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A new penguin fossil from Seymour Island and reassessment of taxonomy and diversity of Eocene Antarctic penguins

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Abstract

Eocene penguins from Seymour Island play an important role in studies related to the taxonomy and evolution of the Sphenisciformes stem group. Among these penguins, the *Palaeeudyptes* species are particularly noteworthy for their unusually large size and the contentious nature of their classification criteria. In this study, we describe a new penguin skeleton with a well-preserved tarsometatarsus discovered in the Upper Eocene of Seymour Island, Antarctica. The new fossil exhibits tarsometatarsal characteristics of *Palaeeudyptes* but differs from two species of *Palaeeudyptes* previously found on Seymour Island, providing insights on the morphological diversity and evolutionary history of early penguins. We conduct normality and unimodality tests on *Palaeeudyptes* taxa from Seymour Island to reassess the hypothesis that size differences between the two species of this genus could be attributed to sexual dimorphism in a single species. The results revealed that size differences are unlikely due to sexual dimorphism. We also use the linear discriminant analysis to evaluate the taxonomic criteria for the two *Palaeeudyptes* species discovered in the Antarctic region. The data showed an overlap in the size distribution, indicating

weakness in the classification criteria. Reassessing previous samples and establishing an additional diagnosis based on critical anatomical features could potentially resolve this issue.

Introduction

Penguins (Sphenisciformes) are a group of flightless, diving birds with specialized bodies and physiology capable of adapting to extreme environments. They are distributed geographically throughout the Southern Hemisphere. The earliest diverging group of Sphenisciformes, *Waimanu*, originated from New Zealand in the late Early Paleocene (Slack et al., 2006). Additionally, multiple early diverging Paleocene taxa, including 6 species of 5 genera, have been reported in New Zealand (Mayr et al., 2017b, Mayr et al., 2018, Mayr et al., 2020, Blokland et al., 2019, Ksepka et al., 2023), as well as *Crossvalia unienwillia* in Antarctica (Tambussi et al., 2005, Jadwiszczak et al., 2013).

Eocene penguins have a remarkably extensive fossil record in the Southern Hemisphere, showing a high diversity of species during this epoch. Among the key localities for Eocene penguin fossils, Seymour Island within the Antarctic Peninsula has the highest diversity of penguin taxa (Simpson, 1971a, Ksepka and Ando, 2011, Acosta Hospitaleche et al., 2019a). Numerous penguin fossils have been collected from both the La Meseta Formation and the Submeseta Formation on Seymour Island. There is only one description of incomplete bones in the lower Eocene La Meseta Formation (Telm 1–2) (Jadwiszczak, 2006a); most of the fossils are found in the upper Eocene (Submeseta Formation or Telm 7), where penguins underwent significant radiation and rapid diversification.

The penguin fossils discovered on Seymour Island are often fragmentary and isolated, with taxonomic diagnoses and phylogenetic analyses relying on the characteristics of individual bones. The tarsometatarsus is commonly used in taxonomic investigation, leading to the establishment of seven genera and eleven species (Wiman, 1905, Simpson, 1971a, Myrcha et al., 2002, Jadwiszczak and Mörs, 2011, Jadwiszczak et al., 2021). Two of these penguins, *Anthropornis* and *Palaeeudyptes*, are considerably larger than the extant *Aptenodytes forsteri* (Jadwiszczak, 2001), while others are of medium to small sizes. The humerus also plays a significant role in taxonomy, with two genera established based on its traits (Tambussi et al., 2006, Acosta Hospitaleche et al., 2017).

However, the diagnostic classification based on individual bones is often controversial, with the case of the *Palaeeudyptes* being the most complex. Currently, *Palaeeudyptes* comprises four species, two from New Zealand and two from Seymour Island (Huxley, 1859, Wiman,

1905, Brodkorb, 1963, Myrcha et al., 1990), exhibiting a broad paleogeographic distribution. The genus-level diagnoses revised by Simpson (1971b) and Myrcha et al. (2002) are clear, but the species-level classification is problematic. Two species on Seymour Island are primarily differentiated by size, rather than by distinct structural differences, a similar situation is observed for the two species in New Zealand (Ksepka et al., 2006, Acosta Hospitaleche and Reguero, 2010). Therefore, the classification criteria for *Palaeeudyptes* species should be applied with caution, as relying solely on the size of a single diagnostic bone may not always provide a sound basis for classification (Jadwiszczak and Mörs, 2011, Jadwiszczak and Acosta Hospitaleche, 2013).

In recent years, several articulated skeletons have been discovered and reported on Seymour Island, contributing to our understanding of Antarctic penguin morphology (Jadwiszczak, 2012, Acosta Hospitaleche and Reguero, 2014, Jadwiszczak and Mörs, 2019). Notably, a few of these skeletons can be attributed to giant penguins. For instance, MLP 14-XI-27-84 (*Anthropornis grandis*) is particularly noteworthy as it is the sole specimen to preserve skull material (Acosta Hospitaleche et al., 2019b). MLP 11-II-20-07 (*Palaeeudyptes klekowskii*) is remarkable for its abundance of bones, including nearly complete wing bones, partial hind limbs and a coracoid (Acosta Hospitaleche and Reguero, 2014). Other significant discoveries include an articulated wing with mineralized skin for *Palaeeudyptes gunnari* (Acosta Hospitaleche et al., 2020) and a skeleton containing several wing bones assigned to *Anthropornis* sp. (Jadwiszczak, 2012). These late Eocene penguin fossils have enriched our anatomical knowledge, but our understanding of these taxa is still incomplete.

In this paper, we present a partially preserved penguin fossil skeleton (CUGB P2003) collected from the Submeseta Formation on Seymour Island. We provide a detailed description of the anatomy of these fossils, discuss the significance of these materials, and propose an improved classification scheme of Seymour Island *Palaeeudyptes*. This finding contributes to our understanding of the diversity of Eocene Antarctic *Palaeeudyptes* penguins.

Abbreviations: CUGB, China University of Geosciences, Beijing, China; IB/P/B, Institute of Biology, University of Białystok, Białystok, Poland; MLP, Museo de La Plata, Ciudad de La Plata, Argentina; NHMUK, Natural History Museum, London, UK.

Section snippets

Geological setting

Seymour Island, situated off the eastern tip of the northern Antarctic Peninsula, is a relatively small island in the James Ross Basin. Seymour Island is known for its abundant fossil discoveries, including vertebrates like fishes, aquatic birds, and frogs (Acosta Hospitaleche et al., 2019a, Reguero, 2019, Mörs et al., 2020), invertebrates such as echinoderms, mollusks, corals, and decapods (Feldmann, 1989, Stolarski, 1996, Blake and Aronson, 1998), as well as plants (Cantrill et al., 2011) and …

Specimen and dataset

The specimen CUGB P2003 was collected during the 36th (2019–2020) Chinese National Antarctic Research Expedition, and consist of a pair of tarsometatarsi, two pedal phalanges, and several fragments of wing and hind-limb elements (Fig. 3). These fossil materials were found in situ and closed to each other during surface collection. Photographs of the penguin fossils were taken with a digital single-lens reflex camera equipped with a 40mm macro lens. Sample measurements were taken using a…

Systematic palaeontology

Class Aves Linnaeus, 1758…

Order Sphenisciformes Sharpe, 1891…

Family Spheniscidae Bonaparte, 1831

…

Genus *Palaeeudyptes* Huxley, 1859…

Type species: *Palaeeudyptes antarcticus* Huxley, 1859.…

Included species: *P. antarcticus* Huxley, 1859, *P. gunnari* Wiman, 1905, *P. marplesi* Brodkorb, 1963, *P. klekowskii* Myrcha, Tatur and Del Valle, 1990.

…

Palaeeudyptes sp.…

(Fig. 4, Fig. 5)

…

Material: CUGB P2003, a partial skeleton of a single individual, comprising a nearly complete tarsometatarsus in addition to fragmentary…

…

Statistical analysis results

Tests for sexual dimorphism were conducted using specific (single variables) and holistic (residuals of variables and PCs) data. Eight tarsometatarsal linear measurements were examined for normality and unimodality (Fig. 6, Fig. 7). The results showed that the *p* values of the normality test for several variables were less than 0.05, indicating they exhibited non-normal distributions, but none of them were significantly non-unimodal (Appendix A). The hypothesis of sexual dimorphism in linear…

Discussion

The new specimen reveals several novel features that are not previously reported. The first is the shallow concavity along the lateral margin of the tarsometatarsus, accompanied by a moderate deflection of trochlea IV. It's important to emphasize that the lateral margin of tarsometatarsi in Eocene giant penguins has often been simplistically characterized as relatively straight, with limited attention given to this feature. To quantitatively assess the degree of lateral deflection in trochlea…

Conclusion

Through comparative anatomical studies and a series of statistical tests, we gain valuable insights: 1) We describe a new penguin fossil skeleton, discovered in the late Eocene of Seymour Island, Antarctica. This specimen is assigned to the genus *Palaeeudyptes*, but the tarsometatarsus exhibits unique characteristics that distinguish it from other Antarctic *Palaeeudyptes* taxa. 2) Normality and unimodality tests reveal no evidence of sexual dimorphism in Seymour Island *Palaeeudyptes*. This finding …

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