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A Late Cretaceous theropod caudal vertebra from the Sultanate of Oman

***Anne S. Schulp, †Samir S. Hanna, ‡Axel F. Hartman and *John W. M. Jagt**

**Natuurhistorisch Museum Maastricht, PO Box 882, NL-6200 AW Maastricht, The Netherlands; e-mail: mail@nhmmaastricht.nl*
†Sultan Qaboos University, Department of Earth Sciences, College of Science, PO Box 36, Al-Khod 123, Sultanate of Oman
‡Schlumberger, Parkstraat 83, NL-2514 JG The Hague, The Netherlands

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A caudal vertebra collected from conglomerates of the Al-Khod Formation (Late Cretaceous) in the Al-Khod area, Sultanate of Oman, is assigned to a medium-sized theropod dinosaur. The Al-Khod discovery represents one of the very few dinosaur records from the Middle East.

KEY WORDS: Dinosauria; Theropoda; Sultanate of Oman; Arabian Peninsula; Late Cretaceous; Maastrichtian.

1. Introduction

Although dinosaur remains are known from all over the world (Weishampel, 1990), in the Middle East only a few dinosaur localities have been described. Dinosaur tracks are known from the Lower Cenomanian of the Jerusalem area (Avnimelech, 1962a, b, 1966). Hooijer (1968) described an indeterminate theropod from Syria, and Nolan *et al.* (1990) mentioned an indeterminate ornithischian vertebra from the type locality of the Al-Khod Conglomerate Formation in the Sultanate of Oman. Recently Martill *et al.* (1996) have recorded a Late Cretaceous ornithopod bone from Jordan, and Jacobs *et al.* (1999) reported on a sauropod discovery from Yemen. Here we describe a proximal caudal vertebra of a theropod from Al-Khod; this specimen constitutes the first evidence of large theropod dinosaurs from the Arabian Peninsula.

2. Locality

In 1997, two of us (ASS and AFH) made a short reconnaissance trip to the Sultanate of Oman to prospect for vertebrate fossils in the Al-Khod area, during which the present vertebra was collected from the type section of the Al-Khod Conglomerate Formation. This section, as described by Nolan *et al.* (1990), is situated between a Palaeogene limestone escarpment and the Semail Ophiolite, SE of the village of Al-Khod (also spelt Al-Khawd or Al-Khoud), approximately 30 km west of the capital of Muscat. In the Al-Khod area, there are series of ridges of NNE-dipping, coarse-grained conglomerates, interbedded with fine sandstones and shales, associated with the lower parts of the topography.

During the reconnaissance, we collected surface material only. In view of the low bone density and the limitations in time and resources, no systematic excavations were undertaken. In February–March 1998, subsequent collecting in the Al-Khod area yielded more vertebrate material, but so far, no additional material attributable beyond doubt to theropods, has been recognized.

3. Geological setting and stratigraphy

During the Late Cretaceous, the Semail Ophiolite was obducted onto the eastern margin of the Arabian Platform. Following this, successions over 800 m thick, of clastic, post-orogenic sediments were deposited. These are known as the Al-Khod Conglomerate Formation, and its lateral equivalent, the Qahlah Formation (Nolan *et al.*, 1990; Hanna, 1995; Alsharhan & Nasir, 1996). A composite section was measured and sampled by us in 1998; a schematic summary is presented in Figure 1. Our composite section extends from the ophiolite hills in the south to

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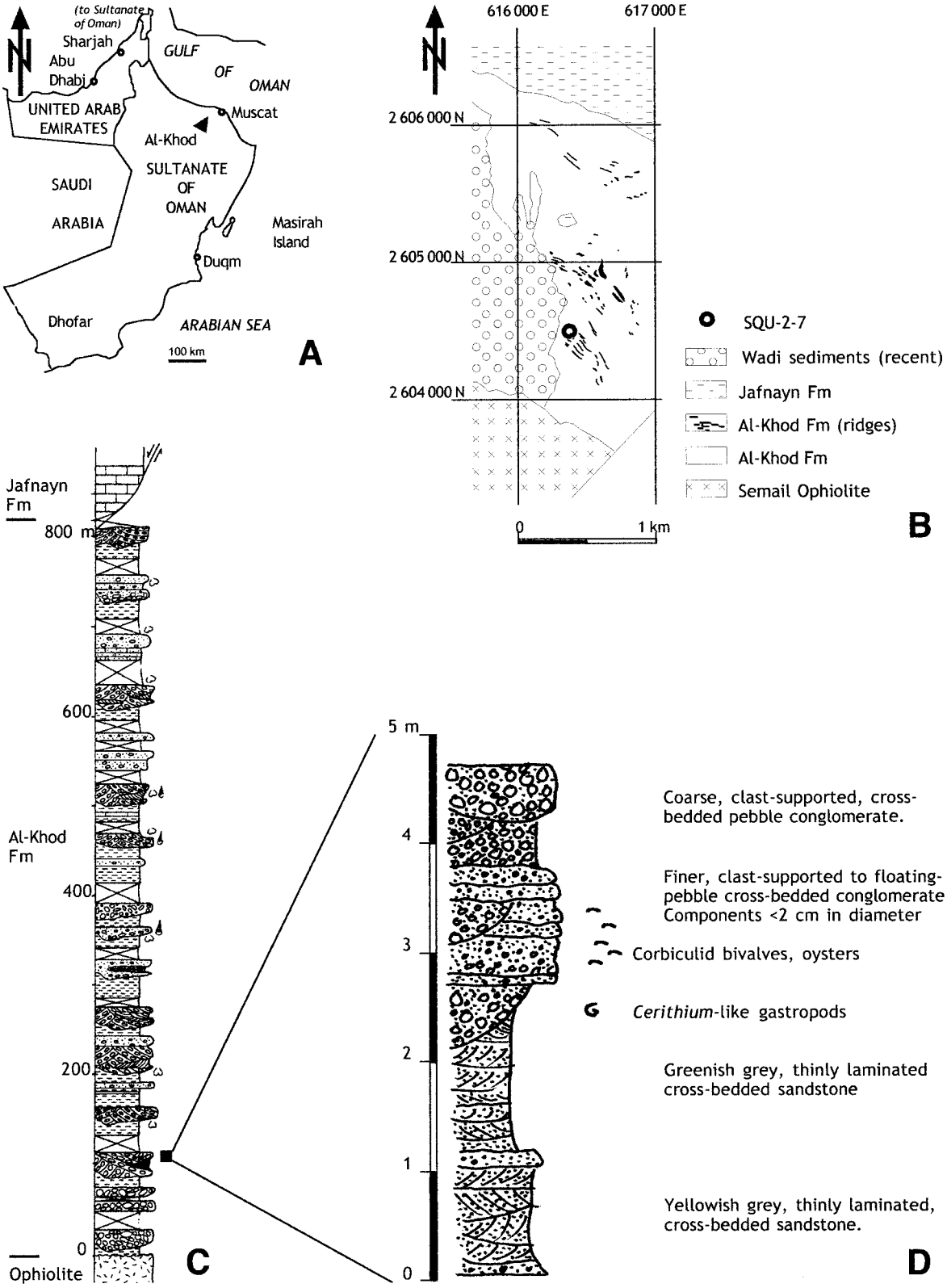
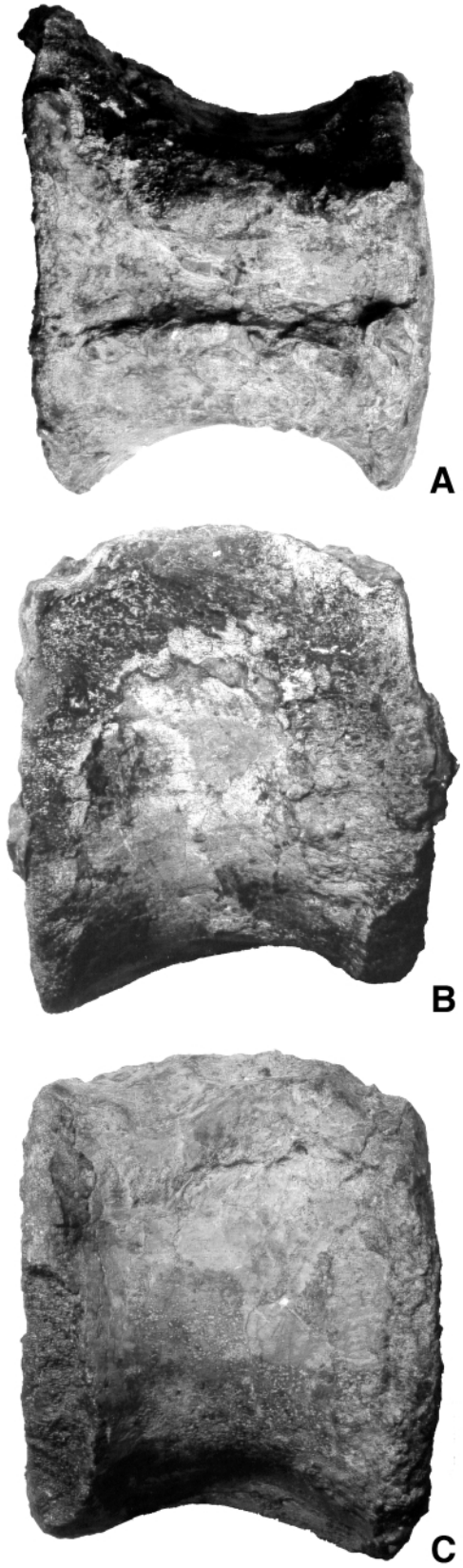


Figure 1. Sketch map showing the Al-Khod locality (A), a schematic geological map (B; aerial photograph interpretation), the composite stratigraphy measured at the type section of the Al-Khod Conglomerate Formation (C; Nolan *et al.*, 1990) and log of the escarpment from which the specimen described was collected (D; recorded in 1998 by the authors).



the pronounced yellow Palaeogene limestone escarpment in the north, and roughly follows the type section as represented in Nolan *et al.* (1990). Grid references are (UTM40): 616 380, 2 603 880 to 617 200, 2 605 600.

The Al-Khod Conglomerate Formation rests disconformably on the Semail Ophiolite along a present-day transtensional fault. As a result few data on the lower part of the section could be recorded.

The formation consists of a series of conglomerates interbedded with sandstones and shales. The clast-supported conglomerates are composed of ophiolite or chert pebbles derived from the Semail Ophiolite or Hawasina imbricates. From bottom to top the conglomerates show a 'reverse' sequence of clasts throughout the formation. The succession starts with a chert- and ophiolite-clast dominated base followed by Mesozoic carbonate debris, and is topped by pre-Permian quartzite clast-dominated conglomerates, representing the source area of the clastics in reverse stratigraphic order.

The sandstones and shales vary from red to green and grey, but are rarely exposed. The invertebrate fauna, which comprises corbiculid bivalves, freshwater gastropods and oysters, is indicative of a palaeoenvironment of varying salinity; driftwood and shell hash are common in some beds. The Al-Khod Conglomerate Formation was considered by Nolan *et al.* (1990) to represent a fan deltaic setting.

Most vertebrate remains were collected from the coarser-grained layers of the formation, which currently form the escarpments, whereas the finer-grained layers appear to be largely barren. Although the majority of dinosaur remains are highly abraded, the presence of a few well-preserved bones suggests that for at least part of the material extensive pre-fossilization degradation and reworking may be excluded. In addition, as the formation consists of derived material from which usually no dinosaur fossils are recorded, it is reasonable to assume that the material described here is of regional origin, and of the same age as the formation itself.

The Al-Khod Conglomerate Formation has yet to be precisely dated, but its age is constrained by the source of the conglomerates, the age of the overlying formation and the presence of presumably unreworked dinosaur remains. As the formation disconformably overlies the Semail Ophiolite, which was

Figure 2. SQU-2-7 in dorsal (A), right lateral (B), and left lateral (C) views. The axial length of the centrum is 92 mm.

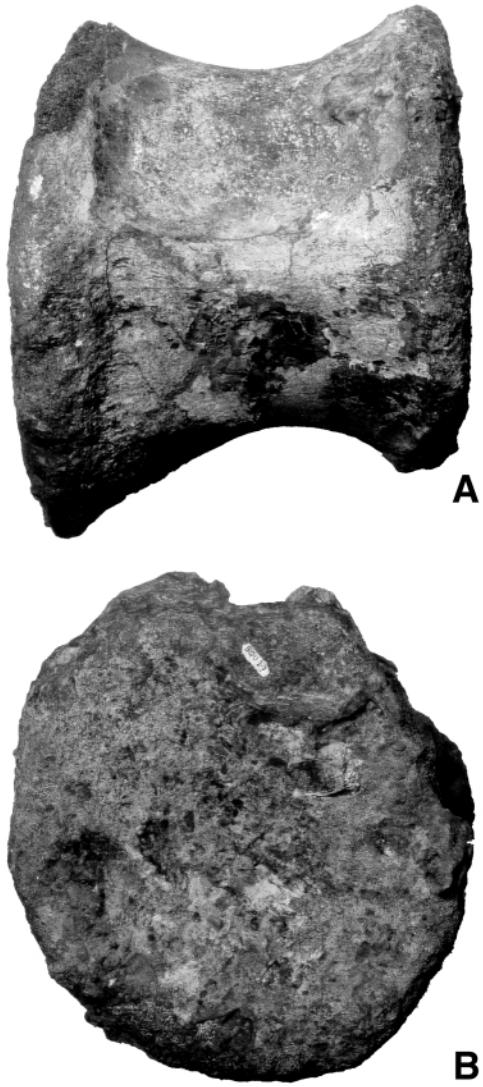


Figure 3. SQU-2-7 in ventral (A) and distal (B) view.

obducted onto the Oman continental margin during the Late Campanian–Maastrichtian (Robertson & Searle, 1990), and as it contains clasts of the same ophiolite, it must be younger than Late Campanian. The disconformably overlying Jafnayn Formation is of Late Palaeocene age (Nolan *et al.*, 1990). If we consider the dinosaur remains not to have been reworked, a latest Campanian–Maastrichtian age may therefore be assumed.

4. Description

Weathered out on the surface, the vertebral centrum described herein was collected from the section in Figure 1D. The specimen is housed in the collections of the Sultan Qaboos University (registration number SQU-2-7); a cast is in the Natuurhistorisch Museum Maastricht collection (NHMM1997113).

The centrum is slightly skewed laterally, and the left anterior surface is distorted laterally. The posterior side appears to be relatively undeformed. The centrum is platycoelous or very slightly amphicoelous, with an excavation not deeper than 7 mm on both sides; the axial length is 92 mm. The anterior facet is 109 mm high and 124 mm wide, but deformation appears to account for about 20 mm of that width. The less deformed posterior surface is 111 mm high and 105 mm wide, suggesting an aspect ratio of almost 1:1.

The ventral surface of the centrum features a prominent axial ridge that is up to 20 mm wide. Chevron facets are barely recognisable on the anterior margin, and are absent on the posterior margin.

No pleurocoels are present. The general appearance of the centrum is rather stout and only slightly waisted, but it is difficult to tell with certainty to what extent this could be the result of axial compression.

The neural canal is 18 mm wide. The neural arch projects upwards about 20 mm behind the anterior surface, and is 57 mm wide at the narrowest preserved point.

A few adnate oysters indicate that the specimen was exposed on the sea floor for a prolonged period prior to final burial.

CAT-scans of the specimen have not revealed much detail of the inner structure of the centrum. Some trabeculation just below the surface layer could be discerned, but the fossil is too heavily permineralized to yield more detailed information.

5. Discussion

The ventral ridge and the laterally excavated and almost platycoelous character are typical of proximal caudal vertebrae of theropod dinosaurs. Direct comparison of our specimen with the Late Cretaceous theropod record of the Afro-Arabian plate is difficult, since the Middle Eastern dinosaur record is extremely poor, as is the latest Cretaceous record in Africa.

Theropod dinosaurs have thus far only been recorded from the Cenomanian deposits in the Middle East. Neither the theropod tracks described by Avnimelech (1962a, b, 1966), nor the theropod tibia described by Hooijer (1968) allow for any meaningful comparisons to be made.

The African record offers a better prospect. Although the Maastrichtian theropod record itself is limited, more material is available from the lower Upper Cretaceous (Weishampel, 1990). A considerable amount of material has been collected in recent

years from the lower Upper Cretaceous of the Sahara, but these remains have not yet been described in detail, only in short communications. However, recent work by Sereno and others (Sereno *et al.*, 1994, 1996, 1998; Currie, 1996) in northern Africa potentially provides a more reliable picture of the early Late Cretaceous Afro-Arabian theropod fauna. From Sereno *et al.* (1996), the picture emerges that advanced allosaurids like *Carcharodontosaurus* flourished on the African continent until the Late Cretaceous.

Although the original material of *Carcharodontosaurus* and *Spinosaurus* that E. Stromer collected from Cenomanian deposits in Egypt during the early 20th century was lost during a Second World War bombing raid on Munich, it is possible to make comparisons of the Al-Khod vertebra with those described by Stromer (1915, 1934). Based on these descriptions and illustrations, the specimen described here differs from *Spinosaurus* in being much stouter, platycoelous and having a 1:1 aspect ratio. Compared to *Carcharodontosaurus* (Stromer, 1931, pl. 1, fig. 10a, b), dimensions and aspect ratio correspond well with the present specimen, but as far as can be judged from the illustration the chevron articulation facets are more pronounced in *Carcharodontosaurus*, and the neural arch seems to attach over a greater length of the centrum than is seen in the present specimen.

In addition, compared to vertebrae of the caudal series of the Late Jurassic theropod *Allosaurus fragilis*, the overall appearance of the centrum closely resembles that of proximal caudal 2, but differs in being much stouter than *Allosaurus*. With an axial length of 92 mm, and assuming an allometry comparable to *Allosaurus*, the total length of the Omani animal would have been approximately 6–7 m.

In comparison to proximal caudals of the abelisaurid theropod *Majungatholus atopus* from the Late Cretaceous of Madagascar (Sampson *et al.*, 1996, 1998), the caudal from Al-Khod is much stouter in general appearance, axially relatively shorter proximocaudally, and considerably less waisted.

More Late Cretaceous theropod material may be expected to come to light in the near future from the Cenomanian Baharîya Formation (Egypt), where some partial theropod skeletons were recorded during a reconnaissance expedition early in 1999 (Smith *et al.*, 1999). Sampson *et al.* (1998) presented an overview of Cretaceous Gondwanan theropod biogeography in which they predicted a greater similarity between the Late Cretaceous terrestrial biota of South America and Indo-Madagascar (via Antarctica) and an increasing endemism in Afro-Arabia. Although based thus far on a single vertebra, the dinosaur material from the Sultanate of Oman shows promise that the region may yet yield more theropod specimens and thereby provide one of the few opportunities to test this hypothesis.

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