauna (» 5.2-4.5 Ma) from Florida (Morgan, 1994; Hulbert *et al*., 2001); and the Kattendijk (» 5.0-4.4 Ma) and Lillo (» 4.2-2.6 Ma) formations from Belgium (Hampe, 1996; Deméré *et al*., 2005). Although unevenly studied, all of these associations share a noticeable modern character, being largely dominated by living groups such as the rorquals (Balaenopteridae) and right whales (Balaenidae) among the mysticetes, and true dolphins (Delphinidae) and beaked whales (Ziphiidae) among the odontocetes, somewhat like the meagre Azorean fossil fauna described in this paper.

CONCLUSIONS

The scarce record of fossil cetaceans herein reported indicates that more significant remains may be expected to be found in the Late Neogene marine sediments of Santa Maria Island. The fact that four out of the ten known occurrences resulted from recent expeditions to the island suggests that this is, indeed, a promising area. The discov-

ery of more complete cetacean remains would be rather important, considering the geographic position of the Azores, and the potential for varied palaeobiogeographic correlations within the North Atlantic realm. The particular stratigraphic interval sampled (Messinian-Zanclean) is also relevant, since it constitutes one of the periods whose cetacean faunas are poorly known within the North Atlantic. Finally, and just as interesting, is the role played by these whale fossils in the local folklore and history of Santa Maria Island, popular references of which may be traced back a few centuries.

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REFERENCES

ABDEL-MONEM, A.A., L.A. FERNANDEZ & G.M. BOONE, 1968. Pliocene-Pleistocene minimum K-Ar ages of the older eruptive centres, Eastern Azores (abstract). *Transactions of the American Geophysical Union*, 49(1): 363.

ABDEL-MONEM, A.A., L.A. FERNANDEZ & G.M. BOONE, 1975. K-Ar ages for the eastern Azores group (Santa Maria, São Miguel and the Formigas islands). *Lithos*, 8: 247-254.

ABEL, O., 1905. Les Odontocètes du Boldérien (Miocène supérieur) d'Anvers. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 3: 1-155.

AGOSTINHO, J., 1937. Sobre a tectónica da ilha de Santa Maria. *Açoreana*, 1(4): 281-285.

ANONYMOUS, 1838. Resumo de observações geologicas feitas em uma viagem ás ilhas da Madeira Porto Santo e Açores nos annos de

1835 e 1836. *The North American Review*, 46(99): 366-386.

BEDEMAR, V. de, 1837. *Resumo de observações geologicas feitas em uma viagem ás ilhas da Madeira Porto Santo e Açores nos annos de 1835 e 1836*, 25 p. Impressão de Galhardo Irmãos, Lisboa.

BEDEMAR, V. de, 1889. Resumo de observações geologicas, feitas em uma viagem ás ilhas da Madeira, Porto Santo e Açores nos annos de 1835 e 1836. *Archivo dos Açores*, 10(58): 289-296.

BEDEMAR, V. de, 1982. Resumo de observações geologicas, feitas em uma viagem ás ilhas da Madeira, Porto Santo e Açores nos annos de 1835 e 1836. *Arquivo dos Açores*, 10: 289-296. (fac-simile reproduction)

BIANUCCI, G., 1997. The Odontoceti (Mammalia, Cetacea) from Italian Pliocene. The Ziphiidae. *Paleontographia Italica*, 84: 163-192.

BOID, E., 1835. *A description of the Azores or Western Islands*, 373 p. Edward Churton, London.

COTTER, J.C.B., 1888-92. Noticia de alguns fosseis terciarios da Ilha de Santa Maria no archipelago dos Açores. *Communicações da Commissão dos Trabalhos Geologicos de Portugal*, 2: 255-287.

DEMÉRÉ, T.A., 1986. The fossil whale, *Balaenoptera davidsonii* (Cope, 1872), with a review of other Neogene species of *Balaenoptera* (Cetacea: Mysticeti). *Marine Mammal Science*, 2(4): 277-298.

DEMÉRÉ, T.A., A. BERTA & M.R. McGOWEN, 2005. The taxonomic and evolutionary history of fossil and modern balaenopteroid mysticetes. *Journal of Mammalian Evolution*, 12(1-2): 99-143.

COTTER, J.C.B., 1953. Notícia de alguns Fósseis Terciários da Ilha de Santa Maria. *Açoreana*, 5(1): 71-101.

ESTEVENS, M., 1998. Mamíferos marinhos do Neogénico de Portugal. Distribuição geográfica e estratigráfica. *Comunicações do Instituto Geológico e Mineiro*, 84(1): A161-A164.

ESTEVENS, M., 2006a. Fossil whales from the Azores. *Program and Abstracts, Atlantic Islands Neogene International Congress*, pp. 13-14. Marine Palaeo-Biogeography Working Group, Ponta Delgada.

ESTEVENS, M., 2006b. *Mamíferos marinhos do Neogénico de Portugal*, 369 p. PhD Dissertation, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Lisboa.

ESTEVENS, M., 2006c. Evolução das faunas de mamíferos marinhos do Neogénico de Portugal: correlações paleoambientais e paleobiogeográficas. *In*: MIRÃO, J. & A. BALBINO (coords.), *VII Congresso Nacional de Geologia. Resumos alargados. Volume II*, pp. 713-716. Pólo de Estremoz da Universidade de Évora, Évora.

FERAUD, G., I. KANEOKA & C.J. ALLÈGRE, 1980. K/Ar ages and stress pattern in the Azores: geodynamic implications. *Earth and Planetary Science Letters*, 46: 275-286.

FERAUD, G., H.-U. SCHMINCK, J. LIETZ, J. GOSTAUD, G. PRITCHARD & U. BLEIL, 1984. New K-Ar ages, chemical analyses and magnetic data of rocks from the islands of Santa Maria (Azores),

Porto Santo and Madeira (Madeira Archipelago) and Gran Canaria (Canary Islands). *Arquipélago, Série Ciências da Natureza*, 5: 213-240.

FERREIRA, O. da V., 1955. A fauna miocénica da Ilha de Santa Maria (Açores). *Comunicações dos Serviços Geológicos de Portugal*, 36: 9-44.

FITZGERALD, E.M.G., 2004. A review of the Tertiary fossil Cetacea (Mammalia) localities in Australia. *Memoirs of Museum Victoria*, 61(2): 183–208.

FORDYCE, R.E., 1982. A review of Australian fossil Cetacea. *Memoirs of the National Museum of Victoria*, 43: 43-58.

FORDYCE, R.E. & C. de MUIZON, 2001. Evolutionary history of cetaceans: a review. *In*: MAZIN, J.-M. & V. DE BUFFRÉNIL (eds.), *Secondary Adaptation of Tetrapods to Life in Water*, pp. 169-233. Verlag Dr. Friedrich Pfeil, München.

FORDYCE, R.E. & A.G. WATSON, 1998. Vertebral pathology in an Early Oligocene whale (Cetacea, ?Mysticeti) from Wharekuri, North Otago, New Zealand. *Mainzer naturwissenschaftliches Archiv/Beiheft*, 21: 161-176.

GLAESSNER, M.F., 1947. A fossil beaked whale from Lakes Entrance, Victoria. *Proceedings of the Royal Society of Victoria*, 58(1-2): 25-35.

GOTTFRIED, M.D., D.J. BOHASKA & F.C. WHITMORE, Jr., 1994. Miocene cetaceans of the Chesapeake Group. *In*: BERTA, A. & T.A. DEMÉRÉ (eds.), *Contributions in Marine Mammal Paleontology Honoring Frank C. Whitmore, Jr.*

Proceedings of the San Diego Society of Natural History, 29: 229-238.

HAMPE, O., 1996. Ein artikuliertes Bartenwalskelett aus dem Neogen (?Uedem-Schichten, Obermiozän) der Niederrheinischen Bucht (NW-Deutschland) und seine systematische Stellung innerhalb der Mysticeti (Mammalia: Cetacea). *Decheniana*, 33: 1-75.

HARTUNG, G., 1860. *Die Azoren in ihrer äusseren Erscheinung und nach ihrer geognostichen Natur*, 350 p. Engelmann, Leipzig.

HARTUNG, G., 1864. *Geologisch Beschreibung der Inseln Madeira, Porto Santo und Santa Maria*, 285 p. Engelmann, Leipzig.

HULBERT, R.C., Jr., G.S. MORGAN & A.E. PRATT, 2001. Whales and dolphins. *In*: HULBERT, R.C., JR. (ed.), *The Fossil Vertebrates of Florida*, pp. 322-330. University Press of Florida, Gainesville.

KREJCI-GRAF, K., J. FRECHEN, W. WETZEL & G. COLLOM, 1958. Gesteine und Fossilien von den Azoren. *Senckenbergiana Lethaia*, 39(5-6): 303-351.

LAMBERT, O., 2005. Systematics and phylogeny of the fossil beaked whales *Ziphirostrum* du Bus, 1868 and *Choneziphius* Duvernoy, 1851 (Mammalia, Cetacea, Odontoceti), from the Neogene of Antwerp (North of Belgium). *Geodiversitas*, 27(3): 443-497.

MEAD, J.G., 1989. Beaked whales of the genus *Mesoplodon*. *In*: RIDGWAY, S.H. & R. HARRISON (eds.), *Handbook of Marine Mammals. Vol. 4. River dolphins and the larger toothed whales*, pp. 349-430. Academic Press.

MORGAN, G.S., 1994. Miocene and Pliocene marine mammal faunas from the Bone Valley Formation of central Florida. *In*: BERTA, A. & T.A. DEMÉRÉ (eds.), *Contributions in Marine Mammal Paleontology Honoring Frank C. Whitmore, Jr. Proceedings of the San Diego Society of Natural History*, 29: 239-268.

REINER, F., J.M. GONÇALVES & R.S. SANTOS, 1993. Two new records of Ziphiidae (Cetacea) for the Azores with an updated checklist of cetacean species. *Arquipélago, Life and Marine Sciences*, 11A: 113-118.

REISS, W., 1862. Mittheilungen über die tertiären Schichten von Santa Maria, der südlichsten der Azoren, und ihre organischen Einschlüsse. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefacten-Kunde*, Jahrgang 1862: 1-22.

SERRALHEIRO, A., 2003. A geologia da Ilha de Santa Maria, Açores. *Açoreana*, 10(1): 141-192.

SERRALHEIRO, A. & J. MADEIRA, 1993. Stratigraphy and geochronology of Santa Maria Island (Azores). *Açoreana*, 7(4): 575-592.

SILVA, M.A., R. PRIETO, S. MAGALHÃES, R. CABECINHAS, A. CRUZ, J.M. GONÇALVES & R.S. SANTOS, 2003. Occurrence and distribution of cetaceans in the waters around the Azores (Portugal), Summer and Autumn 1999-2000. *Aquatic Mammals*, 29(1): 77-83.

TEIXEIRA, C., 1950. Notas sobre a geologia das Ilhas Atlântidas. *Anais da Faculdade de Ciências do Porto*, 23(3-4): 193-233.

WHITMORE, F.C., Jr., 1994. Neogene climatic change and the emergence of the modern whale fauna of the North Atlantic ocean. *In*: BERTA, A. & T.A. DEMÉRÉ (eds.), *Contributions in Marine Mammal Paleontology Honoring Frank C. Whitmore, Jr. Proceedings of the San Diego Society of Natural History*, 29: 223-227.

WHITMORE, F.C., Jr., G.V. MOREJOHN & H.T. MULLINS, 1986. Fossil beaked whales - *Mesoplodon longirostris* dredged from the ocean bottom. *National Geographic Research*, 2(1): 47-56.

ZBYSZEWSKI, G., 1962. Contribution à la connaissance de la géologie du district de Ponta Delgada (Açores). *Estudos científicos oferecidos em homenagem ao Prof. Doutor J. Carríngton da Costa*, pp. 665-709. Junta de Investigações do Ultramar, Lisboa.

ZBYSZEWSKI, G. & O. da V. FERREIRA, 1962a. Étude géologique de l'île de Santa Maria (Açores). *Comunicações dos Serviços Geológicos de Portugal*, 46: 209-245.

ZBYSZEWSKI, G. & O. da V. FERREIRA, 1962b. La faune miocène de l'île de Santa Maria (Açores). *Comunicações dos Serviços Geológicos de Portugal*, 46: 247-291.

ZBYSZEWSKI, G., O. da V. FERREIRA & C.T. de ASSUNÇÃO, 1961. *Carta Geológica de Portugal na escala 1/50 000. Notícia explicativa da folha de Ilha de Santa Maria (Açores)*, 28 p. Serviços Geológicos de Portugal, Lisboa.