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Research paper

The first described *Arsinoitherium* from the upper Eocene Aydim Formation of Oman: Biogeographic implications

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Abstract

A new fossiliferous locality is discovered from the upper Eocene Aydim Formation, in Dhofar, Southern Sultanate of Oman. A left ulna of *Arsinoitherium* is described, and cranial and postcranial specimens found in close proximity are referred to the same taxon. The locality is promising for the recovery of additional fossil specimens. Moreover, the presence of *Arsinoitherium* in Oman is of biogeographic significance; as the Red Sea did not exist during the late Eocene, these large-bodied animals were able to freely travel between what is now the Arabian Peninsula and continental Africa.
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Keywords: *Arsinoitherium*; Oman; Biogeography; Afro-Arabia; Aydim Formation

1. Introduction

Cenozoic fossil vertebrates from the Arabian Peninsula convey an important contribution to palaeontological understanding, representing vertebrates that occupied a myriad of ecological niches, large and small in body size, aquatic and terrestrial in habitat. Yet despite the important geographic position of Arabia with respect to other landmasses, relatively little is known about its early Paleogene large-bodied terrestrial mammalian fauna. Arabian fossils are meaningful for unraveling the Tertiary migrational patterns of different vertebrate clades among the landmasses of Africa, Europe and Asia. During the Paleocene and Eocene, paleobiogeographic reconstructions predict broad similarities between the terrestrial vertebrates of continental Africa and the Arabian Peninsula. Subsequently, large-scale interchange of terrestrial faunas between Arabia and Eurasia took place beginning in the early Miocene via the collision of Arabia and Asia (e.g., Whybrow and Clements, 1999).

Until recently, regional biogeographic inferences were based largely on Arabian marine sequences, and from terrestrial faunas documented in the better-known palaeontological successions on neighboring landmasses. As evidence of Mesozoic vertebrates has grown rapidly in recent years from continental Africa, Madagascar, and India (e.g., Krause et al., 1997, 1999, 2006; Hay et al., 1999; Whybrow and Hill, 1999; Sanders et al., 2004; Sereno et al., 2004; Durand, 2005; O'Connor et al., 2006), vertebrate fossils (dinosaur, turtle and crocodile) have also been recovered from the Late Campanian–Maastrichtian Al-Khod Conglomerate of the Sultanate of Oman (Schulp et al., 2000; Nolan et al., 1990; Buscalioni et al., 2004). Yet whereas Oligocene mammals and other vertebrates have been described from the Dhofar region of Oman (e.g., Thomas et al., 1999), the majority of Tertiary vertebrate research on the Arabian Peninsula has focused upon Miocene and later deposits in Saudi Arabia (Anon, 1975; Whybrow and Hill, 1999) and the United Arab Emirates (Whybrow and Hill, 1999).

The tropical shelf deposits of Oman offer a promising prospect for documenting intermediate stages of mammalian evolution during the Eocene. In this paper we describe an *Arsinoitherium* specimen collected from within the Eocene

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Aydim rock Formation in Dhofar region of Southern Oman (Fig. 1). Oman's location between Egypt and India provides an important data point, facilitating more robust comparisons with *Arsinoitherium* and other Tethyan vertebrates known from continental Africa. This discovery has implications for understanding past environments and biotas, filling a gap in the Eocene Afro-Arabian fossil record.

2. Stratigraphy and geological setting of the Aydim locality

In the eastern part of the Gulf of Aden, rifting of the Afro-Arabian plate began during the Oligocene and continued until early Miocene, followed by oceanization (Lepvrier et al., 2002). After the final regression of the Cretaceous sea, a new major transgressive–regressive series was deposited during the Tertiary in southern Oman (Platel et al., 1992). This depositional series involves three sedimentary groups (Platel et al., 1992; Platel and Roger, 1989; Lepvrier et al., 2002) corresponding to pre-rift, syn-rift and post-rift stages of deposition (Fig. 2): the Hadramawt, Dhofar and Fars groups, respectively. Specimens detailed herein were discovered within the Hadramawt Group, a brief description of which follows.

The Hadramawt Group, Paleocene (Thanetian) to late Eocene (Priabonian) in age, rests unconformably upon Cretaceous strata. In its type area, the Hadramawt Group constitutes an extensive sequence of typical carbonate shelf deposits comprising four formations. The Umm Er Radhuma Formation (Beydoun, 1964), up to 600 m thick, is a late Thanetian–middle Ilerdian limestone with shale intercalations and chert nodules. The latest early Lutetian–Bartonian Dammam Formation, and the Bartonian–Priabonian Aydim Formation each reach more than 400 m in thickness. The thin (60 m) dolomitic and evaporitic tidal-flat deposits of the Rus Formation (late Ilerdian to Cuisian) developed in between. The Aydim Formation was defined in Dhofar in order to distinguish the upper Eocene limestone that overlies the Dammam Formation (Platel et al., 1987; Roger et al., 1989, 1992; Lepvrier et al., 2002). The marine limestone of the Aydim Formation, 100–120 m thick, has very few equivalents in the Arabian Peninsula, as much of the region was emerged dur-

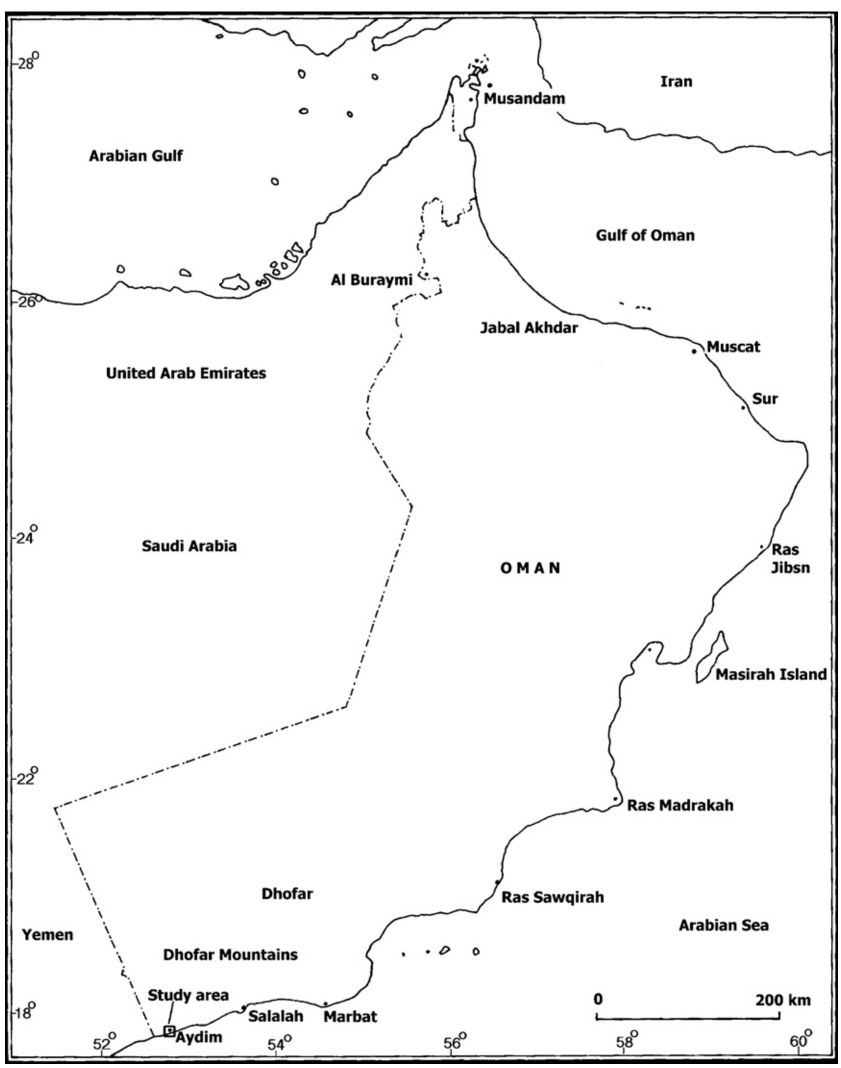

Fig. 1. Location of the study area.

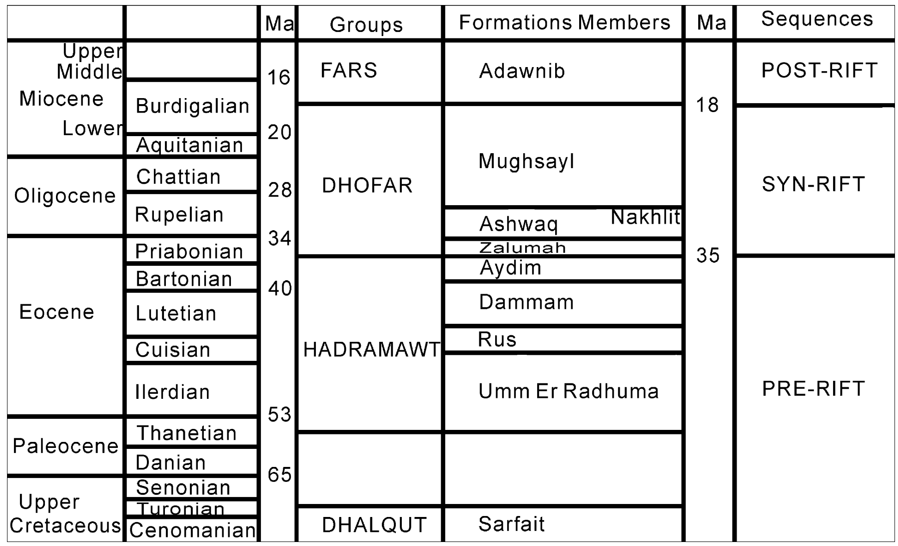

Fig. 2. Mesozoic and Cenozoic stratigraphic units and rift-related sequences in Southern Dhofar (after Roger et al., 1989).

ing the late Eocene (Platel et al., 1987). In Somalia these deposits correspond to the Karkar Formation (Merla et al., 1979). The type-section for the Aydim Formation has been established in the Aydim area (Platel et al., 1987; Roger et al., 1992) where the formation consists of four members of contrasting lithology: the Heiron, Moosak, Tagut and Haluf members (Fig. 3). The basal very thin (1–5 m) Heiron Member comprises a soft green marl, occasionally transitioning into beds of very fine, green mudstone and pink sandy siltstone (2 m). Above this is the Moosak Member, a 20–30 m thick unit of thin-bedded beige, bioclastic limestone, with an interval of cross-bedded yellowish siltstone and calcarenite, rich in *Nummulites*. The macrofauna of these lagoonal facies comprises branched and solitary corals, gastropods, bivalves, and echinoids. The calcarenitic base of the Tagut Member, some 6 m thick, is easily recognizable and contains numerous foraminifera, particularly *Nummulites*. Above this is a thick sequence (50 m) of thin-bedded, whitish, bioclastic or micritic, generally strongly recrystallized limestone, rich in echinoids, corals and foraminifera. The overlying Haluf Member, about 25 m thick, consists of alternating soft, white to yellow chalky marl, and fairly indurated beige to brown biomicritic limestone. In this area, the upper part of the Aydim Formation has a characteristic stepped morphology. Brown algal laminations are abundant at the top of the formation.

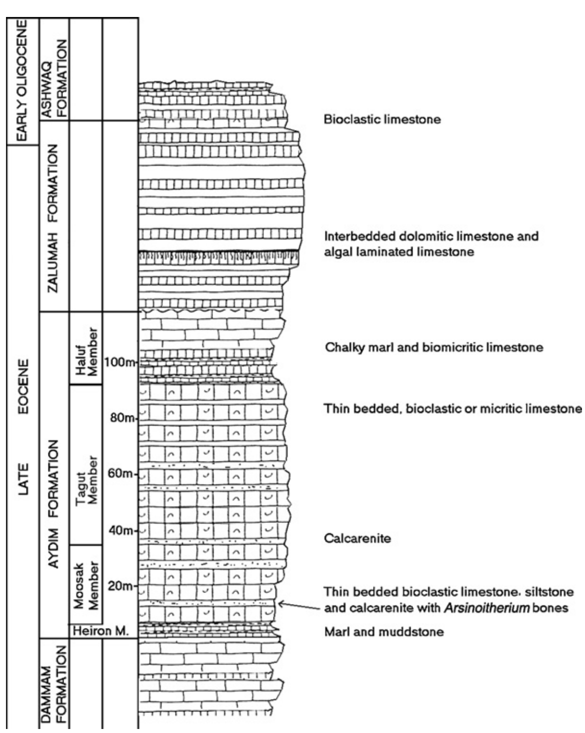

Fig. 3. Lithostratigraphic log of the Aydim Formation.

3. *Arsinoitherium*: an intriguing herbivore

Arsinoitherium is an extinct mammalian taxon known primarily from the late Eocene and early Oligocene of Egypt and Ethiopia (e.g., Andrews, 1906; Sanders et al., 2004). The genus is a member of the enigmatic group, the Embrythopoda, of which the phylogenetic relationships with other early Cenozoic mammalian groups remain poorly understood (e.g., Tabuce et al., 2007). Once allied with hyraxes (Andrews, 1906), more recent studies group the embrythopods most closely with either the proboscideans (Court, 1993) or the tethytheres (Gheerbrant et al., 2005). The genus *Arsinoitherium* was first described by Beadnell (1902) from the Jebel Qatrani Formation, Fayum Depression of Egypt, a geologic unit comprised of ∼350 m of fluvial sandstones, mudstones, siltstones and conglomerates, and estimated at 31 Ma of age (Seiffert, 2006). Subsequent discoveries of *Arsinoitherium* indicate that this animal lived throughout Africa browsing in warm, humid, highly vegetated environments (Moseley, 1988; Kappelman et al., 2003). This taxon has been reconstructed as a massive, graviportal herbivore with forelimbs adapted for strong forelimb retraction rather than adduction, features consistent with occupying a semi-aquatic habitat in which forelimbs provide strong forward propulsion during locomotion (Court, 1993).

4. Systematic palaeontology

Class	Mammalia Linnaeus, 1758
Superorder	Paenungulata Simpson, 1945
Order	Embrithopoda Andrews, 1906
Family	Arsinoitheriidae Andrews, 1904
Genus	*Arsinoitherium* Beadnell, 1902
	Arsinoitherium sp.

4.1. Material

Well-preserved partial left ulna (SQU-287). Fragmentary cranial elements (SQU-289) and pedal phalanges (SQU-288) found in close proximity (~distance; e.g., 0.5 m) to the ulna are here conservatively referred to the same taxon. Specimens are housed in the collections of the Sultan Qaboos University (SQU).

4.2. Description

SQU-287 is a partial left ulna, robust in form, and measuring 38 cm in length (Fig. 4). The proximal portion of the specimen exhibits a wide semilunar notch. A large rugosity is present on the posterior aspect of the olecranon process, associated with strong muscle attachments in life, although what remains of the proximal aspect of the process is badly abraded. Portions of the facets supporting both the medial and lateral humeral condyles are present, creating a saddle-shaped surface separated by a V-shaped notch for the articulation with the radius. As in other *Arsinoitherium* specimens (e.g., Court, 1993), the proximal radius does not appear to have been fused with the ulna. The ulnar diaphysis is flat anteriorly, but triangular in cross-section owing to the prominent ridge running distally from the olecranon process. The midshaft narrows, then expands distally; however, epiphyseal articulations for the carpus are not preserved. SQU-287 differs from the similarly sized *Paleomastodon* in having a more robust ulnar shaft that dramatically expands distally. Moreover, SQU-287 also lacks the deep radial groove running nearly the length of the diaphysis as observed in *Paleomastodon*. Although lacking in specific autapomorphies, the specimen is consistent in size and morphology with other specimens attributed to the genus *Arsinoitherium* (Andrews, 1906).

4.3. Remarks

Currently there are two recognized species of *Arsinoitherium*, *A. zitteli* from the Fayum of Egypt, and the larger *A. giganteum* recovered from the Chilga region of northwestern Ethiopia. An additional species ("*A. andrewsi*") has also been proposed, based on molar size differences within the Fayum sample (e.g., Lankester, 1903; Andrews, 1906). However, Sanders et al. (2004) argued that the range of variation in Fayum arsinoithere tooth size could comfortably be encompassed in a single, sexually dimorphic extant herbivore species, and relegated all Fayum specimens to *A. zitteli*. Due to the incomplete nature of SQU-287, no attempt is made to assign it beyond the level of the genus at this time. Approximately 30 fragmentary specimens referable to *Arsinoitherium* have been recovered from the Aydim locality to date, only three of which are identifiable to element. Importantly, more complete bones remain in situ and await continued excavation. Hence more precise taxonomic placement of the Omani arsinoithere material awaits the recovery of additional elements.

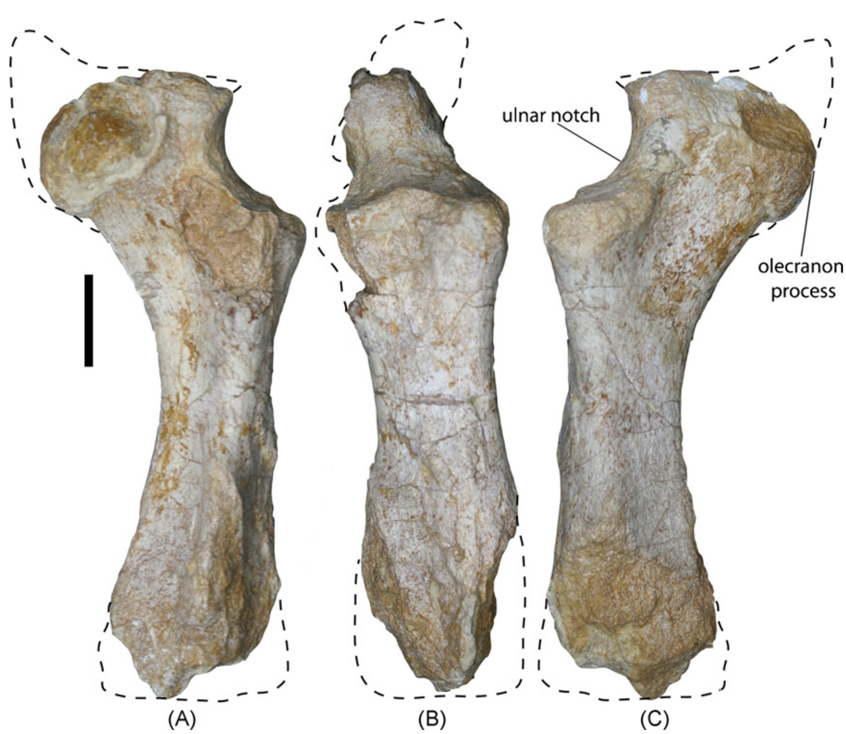

Fig. 4. Left ulna of *Arsinoitherium* (A) medial view; (B) anterior view; and (C) lateral view. Scale bar = 50 mm.

4.4. Occurrence

The specimens described herein were discovered in the upper Eocene calcarenite beds of the Moosak Member of the Aydim Formation (Fig. 3), west of Salalah; approximately 46 km from the Yemen border close to Aydim (Fig. 1).

5. Discussion and biogeographic implications

The location of Oman between Africa and Asia undoubtedly made it an important portal for the global dispersal of early Cenozoic mammals. During the Cretaceous, the vertebrate composition of Oman included taxa reflecting clades that arose prior to the breakup of Gondwanan landmasses (e.g., crocodyliforms: Buscalioni et al., 2004). Still attached to Africa during the Cretaceous and Paleogene, the Arabian Peninsula was mainly a broad, shallow, carbonate-dominated tropical shelf, similar to the South China Sea today. Much of the region was covered by water until the late Eocene (Alsharhan and Nairn, 1997; Abed, 2005). Separation from what is now continental Africa began during the Oligocene and continued until the early Miocene (Beydoun, 1964, 1966, 1970, 1982; Abbate et al., 1988; Bosellini, 1992; Fantozzi, 1996; Fantozzi and Sgavetti, 1998; Lepvrier et al., 2002). Southern Yemen, Oman, and northern Somalia together comprise the site of an Oligo-Miocene extension, related to rifting in the Gulf of Aden (Beydoun, 1964; Lepvrier et al., 2002). Equivalent rift-related deposits are exposed along the conjugate margins of these regions today. As such, the period of rifting and active faulting in the central part of Gulf of Aden lasted about 15 Ma, starting approximately 35 Ma in the late Eocene-early Oligocene, climaxing around 5 Ma later and reaching completion with the deposition of the post-rift sediments beginning around 18 Ma (Lepvrier et al., 2002).

The recovery of *Arsinoitherium* from the Aydim Formation of southern Oman supports the notion that during the late Eocene, the Red Sea did not yet provide a significant barrier to prevent animals from freely crossing between the Arabian Peninsula and Africa. The subsiding area between Dhofar and Somalia in the late Eocene provided a first stage in the opening of the Gulf of Aden due to rifting processes. This scenario explains the persistence of marine deposits in this area, despite the general marine regression associated with a global fall in sea level beginning at the close of the middle Eocene (Roger et al., 1992, 1993). Until this time, the mammalian fauna is essentially African in character (Whybrow and Hill, 1999), with subsequent increases in Asian components, such as rodents (Whybrow and Hill, 1999).

6. Conclusions

Based on a fairly complete left ulna and several associated elements, the genus *Arsinoitherium* is reported from the Paleogene Aydim Formation of Oman. This newly discovered vertebrate assemblage offers promise for comparisons among Paleogene Afro-Arabian faunas. Moreover, exposures in Wadi Aydim vary from bioclastic limestone to calcareous sandstone, mudstone and siltstones similar to those of the Fayum Depression of Egypt. These discoveries suggest that the Aydim locality in Dhofar preserves an Arabian snapshot of a littoral Fayum-like environment. At almost 36 Ma, the Omani mammal is perhaps one of the older arsinoitheres in the world.

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