

New fossils of Sirenia from the Middle Eocene of Navarre (Western Pyrenees): the oldest West European sea cow record

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Abstract – Postcranial remains of Sirenia from the early Middle Eocene (late Lutetian) Urbasa-Andia Formation of Navarre (Western Pyrenees) are described. The material consists of two partial atlas vertebrae, one humerus and several dorsal ribs (from Arrasate, Urbasa plateau), and partial dorsal ribs (from Lezaun, Andia plateau). The morphology of the fossils is consistent with referral to Dugongidae, the only sirenian

clade known so far in the Middle Eocene of Europe. Moreover, the histological study of the ribs shows that the pachyosteosclerosis of extant Sirenia was definitively present by the early Middle Eocene. The oldest sirenian remains reported to date in the Pyrenean Realm were assigned to the Biarritzian, a regional stage that is currently adscribed either to the middle or to the lower-middle Bartonian. Therefore, the sirenian remains of Lezaun, reliably dated as late Lutetian (SBZ16 zone) in age, are definitively the earliest sirenian fossils known in Western Europe and are among the oldest sea cow record of Europe.

Keywords: Sirenia, Middle Eocene, Lutetian, Navarre, Iberian Peninsula.

1. Introduction

Eocene sea cows (Sirenia) have a pan-Tethyan distribution. Most of the occurrences of Eocene sirenians correspond to Old and New World records, with other localities in Africa, Indo-Pakistan and possibly Java (see Domning, Morgan & Clayton, 1982; Sagne, 2001; C. Sagne, unpub. Ph.D. thesis, Mus. Natl. Hist. Nat., Paris, 2001). The oldest and more basal sirenians (*Prorastomus*, *Pezosiren*) come from the early Middle Eocene of Jamaica and have been referred to the Prorastemidae (Savage, Domning & Thewissen, 1994; Domning, 2001), which is regarded as a paraphyletic taxon (Gheerbrant, Domning & Tassy, 2005). Sirenians probably diversified in the Early Eocene, paralleling the diversification of cetaceans in the Tethyan Realm, but so far there is no fossil known with certainty from Ypresian formations (see Zalmout, Ul-Haq & Gingerich, 2003). Other occurrences of early Middle Eocene sirenians have been reported from North America (Domning, Morgan & Clayton, 1982), northern Africa (Gingerich, 1992), Indo-Pakistan (Zalmout, Ul-Haq & Gingerich, 2003; Bajpai *et al.*

2006, 2009) and Europe. Lutetian sirenians from the southern margin of the Mediterranean Tethys (Egypt) and from the eastern Tethys (India, Pakistan) have been assigned to *Protosiren*, *Eosiren*, *Eotheroides* and *Ashokia* (Gingerich *et al.* 1995; Zalmout, Ul-Haq & Gingerich, 2003; Bajpai *et al.* 2006, 2009), those from the western Tethys are tentatively referred to *Protosiren* or a closely related form (Domning, Morgan & Clayton, 1982), and finally those from the northern margin of the Mediterranean Tethys (Hungary) have been attributed to *Sirenavus* and *Anisosiren* (Kretzoi, 1941; Kordos, 1978, 1981, 2002). The above mentioned taxa are assigned either to Protosirenidae (*Protosiren*, *Ashokia*) or to Dugongidae (the remainder), suggesting a rapid early Middle Eocene diversification of sirenians, with generically-distinct and endemic faunas on the north and south shores, respectively, of the former Tethys Seaway (C. Sagne, unpub. Ph.D. thesis, Mus. Natl. Hist. Nat., Paris, 2001; Bajpai *et al.* 2009).

In Western Europe, Lutetian sirenian fossils (i.e., isolated teeth, ribs) are known from the Aquitania Basin (Sickenberg, 1934; Richard, 1946), but the occurrence of *Protosiren* and *Eotheroides* (as *Eotherium*) in these levels is very doubtful (Domning, 1996; C. Sagne, unpub. Ph.D. thesis, Mus. Natl. Hist. Nat., Paris, 2001). In the Eastern Pyrenees, Bataller (1956) and Crusafont (1973) referred some vertebrae and ribs from the Lutetian of the Ebro Basin to *Halitherium* sp. However, both the age of the beds and the status of the material are uncertain (Pilleri, Biosca & Vía, 1989). *Prototherium* is represented by the species *P. veronese* and *P. montserratense* in the Bartonian of Italy and Catalonia, respectively (Zigno, 1875; Pilleri, Biosca & Vía, 1989).

In South-Western Pyrenees, sirenian vertebrae and ribs have been previously described from the Middle Eocene (Bartonian) of the Pamplona Basin (Navarre), and referred to as Dugongidae indet. (Astibia *et al.* 2006). Additional postcranial remains

are known from the Middle to Upper Eocene formations of the Jaca Basin (Huesca) (see references in Astibia *et al.* 2005). The aim of this paper is to describe new sirenian material from the Middle Eocene (upper Lutetian to lowermost Bartonian) limestones of the Urbasa and Andia plateaus in Navarre, and to discuss its affinities. These new records of sirenians are the oldest known in Western Europe.

Institutional abbreviations: MNHN, Muséum National d'Histoire Naturelle, Paris; UF, Florida Museum of Natural History, University of Florida, Gainesville; UPV/EHU, Universidad del País Vasco/Euskal Herriko Unibertsitatea, Bilbao; USNM, United States National Museum of Natural History, Washington D.C.

2. Geological context

The sirenian fossils reported herein were collected in the Middle Eocene Urbasa-Andia limestone Formation (A. Payros, unpub. Ph.D. thesis, Univ. País Vasco, Bilbao, 1997), which crops out widely in the core of the E-W trending syncline that makes up the so-called plateaus (Fig. 1a). A comprehensive study of its sedimentological and stratigraphic characteristics has recently been carried out by Payros *et al.* (2009), and the following description is based on that work. The Urbasa-Andia Formation is composed of varied shallow-marine limestones that, according to their sedimentary facies and benthic fossil assemblages, were accumulated in coastal, inner ramp, middle ramp and outer carbonate ramp environments. These limestones grade northeastwards into marls of the Erize Formation (A. Payros, unpub. Ph.D. thesis, Univ. País Vasco, Bilbao, 1997), whose planktonic foraminiferal content (middle Lutetian-early Bartonian E10 and E11 zones of Berggren & Pearson, 2005) attests to hemipelagic deposition. These characteristics show that the Urbasa-Andia limestones accumulated in a 15-20

km wide distally-steepened carbonate ramp that deepened northeastwards (Fig. 1b). It was part of a wider shelfal system that flanked the southern margin of a deep-marine gulf, which was located between the Iberian peninsula and mainland Europe and opened northwestwards into the Atlantic Ocean at approximately 35°N palaeolatitude (Fig. 1a).

Five depositional sequences occur in the Urbasa-Andia Formation, which onlap southwestwards onto a major angular unconformity (Payros *et al.* 2009). Hence, the thickness and age of the Urbasa-Andia Formation are highly variable between localities. The sirenian remains were collected from two localities. One is a limestone quarry (UTM X580856 Y4735347) near Lezaun in the Andia plateau. The fossils occur in cross-bedded orthophragminid grainstones that were accumulated in outer ramp dunes, at a depth of about 100 m, by return bottom currents (Payros *et al.* 2009). Therefore, the sirenian remains were probably washed offshore during storm episodes. Underlying nummulitid beds yielded *Nummulites blondeaui* and *N. cf. discorbinus*, whose range corresponds to the late Lutetian SBZ16 zone of Serra-Kiel *et al.* (1998). Correlative beds in neighbouring outcrops contain *N. deshayesi*, *N. carpenteri*, *N. praepuschi*, *N. beaumonti*, *N. discorbinus* and *N. meneghinii*, which confirm the late Lutetian age. The second locality with sirenian remains corresponds to the Arrasate (“Limitaciones de las Ameskoas”) area of the Urbasa plateau (UTM X561160 Y4741051). The fossils were found in pebbly/sandy grainstones rich in porcelaneous larger foraminifera, peloids and fragments of encrusting foraminifera and red algae, many with a hooked shape. Some cross-laminations were observed. These characteristics suggest deposition in a subtidal shallow-marine setting, probably less than 20 m deep, relatively close to terrestrial source areas (Payros *et al.* 2009). The area was covered with perennial seagrasses and other macrophytes with flattened blades. Despite the baffling protection offered by this vegetation, the area was subjected to the action of continuous high-

energy currents, showing that the coastal area was neither protected nor isolated from the open sea. Taking everything into account, these sirenian fossils are regarded as nearly autochthonous. It was not possible to determine the age of these deposits, but correlation with neighbouring areas suggests that they might have been formed during the late Lutetian SBZ16 or earliest Bartonian SBZ17 zones.

3. Material and Methods

The sirenian material of Navarre described below consists of axial remains (two atlas vertebrae, one of them very fragmentary, dorsal ribs) and one appendicular bone (humerus). Most of the material was found in an area called Arrasate in the Urbasa plateau (abbreviation: UR). A few dorsal ribs come from a quarry near Lezaun (abbreviation: LE), in the Andia plateau. During the study of the material, it is kept at the Palaeontology laboratory of the Universidad del País Vasco/Euskal Herriko Unibertsitatea (UPV/EHU), Bilbao. Casts of the more significant fossil remains are housed in this institution.

Methods of thin-sectioning have followed standard procedures. A rib was sectioned transversely. The thin sections were ground to a thickness of 100 to 150 μm . They were studied at low and high magnifications using a petrographic microscope under normal and polarized light. The histological terminology and the typology of bone tissues used in this study refer to Francillon-Vieillot *et al.* (1990). See Buffrénil *et al.* (2008) for a previous histological study of sirenian ribs from the Middle Eocene of Navarre.

4. Palaeontology

Sirenia ILLIGER, 1811

Sirenia indet.

Fig. 2

Material: UPV/EHU LE1.1-LE1.5, incomplete to fragmentary ribs.

Provenance and age: Quarry near Lezaun (Navarre) (UTM X580856 Y4735347);

Middle Eocene, late Lutetian SBZ16, middle part of the Urbasa-Andia Formation.

Description and comparisons: The ribs are banane-like, thick and massive in cross section, without a medullar cavity (Fig. 2a). They differ from the ribs of *Protosiren* from Egypt and Balochistan, which are dense but lack pachyostosis (Gingerich *et al.* 1995; Zalmout, Ul-Haq & Gingerich, 2003). The cross sections are similar to those of *Prototherium solei* from Catalonia (Pilleri, Biosca & Vía, 1989: figs. 4a-c), *Halitherium taulannense* from Provence (Sagne, 2001; undescribed material) and an indeterminate dugongid from the Pamplona Basin of Navarre (Astibia *et al.* 2006).

The thin sections of the ribs show well-preserved histological microstructures (Fig. 2b). In the Lezaun ribs, there is internally a nearly peripheral, approximately 1 mm thick, alteration layer exhibiting a branching three-dimensional network tunnels filled by pyrite and/or iron oxides. The Lezaun samples show a larger number of fractures than those of Urbasa. Some of these fractures reach the external surface of the bone, where they show a replacement by secondary francolite, with different light-coloured layers on each side. The X-ray diffraction analyses indicate that the fossil bone is mostly composed of francolite (carbonate fluorapatite [Ca₅(PO₄, CO₃)₃(F)]).

Rib diaphyses have an extreme compactness (ca. 98%) and histologically display a typical sirenian pattern. The medullar region is completely occluded; it

includes thick perivascular layers of endosteal lamellar bone, between which small remnants of calcified cartilage matrix are interspersed. Deep cortical regions consist of a thick layer of fibro-lamellar tissue (see Francillon-Vieillot *et al.* 1990 for bone typology) with a longitudinally oriented network of vascular canals. Towards cortical periphery vascular density decreases, and very conspicuous cyclical growth marks, in the form of annuli, occur (Fig. 2b). Unfortunately, the outermost cortical layers are not preserved; as a consequence, the individual ages of these specimens, as also the modification of bone structure in late growth stages, cannot be observed. Haversian remodelling is relatively discreet, especially in peripheral cortical territories. As a whole, the basic histological features of the studied specimens are closely similar to those observed by Buffrénil *et al.* (2008) in *Prototherium montserratense* from the Bartonian of Catalonia and of an undetermined dugongid from the Bartonian of the Pamplona Basin of Navarre, in the eastern and western Pyrenees respectively.

Dugongidae GRAY, 1821

?Dugongidae indet.

Figs. 3-4

Material: UPV/EHU UR1.4, atlas; UR1.12, fragment of atlas neural arch; UR1.5, proximal half of right humerus; UR1.1-3 and UR1.6-11, rib fragments.

Provenance and age: Arrasate (“Limitaciones de las Ameskoas”) area of the Urbasa plateau, Navarre (UTM X561160 Y4741051); Middle Eocene, probably late Lutetian SBZ16 or early Bartonian SBZ17, middle part of the Urbasa-Andia Formation.

Measurements: see **Table 1.**

Description and comparisons: Atlas (UPV/EHU UR1.4, UR1.12). The atlas is low, compressed dorsoventrally (Fig. 3a, c). The dorsal arch is low, producing a broad neural canal. There is not a prominent neural tubercle but a scarcely rugose and incipient area in the two atlases (Fig. 3b). The ventral arch is broken. The anterior cotylar articular facets are long, deeply concave and have a bulbous dorsal rim. The arterial canal above the anterior cotyle is unbridged. The transverse processes are long, robust and club-like. The wings are rugose dorsally, but smooth and more slender ventrally; each one is pierced near its roots by a large transverse (vertebrarterial) foramen. The posterior articular facets are subcircular in outline, less prominent and concave than the anterior articular facets. The tops of the posterior cotyles lie well below the dorsal surface of the transverse processes.

There are few atlases of early sirenians available in the literature. Savage, Domning & Thewissen (1994) described two fragmentary atlases of *Prorastomus sirenoides* from the early Middle Eocene of Jamaica and two atlases from the Late Eocene of Floride that they referred to Prorastomidae indet. UR1.4 is slightly smaller in size than the other atlases. It seems more robust and higher dorsoventrally than the holotypic atlas of *P. sirenoides* (BMNH 44897), and has longer and blunter transverse processes. In dorsal view, UR1.4 is less concave than BMNH 44897. The Navarrese specimen is also more robust than the referred atlas of *P. sirenoides* (USNM 437769) and two “prorastomid” atlases (UF 123678; cast UF 135798) (Savage, Domning & Thewissen, 1994). These fossils display shorter and laterally grooved transverse processes than in UR1.4. The dorsal or neural tubercle is more marked in “prorastomids” than in UR1.4, but this character appears to be variable among

sirenians: for example, atlases of the dugongid *Halitherium schinzi* from the Early Oligocene of France and Germany have a more or less marked neural tubercle (MNHN collections).

With regard to the atlas of *Protosiren* sp. from the Middle Eocene of North Carolina, USA (Domning, Morgan & Clayton, 1982), UR1.4 is similar in size or slightly smaller, lower dorsoventrally and wider laterally. The atlas of *Protosiren* shows a well developed neural arch and stout transverse processes (Domning, Morgan & Clayton, 1982). These differences (dorsoventral height, presence of a neural tubercle, wing robustness) are even more developed in representatives of Trichechidae, such as *Potamosiren* from the Miocene of Colombia (Domning, 1982). Moreover, the posterior articular surfaces of *Potamosiren* are lower relative to the wings than those observed in UR1.4.

The atlas UR1.4 differs from those of extant Sirenia (*Dugong dugon* –dugong–, *Hydrodamalis gigas* –Steller’s sea cow– and *Trichechus* spp. –manatees–), which bear in dorsal view a marked midline crest on the dorsal surface and less prominent anterior cotylar articular facets. The general aspect of UR1.4 looks more like that of dugongids, though being less robust than that of trichechids that bear much more gracile transverse processes.

The presence or absence of a vertebrarterial canal through the transverse process is a common variation in sirenians (Domning, Morgan & Clayton, 1982).

Humerus (UPV/EHU UR1.5). It includes the proximal half of a robust, lateromedially compressed right humerus (Fig. 4). This appears to have been damaged during extraction. The bone belonged to a mature individual as the diaphysis and proximal epiphysis are fused, but it was probably not an old adult as the surfaces for attachment

of ligaments and insertion scars are neither rugose nor protuberant (Domning, 1997). The articular surface of the head is not complete. The deltoid crest seems broad but scarcely prominent (Fig. 4a, c). The deltoid tuberosity is broken. The greater and lesser tubercles are well developed anteromedially, delimiting a deep bicipital groove (Fig. 4a, e). The greater tubercle extends proximally of the humeral head. In lateral view, the surface of the greater tubercle is rugose, and there are two well defined scars for the supraspinatus and infraspinatus muscles (Fig. 4c). The humerus has a subtriangular cross-section at midshaft.

UR1.5 resembles the humerus of *Halitherium* more than that of *Prototherium* in its general form and robustness. The humeri of *Prototherium veronense* from the Bartonian of Italy (Sickenberg, 1934) and *P. solei* from the Priabonian of Catalonia (Pilleri, Biosca & Via, 1989) are comparatively slender than UR1.5 and than those of *H. taulannense* from the Priabonian of Provence and *Halitherium schinzii* from the Early Oligocene of Germany (MNHN collections), among other taxa. Moreover, the greater tubercle of UR1.5 appears to extend more proximally relative to the humeral head than in *P. solei*, but the specimen from Catalonia is too fragmentary to be certain. The humerus of *P. solei* is quite smaller in size than that from Navarre.

Both extant dugong and manatee possess a proximal trochiter divided in two well separated ovoid to rounded parts, a large ventral one and a smaller lateral one. On manatee, moreover, the large ventral part is located more median than in dugong, where both processes are located laterally. On the contrary, the Steller's sea cow humerus exhibits a laterally located trochiter, elongated in shape and unique, as in most fossil sirenians, so that this character could be plesiomorphic for the clade. UR1.5 bears a trochiter comparable in shape to that of the Steller's sea cow and other extinct sirenians,

which is an elongated and probably unique trochiter (though this area is partially broken).

Dorsal ribs (UPV/EHU UR1.1-3, UR1.6-11). Several fragmentary ribs are thick and massive, without a medullary cavity. The only preserved articular head displays a subcircular and rugose articular facet. The tuberculum is well developed.

One of the rib fragments is very thick in cross-section and closely resembles the rib sections of *Eosiren libyca* from the Priabonian of Egypt and *Halitherium schinzii* from the Early Oligocene (Rupelian) of Germany (see Astibia *et al.* 2006).

The histological features of the dorsal ribs are similar to those observed in the material of Lezaun (see above).

4. Discussion and Conclusions

With the exception of two records of Miosireninae (Trichechidae) from the Late Oligocene of Westfalia and the Early Miocene of Belgium, only dugongids are known in the fossil record of Europe (see Domning, 1994; Sagne, 2001; C. Sagne, unpub. Ph.D. thesis, Mus. Natl. Hist. Nat., Paris, 2001). Dugongidae representatives are known from the early Middle Eocene to present (*Dugong*). In the northern margin of the Mediterranean Tethys, dugongids are recorded from the Lutetian to the Pliocene (Gheerbrant, Domning & Tassy, 2005).

The new sirenian material found in the Middle Eocene deposits of Lezaun (Andia plateau, Navarre) includes partial dorsal ribs of late Lutetian age. The pachyosteosclerotic ribs are undistinguishable from those of dugongids from the mid to late Eocene and Oligocene of Europe. Skeletal pachyosteosclerosis (increased volume plus increased density of bones), present at least in ribs, is characteristic of sirenians

except for the basal form *Protosiren* (Buffrénil & Schoevaert, 1989; Buffrénil *et al.* 2008).

Additional material from Arrasate (Urbasa plateau, Navarre) consists of two atlases, dorsal ribs and a humerus. The morphology of the atlas (low dorsal arch, absence of a prominent neural tubercle) and humerus (robust bone, with a greater tubercle that extends proximally of the humeral head) resembles the condition observed in some elements of *Halitherium* from the Late Eocene and Early Oligocene of Europe (Sagne, 2001; C. Sagne, unpub. Ph.D. thesis, Mus. Natl. Hist. Nat., Paris, 2001) and is consistent with referral to Dugongidae.

Though the presence of sirenian fossils in the Lutetian of Western Europe (Aquitaine and Pyrenees) has been widely accepted in the past (Sickenberg, 1934; Richard, 1946; Bataller, 1956; Crusafont, 1973), the reliability of these finds in both the age of the beds and the status of the material is doubtful (Pilleri, Biosca & Vía, 1989; Domning, 1996; Sagne, 2001; C. Sagne, unpub. Ph.D. thesis, Mus. Natl. Hist. Nat., Paris, 2001).

The oldest sirenian remains reported to date in the Pyrenees were assigned to the Biarritzian (Pilleri, Biosca & Vía, 1989), a regional stage defined by Hottinger & Schaub (1960) on the basis of larger foraminifera. The Biarritzian stratotype is characterized by SBZ17 larger foraminifera and middle Bartonian NP17 calcareous nannofossils and E13 planktonic foraminifera (Mathelin & Sztrákoz, 1993), although Serra-Kiel *et al.* (1998) later assumed that the Biarritzian stage embraces the whole SBZ17 zone, therefore also including the lower part of the Bartonian stage (equivalent to the upper part of calcareous nannofossil zone NP16). Given this off-putting stratigraphic framework it is not straightforward to determine the age of previously reported sirenian fossils in modern terms. However, it is clear that all the so-called

Biarritzian sirenian remains should be ascribed either to the middle Bartonian (according to a strict stratotypic viewpoint) or to the lower-middle Bartonian (according to the ampler concept of Serra-Kiel *et al.* 1998). Therefore, the Lezaun sirenian remains, reliably dated as late Lutetian (SBZ16 zone) in age, definitively constitute the oldest sirenian record known in Western Europe. The age of the Urbasa sirenian remains could not be specified accurately by biostratigraphic means, but it can be indirectly inferred by correlation with neighbouring sections. This correlation suggests that the Urbasa material could also be included in the late Lutetian SBZ16 zone or maybe in the lowermost part of the earliest Bartonian SBZ17 zone, being also among the oldest sirenian fossils reported in Western Europe.

Finally, the late Lutetian (to basalmost Bartonian) sirenian remains from Navarre show that the pachyosteosclerosis of extant *Sirenia* was definitively present by the early Middle Eocene, as previously suggested with slightly younger (Bartonian) remains from the Pamplona Basin of Navarre (Astibia *et al.*, 2006, Buffr enil *et al.*, 2008).

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Captions of the figures and table

Figure 1. (a) Simplified geological map of the study area, highlighting Eocene stratigraphic units in grey. Locations of the sirenian findings in the Urbasa-Andia Formation are shown with stars (Lezaun and Urbasa). Inset shows the early Middle Eocene palaeogeographic reconstruction of the Pyrenean area, with location of the study area (black dot). (b) Stratigraphic architecture of the Urbasa-Andia Formation showing the distribution of depositional sequences (DS1 to DS5). The two sirenian sites are included within depositional sequence DS4, which extends from the late Lutetian SBZ16 to the earliest part of the Bartonian SBZ17 zones. Adapted from Payros *et al.* (2009).

Figure 2. Sirenia indet. from the early Middle Eocene of Lezaun (Urbasa-Andia Formation, Navarre). (a) LE1.1, dorsal rib; (b) microscopic characteristics of the same rib. Densely packed Haversian systems and alternating cancellous growth bands. Peripheral region altered with tunnel network structures, probably made by microbial activity, filled by pyrite and iron oxides. Photograph with parallel polarizer (5.2 mm width).

Figure 3. ?Dugongidae indet. from the early Middle Eocene of Arrasate (Urbasa-Andia Formation, Navarre). Atlas UR1.4 in anterior (a), dorsal (b) and posterior (c) views.

Figure 4. ?Dugongidae indet. from the early Middle Eocene of Arrasate (Urbasa-Andia Formation, Navarre). Right humerus UR1.5 in anterior (a), posterior (b), lateral (c), medial (d) and proximal (e) views.

Table 1. Measurements (in mm) of the atlas UR1.4 and humerus UR1.5 of ?Dugongidae indet. from the early Middle Eocene of Arrasate (Urbasa-Andia Formation, Navarre).







