

# 3D models related to the publication: The ossicular chain of Cainotheriidae (Mammalia, Artiodactyla)

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## Abstract

This contribution includes the 3D models of the reconstructed ossicular chain of the cainotheriid *Caenomeryx filholi* from the late Oligocene locality of Pech Desse (MP28, Quercy, France) described and figured in the publication of Assemat et al. (2020). It represents the oldest ossicular chain reconstruction for a Paleogene terrestrial artiodactyl species.

**Keywords:** Caenomeryx, incus, Late Oligocene, malleus, Stapes

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## INTRODUCTION

The 3D models presented here represent the first reconstruction of a Paleogene terrestrial artiodactyl ossicular chain (see table 1 and fig. 1). It is based on ossicles preserved in the middle ear cavity of the basicranium UM PDS 3353 from Pech Desse (MP 28, Quercy) referred to the cainotheriid *Caenomeryx filholi*. Cainotheriidae are an extinct family of small European endemic artiodactyls (even-toed ungulates) documented between the Late Eocene and the Middle Miocene in Western Europe (Blondel, 2005). The recent results of Weppe et al. (2020) indicate that Cainotheriidae are closely related to other European endemic families such as Mixtotheriidae, Anoplotheriidae and Robiacinidae. Cainotheriidae are a major component of mammalian faunas from karstic localities in Quercy, southwestern France. This diverse family, including at least five genera, ranges from rabbit-sized species to species of the size of a small ruminant (Erfurt & Métais, 2007; Theodor, 2010). Contrary to many European endemic ungulates, cainotheriids made it through the Eocene/Oligocene transition and are one of the rare European endemic artiodactyl groups that diversified during Oligocene times (Blondel, 2005). The ossicular chain, contained within the air-filled middle ear cavity, is composed of three ossicles, the malleus, the incus, and the stapes. These three ossicles play a fundamental role in hearing process by transmitting airborne sound waves from the tympanic membrane (at the interface between the outer and middle ear) to the fluid-filled cochlea of the inner ear, while performing an anatomical impedance match between air and the cochlear fluid (e.g., Hemilä et al. 1995; Nummela & Thewissen, 2008; Mason, 2016). Because of their fragility and small size, the middle ear ossicles of fossil taxa are rarely documented. Yet, when retrieved, they can bring useful observations for the systematics and/or for the ecology of taxa [e.g., systematic position of Pakicetidae (Thewissen & Hussain, 1993) and hearing mechanisms (Nummela et al. 2004; Nummela et al. 2007)]. The specimen UM PDS 3353 from Pech

Model IDs	Taxon	Description
UMPDS3353	<i>Caenomeryx filholi</i>	middle ear with petrosal, bulla, stapes, incus, malleus

**Table 1.** Model. Collection: University of Montpellier.

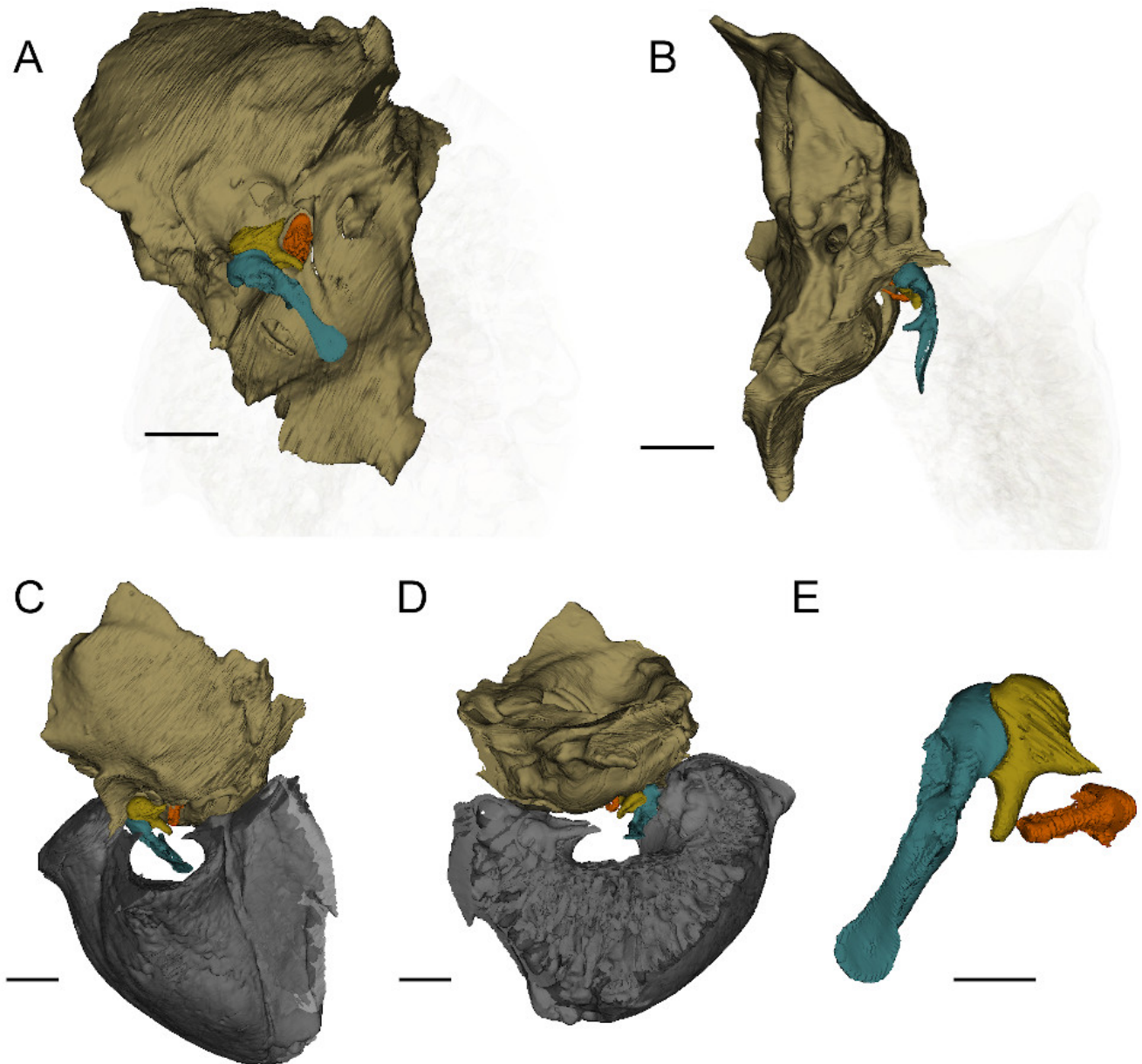
Desse exceptionally preserves a complete set of ossicles: the malleus and the stapes are preserved within the left bullar space, while the malleus and the incus are preserved on the right side.

## METHODS

The partial cranium UM PDS 3353 was scanned using the high-resolution micro CT-scanner EasyTom of the technical facility of the Montpellier Rio Imaging platform, at a high voltage (150 kV) using a copper filter, with a resolution of 23.81 µm. The ossicular chain was virtually reconstructed with the freeware MorphoDig (Lebrun, 2018) using the left bulla, petrosal and incus and mirror-3D models of the right malleus and stapes. Indeed, due to differential preservation and postmortem soft-tissue decay, the ossicles were not preserved on both sides and no longer in connection. Original position of the three ossicles was reconstructed by 1) placing the stapes back on the fenestra vestibuli; 2) articulating the incus and the malleus; 3) placing the flat surface of the manubrium parallel to the plan of the tympanic ring. The 3D surfaces of the petrosal, tympanic bulla and ossicles of UM PDS 3353 were extracted slice-by-slice manually within AVIZO 9.0 (Visualization Sciences Group) with the limited range only option of the brush tool. The 3D surface models are provided in .vtk format, and can therefore be opened with a wide range of freeware.

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**Figure 1.** Reconstruction of the ossicular chain within the middle ear cavity of *Caenomeryx filholi* UM PDS 3353. A-B, petrosal and ossicles in A) ventro-lateral and B) postero-medial views, C-D, complete middle ear in C) dorso-lateral and D) ventral views; E, ossicular chain in lateral view (red, stapes; yellow, incus; blue, malleus; bone, petrosal; grey, tympanic bulla). Scale bar = 2 mm for A-D, 1 mm for E.

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## BIBLIOGRAPHY

Assemat, A., Mourlam M.J., Weppe R., Maugoust J., Antoine P.-O., Orliac M.J., 2020. The ossicular chain of Cainotheriidae (Mammalia, Artiodactyla). *Journal of anatomy*. <https://onlinelibrary.wiley.com/doi/abs/10.1111/joa.13190>

Blondel, C., 2005. New data on the Cainotheriidae (Mammalia, Artiodactyla) from the early Oligocene of south-western France. *Zoological Journal of the Linnean Society* 144(2), 145–166. <https://doi.org/10.1111/j.1096-3642.2005.00166.x>

Erfurt, J., Métais, G., 2007. Endemic European Paleogene Artiodactyls: Cebochoeridae, Choeropotamidae, Mixtotheriidae, Cainotheriidae, Anoplotheriidae, Xiphodontidae, and Amphimerycidae. In: Prothero DR, Foss SE (Eds.) *The Evolution of Artiodactyls*, pp. 59–84. Baltimore, Maryland: The Johns Hopkins University Press.

Hemilä, S., Nummela, S., Reuter, T., 1995. What middle ear parameters tell about impedance matching and high-frequency hearing. *Hearing research* 85, 31–44. [https://doi.org/10.1016/0378-5955\(95\)00031-X](https://doi.org/10.1016/0378-5955(95)00031-X)

Lebrun, R., 2018. MorphoDig, an open-source 3D freeware dedicated to biology. 5th International Paleontological Congress, Paris.

Mason, M. J., 2016. Structure and function of the mammalian middle ear. II: Inferring function from structure. *Journal of Anatomy* 228, 300–312. <https://doi.org/10.1111/joa.12316>

Nummela, S., Thewissen, J. G. M., Bajpai, S., Hussain, S. T., Kumar, K., 2004. Eocene evolution of whale hearing. *Nature* 430(7001), 776–778. <https://doi.org/10.1038/nature02720>

Nummela, S., Thewissen, J. G. M., Bajpai, S., Hussain, S. T., Kumar, K., 2007. Sound transmission in archaic and modern whales: anatomical adaptations for underwater hearing. *Anatomical Record* 290(6), 716–733. <https://doi.org/10.1002/ar.20528>

Nummela, S., Thewissen, J. G. M., 2008. The Physics of Sound in Air and Water. In: Thewissen JGM, Nummela S (Eds.) *Sensory Evolution on the Threshold: Adaptations in Secondarily Aquatic Vertebrates*, pp. 175–182. University of California Press. <https://doi.org/10.1525/california/9780520252783.003.0011>

Theodor, J. M., 2010. Micro-Computed Tomographic Scanning of the Ear Region of *Cainotherium*: Character Analysis and Implications. *Journal of Vertebrate Paleontology* 30(1), 236–243. <https://doi.org/10.1080/02724630903415979>

Thewissen, J. G. M., Hussain, S. T., 1993. Origin of underwater hearing in whales. *Nature* 361(6411), 444–445. <https://doi.org/10.1038/361444a0>

Weppe, R., Blondel, C., Vianey-Liaud, M., Escarguel, G., Pélissié, T., Antoine, P.-O., Orliac, M. J., 2020. Cainotheriidae (Mammalia, Artiodactyla) from Dams (Quercy, SW France): phylogenetic relationships and evolution around the Eocene–Oligocene transition (MP19–MP21). *Journal of Systematic Palaeontology* 18(7), 541–572. <https://doi.org/10.1080/14772019.2019.1645754>