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SUPPLEMENTARY ONLINE MATERIAL FOR

Youngest record of the extinct walrus *Ontocetus emmonsi* from the Early Pleistocene of South Carolina and a review of North Atlantic walrus biochronology

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Supplementary Online Material

SOM 1. Occurrence and age of *Ontocetus emmonsi* specimens from the North Atlantic.
SOM 2. Occurrence and age of *Odobenus rosmarus* specimens from the North Atlantic.

SOM 1

Occurrence and age of *Ontocetus emmonsi* specimens from the North Atlantic.

Yorktown Formation, Virginia and North Carolina, USA.—The largest available sample of *Ontocetus emmonsi* specimens including cranial fragments, tusks, teeth, mandibles, and postcrania has been reported from the Yorktown Formation of Virginia and North Carolina, chiefly from the Lee Creek Mine (Berry and Gregory 1906; Kohno and Ray 2008). According to Ward (2008), the majority of vertebrate fossils from the Yorktown Formation within the mine originate from the basal Sunken Meadow Member; vertebrates are numerically less abundant and less diverse from the overlying Rushmere Member, and rare in the Morgarts Beach and Moore House Members; this observation was independently made by Whitmore and Kaltenbach (2008) for cetacean specimens. Unfortunately, Kohno and Ray (2008) provided no finer intraformational stratigraphic control. The Yorktown Formation has produced a terrestrial mammal assemblage (Eshelman and Whitmore 2008) correlative with the late Hemphillian (Hh3–Hh4), indicating an age of 6.8–4.6 Ma (Tedford et al. 2004). Strontium isotope dates from the Yorktown Formation range in age from 4.6–2.8 Ma (Browning et al. 2009). Ostracods of the *Orionina vaughani* Zone (Hazel 1981); this zone corresponds to the better dated planktonic foraminiferal zones N19–N20 of Blow (1969) and calcareous nannoplankton zones NN13–NN15 (Hazel 1981), and in Virginia this ostracod zone is associated with a 4.4 Ma K/Ar date derived from glauconite (Hazel 1983). Further foraminiferal biostratigraphy by Dowsett and Wiggs (1992) reported foraminifera indicating correlation with zones PL1b–PL3 of Berggren (1973), indicating an age of 5.67–3.16 Ma (Gradstein et al. 2012). Zones N19–N20 correspond to an age of 5.53–3.35 Ma (Gradstein et al. 2012). Calcareous nannoplankton zones NN13–NN15 correspond to an age of 5.12–3.92 (Gradstein et al. 2012). These dates support a Zanclean age and finest age control is provided by $^{87}Sr/^{86}Sr_a$ (maximum) and calcareous nannoplankton (minimum) and indicating the Yorktown Formation assemblage is 4.9–3.92 Ma in age.

Goose Creek Limestone and/or Raysor Formation, South Carolina, USA.—Kohno and Ray (2008: 48) referred a tusk, mandible, and astragalus to *Ontocetus emmonsi* from the Raysor Formation exposed at Cross Quarry in Berkeley County, South Carolina. Confusingly, they referred to this unit as the "Goose Creek coarse sands of the Raysor Formation". Both units are exposed within the quarry (Tseng and Geisler 2016), with the underlying Goose Creek Limestone dating to 3.9–3.6 Ma based on nannoplankton indicating zone NN16–NN14, and the Raysor Formation dating to 3.6–3.1 Ma based on planktonic foraminifera corresponding to zone PL3 (Tseng and Geisler 2016, and references therein). These units within Cross Quarry are thus 3.9–3.1 Ma in age. Other specimens have been questionably identified as originating from the Goose Creek Limestone (Kohno and Ray 2008), including specimens from the Austin Sand Pit which are not from the Goose Creek Limestone.

?Canepatch Formation.—In South Carolina the Canepatch Formation has yielded Uranium series dates from corals indicating an age of 0.57–0.3 Ma (McCartran et al. 1982). According to Kohno and Ray (2008), these specimens are likely reworked and are not considered further.

Bone Valley Formation (Palmetto Local Fauna), Florida, USA.—Tusks of *Ontocetus emmonsi* were originally reported by Morgan (1994) as *Trichecodon huxleyi* and additional specimens were referred and described by Kohno and Ray (2008). Land mammals from the Bone Valley Formation correlate the Palmetto Local Fauna with the latest Hemphillian (Hh4) NALMA (Wallace and Hulbert 2013), corresponding to an age of 5.8–4.6 Ma (Tedford et al. 2004).

Lower Tamiami Formation, Florida, USA.—Tusks, a partial rostrum, and humerus have been reported from the Tamiami Formation by Ray (1960), Morgan (1994), and Kohno and Ray (2008); according to Kohno and Ray (2008: 43), all specimens are from Bed 11 of the Tamiami Formation. Bed 11 is equivalent in age to the Sunken Meadow Member of the Yorktown Formation (Allmon et al. 1996), and Williams et al. (2009) assigned an age of 3.9–4.2 Ma.

Pinecrest Beds of the Tamiami Formation, Florida, USA.—Tusks and a mandible from the Pinecrest Beds of the Tamiami Formation were referred to *Ontocetus emmonsi* by Kohno and Ray (2008). Beds 2–10 of the Tamiami Formation are known as the Pinecrest Beds; stratigraphic positions (e.g., bed number) were not specified by Kohno and Ray (2008). A more precise date would be possible with higher stratigraphic precision for *Ontocetus emmonsi* specimens. The Pinecrest Beds range in age from 2–3.5 Ma based upon (Jones et al. 1991).

Westkapelle and/or Brielle Ground Formation, Netherlands.—A number of different specimens of *Ontocetus emmonsi* collected from estuaries and the floor of the North Sea have been reported including crania, tusks, mandibles, and postcrania (Erdbrink and Van Bree 1990; 1999a, b, c; Van Deinse 1944; Van der Feen 1968). These occurrences were attributed, without justification, to the Ijmuiden Ground Formation by Kohno and Ray (2008). Post and Bosselaers (2005) remarked, without citation, that "*Alachtherium cretsii*" (= *Ontocetus emmonsi*) and other marine mammals collected from the seafloor, rivers, and estuaries in the vicinity of the mouth of the river Scheldt are probably older than the Ijmuiden Ground Formation and likely derive from the Westkapelle Ground Formation. Furthermore, in this region, the upper Pliocene Brielle Ground Formation is present in the subsurface and is the oldest possible unit for which locally occurring marine mammal fossils may be derived from (Post and Bosselaers 2005). The Westkapelle Ground Formation is correlated with the Praetiglian and early Tiglian Dutch pollen stages (King 2016). The overlying Ijmuiden Ground Formation has yielded late Tiglian (C4c) pollen assemblages (King 2016). The underlying Brielle Ground Formation is Reuverian, providing a maximum age of 3.4 Ma for the assemblage (King 2016); the Westkapelle Ground Formation is 2.1 Ma at the youngest (King 2016), providing an age of 3.4–2.1 Ma.

Lillo Formation, Belgium.—The earliest reported specimens of *Ontocetus emmonsi* (originally referred to *Alachtherium antwerpiensis*, *Alachtherium cretsii*, *Odobenus antverpiensis*, and *Odobenus koninckii*; see Kohno and Ray 2008: 45, 56–58) were reported from the "Scaldisian sands" of Belgium (Van Beneden 1871, 1877; Hasse 1909, 1911; Rutten 1907). These fossils are now understood to have been collected from the Lillo Formation rather than the underlying Kattendijk Formation (Kohno and Ray 2008). Dating for the Lillo Formation is sparse but benthic foramina indi-

cate correlation with zone NS44 and diatoms indicate correlation with zone DP2, providing an age of 3.71–2.5 Ma (De Schepper et al. 2009; King 2016). An *Odobenus*-like mandible (see Deméré 1994a) fragment referred to *Odobenus koninckii* by Van Beneden (1877) apparently originated from the Lillo Formation as well, but is in need of redescription and stratigraphic reassessment in order to demonstrate a pre-late Pleistocene occurrence of *Odobenus* in the North Atlantic.

Red Crag, East Anglia, UK.—Isolated tusks of *Ontocetus emmonsi* (originally reported as *Trichecodon huxleyi*) from the Red Crag in East Anglia (chiefly Suffolk) are some of the earliest reports of fossil walruses (Lankester 1865, 1880, 1882). These specimens are often heavily mineralized and typically found near the base of the Red Crag (Kohno and Ray 2008). Other large, dense and similarly preserved vertebrate fossils (e.g., teeth of *Carcharocles megalodon* and the early–mid Miocene odontocete *Squalodon*) occur at the base (Newton 1881; Donovan 1988; King 2016), suggesting reworking from earlier deposits (erosional vacuity) or that the specimens date to the period of depositional hiatus. The Red Crag unconformably overlies the lower Pliocene Coralline Crag to the north and oversteps onto the Eocene London Clay in the south, raising the possibility for significant erosion of Cenozoic fossils (King 2016). Vertebrates occur within the underlying Coralline Crag as well (Newton 1891) and this unit could be a source of reworked tusks of *Ontocetus emmonsi* as it is contemporaneous with the Yorktown Formation (e.g., King 2016). However, the stratigraphically lowest tusks occur within the "nodule bed" at the base of the Red Crag (Newton 1891: 18). Therefore, we suggest that tusks of *Ontocetus emmonsi* likely date to the lacuna between the Coralline Crag and Red Crag. Based on diatoms, calcareous nannoplankton, and foraminifera, the Coralline Crag is 3.7–3.5 Ma in age (King 2016). The age of the basal nodule bed of the Red Crag is unknown (but younger than the Coralline Crag); pollen indicate correlation with the Reuverian B–C stage (~2.6 Ma), diatoms indicate correlation with zone DP4, and foraminifera correspond to zones NS44–45 (~3–1.9 Ma; King 2016, and references therein). In summary, allochthonous or parautochthonous specimens from the Red Crag are likely 3.7–1.9 Ma in age.

Norwich Crag, East Anglia, UK.—A tusk and mandible of *Ontocetus emmonsi* were referred from the Norwich Crag by Kohno and Ray (2008) without citation. Newton (1882: 26–28, pl. 5) reported tusks from the "Forest Bed" which is a horizon within the Norwich Crag. Foraminifera correlate the Norwich Crag with zones NS44–46, and Pollen indicates correlation with the the Dutch Tiglian TC3; other fossils correspond to the Bramertonian and Baventian stages (King 2016) which lack precise boundary dates. However, these British stages correspond to the Dutch Tiglian Stage, which is 2.2–1.7 Ma in age (Westerhoff 2009). An age of 2.2–1.7 Ma is assigned to the Norwich Crag.

Ahl al Ouglam, Morocco.—The southernmost record of walruses in the eastern North Atlantic is from the Ahl al Oughlam locality near Casablanca in Morocco, originally named *Alachtherium africanus* (Geraads 1997) but declared a junior synonym of *Ontocetus emmonsi* by Kohno and Ray (2008). No microfossil biochronology or absolute dates are available, but terrestrial mammals indicate an age of approximately 2.5 Ma (Geraads 2006).

SOM 2

Occurrence and age of *Odobenus rosmarus* specimens from the North Atlantic.

Countless records of *Odobenus* have been reported from the North Atlantic and Arctic, and many with poor geochronologic control. Many specimens were derived from strata without associated fauna, dredged from the sea floor, or found isolated on beaches. Many records are radiocarbon dated; however, with a maximum dating range of 40 Ka, the utility of radiocarbon dates is quite limited for older specimens. We focused on records with geologic context, and in some cases, dredged assemblages containing mammalian index fossils. Many occurrences in the literature are simply reported as "Pleistocene" without further thought. In other situations, stratigraphic study and subdivision of local rocks was not formalized until decades or even a century after fossil occurrences were reported (e.g., Ray 1975) and retroactive assignment of specimens to a particular unit is speculative at best.

Pleistocene strata, New Jersey, USA.—The holotype of *Hemicaulodon effodiens* was regarded to be a specimen of *Odobenus rosmarus* by Ray (1975). The specimen is lost, and was collected prior to modern stratigraphic study of the New Jersey coastal plain. Because the holotype is lost and the host stratum unknown (speculated to be the Plio-Pleistocene Pensauken Formation by Ray 1975), it is not considered further.

Acredale Formation, Virginia, USA.—Specimens of *Odobenus rosmarus* were reported (but not described or figured) from the Kempsville Member of the Acredale Formation of Virginia by Spencer and Campbell (1987), and described in depth by Ray et al. (1968). The Kempsville member was correlated with marine isotope stage 5 (0.08–0.13 Ma), late Pleistocene (Spencer and Campbell 1987).

Unnamed deposit at Chincoteague Island, Virginia, USA.—A specimen of *Odobenus rosmarus* reported by Manville and Wilson (1970) from Chincoteague Island, Virginia, yielded a radiocarbon date of 15 Ka.

Unnamed deposit at Edisto Island, South Carolina, USA.—Cranial fragments of *Odobenus rosmarus* have been reported from an unnamed Pleistocene deposit at Edisto Island (Ray et al. 1968; Roth and Laerm 1980). These finds are isolated on the beach and include occasional Oligocene and Pliocene specimens, but Pleistocene specimens all share similar preservation and come from an unnamed deposit just offshore. This deposit yields Rancholabrean NALMA correlative mammals and was estimated at 10–50 Ka in age by Sanders (2002) who also reported an experimental 40 Ka amino acid racemization date from turtle (*Pseudemys*) shell.

Ten Mile Hill Beds, Charleston, South Carolina, USA.—A single fragmentary tusk of *Odobenus* sp. was reported by Sanders

(2002) from the Ten Mile Hill Beds near Summerville, SC. The Ten Mile Hill Beds were deposited during marine isotope stage 7 (Weems et al. 1994), indicating an age of 244–190 Ka.

Wando Formation, Charleston, South Carolina, USA.—A number of tusks of *Odobenus* were reported by Sanders (2002) from several localities in the vicinity of Charleston, SC. The Wando Formation was deposited entirely within marine isotope stage 5 (Weems et al. 1994), indicating an age of 130–80 Ka.

Unnamed deposit, Cedar Creek Marina, South Carolina, USA.—A tusk fragment of *Odobenus rosmarus* was reported by Sanders (2002) from unnamed Pleistocene shelly deposits in Horry Co., South Carolina. Sanders (2002) speculated that the unit (now covered) was the Socastee Formation. According to Weems (in Sanders 2002) the Socastee is Sangamonian and likely about 120 Ka in age.

Unnamed deposit, Atlantic City, New Jersey, USA.—A partial skull with tusks of *Odobenus rosmarus* was reported by Gallagher et al. (1989) along with Rancholabrean correlative mammals including *Bison* and *Rangifer*. This indicates a maximum age of 0.23 Ma, though Gallagher et al. (1989) suggested a Wisconsinan age instead. We tentatively use the broader 230–11 Ka age instead.

Various unnamed late Pleistocene deposits, Quebec, Labrador, Newfoundland.—A number of late Pleistocene localities with unnamed host strata have yielded modern walrus specimens in Arctic and Atlantic Canada, recently summarized by Dyke et al. (1999), and have reported radiocarbon dates of <1 Ka to >40 Ka (late Pleistocene to Holocene).

Various occurrences reported by Hay (1923).—A number of Pleistocene occurrences of *Odobenus* were reported by Hay (1923) but few are useful here given the lack of stratigraphic, biostratigraphic, or geochronologic details reported. One specimen from Gardiner, Maine, was reported with *Bison*, a Rancholabrean index fossil thus indicating an age of 230–11 Ka.

Hamburg, Germany.—An occurrence of *Odobenus* rosmarus was reported by Kurten (1964) along with polar bear fossils, from strata correlated with the Wurm glaciation (latest Pleistocene).

Various occurrences reported by Kardas (1965).—Numerous records of *Odobenus* were reported from western Europe and Iceland by Kardas (1965), mostly reported as Pleistocene or late Pleistocene with little stratigraphic data.

Dredged walrus specimens, North Sea.—*Odobenus rosmarus* fossils are well known from North Sea dredgings, and unfortunately, few are known with any geochronologic control. Some are radiocarbon dated with dates as old as 50 Ka (Post 1999; Mol et al. 2006). A series of papers by Erdbrink and Van Bree (1986, 1999a, b, c) synonymized all European walruses into *Odobenus* and included confusing discussions of possible stratigraphic origin, conflating Pliocene sources of *Ontocetus* specimens (see above) with younger rocks. Few specimens are known with good geochronologic control. Several are considered to originate from the Westkapelle or Ijmuiden ground formations, which are late Pliocene; the former of which is the probable source of some *Ontocetus* specimens (see above). However, owing to the synonymy of genera by these authors and nondiscrimination between specimens and localities, it is difficult to say much further about dredged North Sea *Odobenus*.

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