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The first record of a sauropod dinosaur from the Late Cretaceous phosphates of Morocco

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Abstract

Sauropod dinosaur remains have been discovered recently in the Late Cretaceous (Maastrichtian) phosphatic deposits of the Oulad Abdoun Basin, near Khouribga (central Morocco). The material consists of right hindlimb bones (femur, tibia and fibula) from a small-sized individual. The marine associated fauna, mainly selachians, actinopterygians, turtles, mosasaurids and plesiosaurs, suggests a marine depositional environment, so that the dinosaur remains may be a remnant of a floating carcass. The femur exhibits a prominent lateral bulge on the proximal one-third, a diagnostic feature of Titanosauriformes. The Moroccan sauropod lacks synapomorphies of Titanosauria and less inclusive clades (i.e., distal tibia expanded transversely to twice mid-shaft breadth; femoral distal condyles angled dorsomedially relative to the shaft); therefore, it is here assigned to a basal titanosauriform as Titanosauriformes indet. This is the first sauropod reported from the Maastrichtian of Morocco and one of the few dinosaur records from the uppermost Cretaceous formations of northern Africa. This discovery confirms the wide geographical distribution of Titanosauriformes during the Late Cretaceous and supports their survival into the Late Maastrichtian of Africa.

Résumé

Des restes fossiles appartenant à un dinosaure sauropode ont été récemment découverts dans les dépôts phosphatés du Crétacé supérieur (Maastrichtien) du Bassin des Oulad Abdoun, près de Khouribga (Maroc). Il s'agit d'os du membre postérieur droit (fémur, tibia et fibula) d'un individu de petite taille. La faune marine associée, comprenant principalement des sélaciens, des actinoptérygiens, des tortues, des mosasaures et des plésiosaures, suggère un millieu de dépôt marin, de sorte que les restes de sauropode pourraient provenir d'un cadavre flotté. Le fémur présente un gonflement latéral proéminent sur le tiers proximal, un caractère diagnostique des Titanosauriformes. Le sauropode marocain ne montre pas de synapomorphies de Titanosauria ou de clades moins inclusifs (par exemple, extrémité distale du tibia mesurant transversalement au moins le double de la largeur prise au milieu de la diaphyse; condyles distaux du fémur orientés dorsomédialement par rapport à la diaphyse); il est ici attribué à un titanosauriforme basal indéterminé. Il s'agit de la première mention d'un sauropode dans le Maastrichtien du Maroc et d'un des rares spécimens de

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dinosaure trouvés jusqu'à présent dans les formations d'âge finicrétacé d'Afrique du Nord. Cette découverte confirme la vaste distribution géographique des Titanosauriformes durant le Crétacé supérieur et plaide en faveur de leur survie dans le Maastrichtien supérieur d'Afrique.

Keywords: Dinosauria; Sauropoda; Titanosauriformes; Phosphates; Maastrichtian; Morocco
Mots clés: Dinosauria; Sauropoda; Titanosauriformes; Phosphates; Maastrichtien; Maroc

1. Introduction

Dinosaur remains from Morocco have been found since the 1920s, when sauropod and theropod bones were collected from the Middle Jurassic of the Fès region (Termier et al., 1940; de Lapparent, 1955). Since then, important dinosaur specimens have been found at a number of Moroccan localities, the most significant are those of the sauropod *Atlasaurus* from the Middle Jurassic (Bathonian-Callovian) of the central High Atlas Mountains (Monbaron et al., 1999), and of the theropods *Carcharodontosaurus*, *Deltadromeus* and *Spinosaurus*, as well as the sauropod *Rebbachisaurus*, all from the Albian-Cenomanian of the Kem Kem region (Lavocat, 1954; Russell, 1996; Sereno et al., 1996). In addition, the Moroccan record includes dinosaur footprints from the Upper Triassic of the Argana Basin, the Lias and Middle Jurassic of the central High Atlas and the Middle Atlas (see Dutuit and Ouazzou, 1980; Jenny et al., 1981; Monbaron et al., 1985 and references therein), and the Upper Cretaceous (Maastrichtian) of Agadir (Ambroggi and de Lapparent, 1954).

Recently, sauropod remains have been found during palaeontological fieldwork in the Maastrichtian phosphatic deposits near Khouribga (Morocco). This discovery results from the active collaboration between the Office Chérifien des Phosphates (OCP), the Ministère de l'Energie et des Mines and the Centre National de la Recherche Scientifique (CNRS) in the Oulad Abdoun Basin of central Morocco over the last few years (see Gheerbrant et al., 2003; Bardet et al., 2004). The aim of this paper is to describe the sauropod material and to discuss its main implications.

The specimen described here is kept at the Laboratoire de Paléontologie of the Office Chérifien des Phosphates (Khouribga, Morocco) under the number collection OCP DEK/GE 31.

2. Geographical and geological setting

The sauropod remains were discovered in the eastern part of the Oulad Abdoun Phosphatic Basin, near the city of Khouribga, Morocco (Fig. 1A and B). They come from a site about 1.5 km south of "point A" (N 32°51′236″, W 6°38′641″) in Sidi Daoui, in the northern part of Grand Daoui, an area actively quarried for phosphate. Stratigraphically, the sauropod remains occur in the upper part of the phosphatic unit called "couche III" (bed III) by the miners, which is Late Maastrichtian on the basis of selachian teeth (Cappetta, 1987). In addition to the dinosaur bones, the site has yielded isolated selachian and mosasaurid teeth as well as bones of large marine turtles.

The Maastrichtian phosphatic series of the Oulad Abdoun Basin ("Couche III") is very condensed, being only about 2–5 m thick. It consists of two units: the lower Couche III is composed of a basal grey limestone rich in fish remains and yellow, soft, exploited phosphates; the upper Couche III is composed of grey (with brown stripes), soft, exploited phosphates and marls; these two units are separated by a thin yellow marly level (Fig. 1C). The vertebrate fauna consists mainly of sharks and rays, actinopterygians, mosasaurids, plesiosaurs, turtles (Arambourg, 1952; Cappetta, 1987; Noubhani and Cappetta, 1997; Bardet et al., 2004) and recently discovered pterosaur remains (Pereda Suberbiola et al., 2003). This fauna as a whole indicates a marine depositional environment (Arambourg, 1952). The sauropod bones were found closely associated and therefore most probably belong to the same individual. They may be a remnant of a floating carcass that drifted over a distance from a land area.

3. Description

The specimen (OCP DEK/GE 31) consists of a partial right hindlimb, including the femur, tibia and fibula (Fig. 2). The remains are still partly in the matrix, so the following description is based on visible parts. The bones are broken and relatively crushed, with the external surface chipped off in places, mainly in the proximal regions of the femur and tibia. For measurements see Table 1.

The femur, approximately 1 m long, is broken at the midlength. The shaft is straight and relatively robust. The proximal end is slightly more expanded than the distal one. The femoral head is oriented at about 100–110° to the shaft. It rises slightly above the greater trochanter. There is no evidence of a lesser trochanter. The shaft is deflected medially on the proximal third of the lateral margin, forming a prominent bulge below the greater trochanter (Fig. 2A). As quantified by

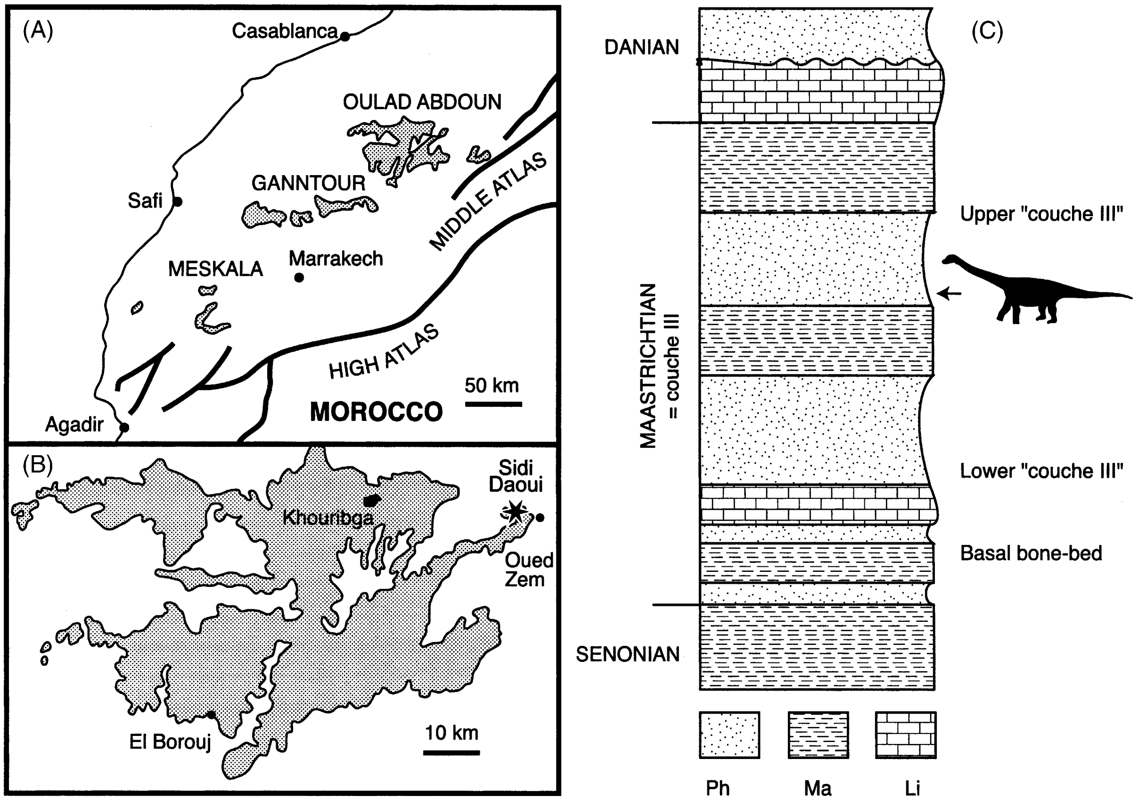

Fig. 1. Location map of the sauropod site in the Oulad Abdoun Basin of Morocco (A,B) and stratigraphical log showing the occurrence of the specimen in the Maastrichtian phosphatic series (C). Abbreviations: Li, limestones; Ma, marls; Ph, phosphates.

Fig. 2. OCP DEK/GE 31, Titanosauriformes indet., partial right hindlimb bones: (A) femur in posterior view; (B) tibia in posterior view; (C) fibula in medial view. The arrow indicates the medial deflection of the proximal third of the femur. Scale bars: 100 mm.

Table 1
Measurements in mm of the right hindlimb bones (OCP DEK/GE 31) of the Moroccan sauropod

	Femur	Tibia	Fibula
Length	1000	605	575+
Maximum width of proximal end	290	250	155
Maximum width of distal end	275	165	100
Minimum width of shaft	175	130	75

Salgado et al. (1997, Fig. 10), the distance from the straight line that contains the greater trochanter and the lateral point of the shaft where it reaches its minimum transverse width up to the parallel that comprises the most lateral point of the lateral bulge, is about 36% of the minimum transverse width of the shaft. At the midlength, the shaft is elliptical in cross-section, with a transverse diameter about two and a half times the anteroposterior diameter. The transverse section displays a cancellous bone thicker than the surrounded compact bone. The fourth trochanter is weakly developed on the proximal half of the lateral margin of the femur, near the midlength of the shaft. The distal condyles are oriented perpendicular to the femoral shaft. The medial condyle is broader than the lateral one. The articular surfaces of the condyles are restricted to the distal portion of the femur.

The tibia and fibula are broken in two fragments at the midlength (Figs. 2B and C). The tibia is approximately 60% of the femur length ratio and, unlike the common condition in sauropods (McIntosh, 1990), it seems to be slightly longer than the fibula. The proximal end is more expanded than the distal one, nearly twice the midshaft width; the distal extremity is approximately 125% of the midshaft width. The proximal condyle is elliptical, with the long axis expanded transversely (but there is evidence of anteroposterior flattening of the condyle due to crushing). The cnemial crest is projected laterally and dorsally expanded. As preserved, the greater expansion of the cnemial crest is not below the level of the condyle surface but approximately at the same level, resembling more the condition observed in prosauropods and other dinosaurs than in sauropods. On the distal third, the shaft has also suffered deformation: it is medially expanded and delimits an ovoid cavity. This feature, unknown in sauropod tibiae (McIntosh, 1990), is probably a taphonomic artefact owing to compression. The distal end of the tibia is not expanded transversely. The posteroventral process is narrow and projects distally below the articular surface for the ascending process of the astragalus.

The fibula is relatively robust and nearly straight. Proximally, the articular surface for the tibia is developed as a triangular area that extends downward up to about a quarter of the fibular length. The presence of a lateral trochanter cannot be confirmed, as the lateral side of the fibula is still unprepared. The distal condyle is not expanded transversely but is approximately subequal to the breadth of the shaft.

Based on comparisons of the femur plus tibia/fibula to total length ratio from sauropod skeletal reconstructions (McIntosh et al., 1997; Wilson and Sereno, 1998; Lehman and Coulson, 2002), the estimated total length of the Moroccan specimen was about 9–10 m.

4. Discussion

The dinosaur remains from the phosphates of Morocco can clearly be placed among the Sauropoda because of the elliptical cross-sectional shape of the femur (long axis oriented mediolaterally), and because of the reduced fourth trochanter (Upchurch, 1998; Wilson and Sereno, 1998; Wilson, 2002). Moreover, the material exhibits the following synapomorphies of Eusauropoda (all sauropods but *Vulcanodon;* Upchurch, 1995): absence of lesser trochanter; tibial condyle much broader than the fibular one on the femur; cnemial crest projected laterally; and reduced distal posteroventral process on the tibia (Salgado et al., 1997; Wilson and Sereno, 1998; Wilson, 2002). Although the tibia of the Moroccan sauropod is crushed anteroposteriorly, it is reminiscent of *Jobaria* and Neosauropoda, the clade comprising Diplodocoidea and Macronaria (Wilson and Sereno, 1998), in having a transversely expanded proximal condyle.

The Moroccan sauropod is referred to the Titanosauriformes on the basis of the presence of a prominent lateral bulge on the proximal one-third of the femoral shaft (see McIntosh, 1990; Salgado et al., 1997; Upchurch, 1998; Wilson and Sereno, 1998; Wilson and Carrano, 1999; Curry Rogers and Forster, 2001; Smith et al., 2001; Wilson, 2002). According to Wilson and Sereno (1998), the clade Titanosauriformes includes the Brachiosauridae and Somphospondyli (*Euhelopus*+Titanosauria). Within Titanosauriformes, the Moroccan sauropod lacks the following synapomorphy of Titanosauria: distal end of tibia expanded transversely to twice mid-shaft breadth (Wilson, 2002). In addition, it lacks synapomorphies of less inclusive clades within Titanosauria. For example, the femoral distal condyles are approximately perpendicular to the long axis of the shaft rather than angled dorsomedially as in saltasaurids (Wilson and Carrano, 1999; Wilson, 2002). It should be noted that the transverse diameter at midshaft of the femur of the Moroccan specimen is approximately twice the anteroposterior diameter (marked femoral eccentricity of Wilson and Carrano, 1999), as is commonly the case in *Saltasaurus*. However, this feature could be better explained as the result of crushing, a current phenomenon observed in vertebrate bones of the phosphatic deposits of Morocco.

The Moroccan sauropod has been compared to basal Titanosauriformes, especially the Brachiosauridae (*Brachiosaurus* and closely related forms; see below) and non-titanosaur somphospondylians (Wilson, 2002, Table 13). Brachiosaurids consist *of Brachiosaurus*, *Bothriospondylus*, *Cedarosaurus*, *Sauroposeidon*, and *Venenosaurus* (Wedel et al., 2000; but note that Salgado and Calvo, 1997 regarded the Brachiosauridae as a paraphyletic assemblage). The Moroccan specimen is similar to *Brachiosaurus brancai* from the Late Jurassic of Tanzania (Janensch, 1961) in having a fourth trochanter located proximally on the femoral shaft, near the medial margin, and a nearly straight fibula, but it differs in that the tibia and fibula are more robust than in *Brachiosaurus* and the distal condyle of the fibula is not expanded transversely but is scarcely broader than the midshaft (Figs. 3A and B, 4A and B, 5A and B). A broadly expanded distal condyle is also present in the fibula *of Bothriospondylus madagascariensis* from the Late Jurassic of France (de Lapparent, 1943). The femur and tibia of *Bothriospondylus* are larger in size than those of the Moroccan sauropod, and the slender femur has a less prominent lateral bulge (Fig. 3C, 4C). *Cedarosaurus weiskopfae* from the Early Cretaceous of North America (Tidwell et al., 1999) differs from OCP DEK/GE 31 in having a more distinct femoral head and a reduced medial deflection on the proximal third

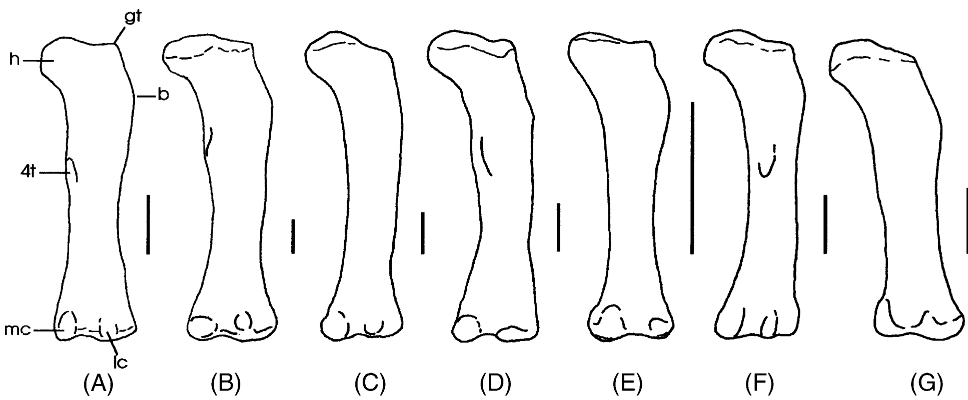

Fig. 3. Schematic drawings of titanosauriform femora in posterior view. (A) Moroccan sauropod OCP-DEK/GE 31; (B) *Brachiosaurus brancai* (after Janensch, 1961, J, Fig. 1a); (C) *Bothriospondylus madagascariensis* (after de Lapparent, 1943, pl. 9, Fig. 15); (D) *Phuwiangosaurus sirindhornae* (after Martin et al., 1999, Fig. 18, 2); (E) juvenile *Pleurocoelus nanus* (after Lull, 1911, pl. 17, Fig. 2); (F) *Euhelopus zdansky* (after Wiman, 1929, pl. 4, Fig. 5); (G) *Saltasaurus loricatus* (after Powell, 2003, pi. 44, Fig. c; reversed). Abbreviations: 4t, fourth trochanter; b, lateral bulge; gt, greater trochanter; h, femoral head; 1c, lateral (fibular) condyle; mc, medial (tibial) condyle. Bones are normalized to the same length for comparison. Scale bars equal to 200 mm.

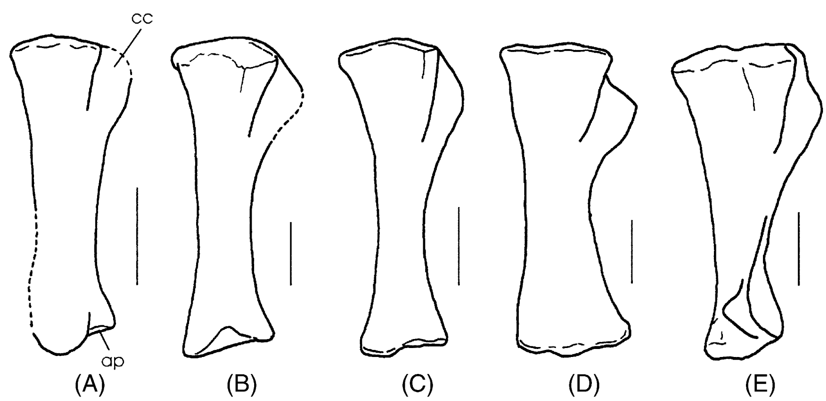

Fig. 4. Schematic drawings of titanosauriform tibiae in lateral view. (A) Moroccan sauropod OCP-DEK/GE 31; (B) *Brachiosaurus brancai* (after Janensch, 1961, K, Fig. 1a); (C) *Bothriospondylus madagascariensis* (after de Lapparent, 1943, pl. 8, Fig. 2a; reversed); (D) *Tangvayosaurus hoffeti* (after Allain et al., 1999, Fig. 2e; reversed); (E) *Saltasaurus loricatus* (after Powell, 2003, pl. 45, Fig. 1b). Abbreviations: ap, articular surface for ascending process of astragalus; cc, cnemial crest. Bones are normalized to the same length for comparison. Scale bars equal to 200 mm.

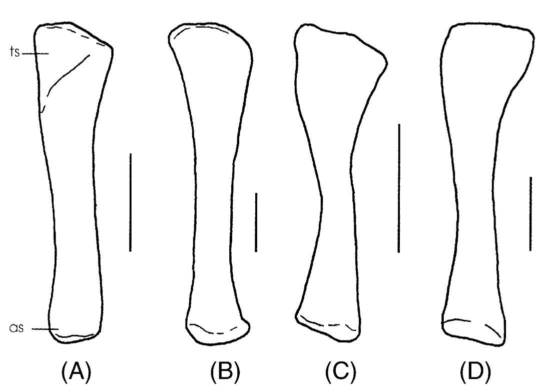

Fig. 5. Schematic drawings of titanosauriform fibulae in medial view. (A) Moroccan sauropod OCP-DEK/GE 31; (B) *Brachiosaurus brancai* (after Janensch, 1961, K, Fig. 2b; reversed); (C) *Alamosaurus sanjuanensis* (after Lehman and Coulson, 2002, Fig. 10.2; reversed); (D) *Saltasaurus loricatus* (after Powell, 2003, pl. 46, Fig. a; reversed). Abbreviation: as, astragalar articular surface; ts, tibial articular surface. Bones are normalized to the same length for comparison. Scale bars equal to 200 mm.

of the shaft. *Sauroposeidon proteles* (Wedel et al., 2000) and *Venenosaurus dicrocei* (Tidwell et al., 2001), both from the Early Cretaceous of North America, do not preserve hindlimb elements and thus are irrelevant to our comparison.

The femur of the Moroccan sauropod looks like that of *Austrosaurus mckillopi*, a basal titanosauriform from the Albian of Australia (Coombs and Molnar, 1981, pl. 5b), in the position and development of the lateral bulge, but differs in having a less defined articular head. The titanosauriform *Tangvayosaurus hoffeti* from the Aptian-Albian of Laos (Allain et al., 1999) has a more massive femur whose fibular condyle is located more medially than in the Moroccan sauropod. The femur *of Tangvayosaurus* is similar in some respects to that of *Phuwiangosaurus* from the Early Cretaceous of Thailand (Fig. 3D), which has been regarded as nemegtosaurid (Martin et al., 1999) and titanosaurian (Wilson, 2002). The juvenile titanosauriform *Pleurocoelus nanus* from the Early Cretaceous of USA (Lull, 1911; Langston, 1974) shows less robust hindlimb bones than the Moroccan specimen (Fig. 3E), with a tibia more expanded distally. The latter character is also observed in *Tangvayosaurus* (Fig. 4D).

In *Euhelopus zdanskyi* from the Early Cretaceous of China (Wiman, 1929), the fourth trochanter is more marked than in the Moroccan sauropod and it is not located on the lateral margin of the femur (Fig. 3F). The phylogenetic relationships *of Euhelopus* are controversial (see discussion in Wilkinson et al., 2000; Wilson, 2002), having been regarded as a basal somphospondylian (Wilson and Sereno, 1998) and a member of Euhelopodidae, a clade that occupies a basal position within Eusauropoda (sensu Upchurch, 1995, 1998). In addition to a distal tibia expanded transversely, the fibula of titanosaurians commonly exhibits a sigmoid curvature (see Salgado et al., 1997; Wilson, 2002) (Figs. 4E, 5C and D). As noted below, the femoral distal condyles are angled dorsomedially relative to the long axis of the shaft in saltasaurids (Wilson and Carrano, 1999) (Fig. 3G).

The cnemial crest of the Moroccan tibia is not below the level of the condyle surface as in all other sauropods but is dorsally expanded. This feature could be a diagnostic character or, more probably, an artefact due to deformation.

To sum up, the Moroccan material is referred to as Titanosauriformes gen. et sp. indet. Pending new discoveries, the fossils are here provisionally regarded as those of a basal titanosauriform different from known brachiosaurids and *Euhelopus*.

5. Implications

Up to now, dinosaur remains were unknown in the uppermost Cretaceous formations of northern Africa, with the exception of a few theropod and ornithischian records from Egypt (Stromer and Weiler, 1930; Weishampel, 1990). In their review of Cretaceous dinosaurs of Africa, Jacobs et al. (1996, Table 1) mentioned, following Weishampel (1990), the occurrence of a "titanosaurid indet" in the Maastrichtian of Agadir. This is probably a mistake because Weishampel (1990, p. 138) listed solely theropod footprints in Agadir (see Ambroggi and de Lapparent, 1954). The hindlimb bones from the Oulad Abdoun Basin represent the first sauropod remains reported from the Maastrichtian of Morocco and northern Africa. This discovery fills a gap of approximately 20 My, as the youngest sauropod remains known to date in Morocco were those from the mid-Cretaceous Kem Kem beds ("Continental Intercalaire") of the Tafilalt region. The age of the Kem Kem beds is considered Albian (Russell, 1996) or Cenomanian (Sereno et al., 1996; Wellnhofer and Buffetaut, 2000). Sauropods from the red sandstones ("Grès rouges infracénomaniens") of the Tafilalt include the diplodocoid *Rebbachisaurus* and a basal titanosauriform. Russell (1996) referred two caudal centra and an astragalus to the latter as Andesaurinae indet. The neural arches of the vertebrae are shifted to the anterior end of the centra, as in Titanosauriformes (Salgado et al., 1997). Moreover, they differ from those of Titanosauria except *Malawisaurus* (Jacobs et al., 1993) in having amphicoelous articular faces (see Wilson, 2002). Unfortunately, this material cannot be compared with the Khouribga specimen.

Sauropods from the Late Cretaceous of Africa consist mainly of titanosauriforms, but diplodocoid material has also been reported (see Buffetaut, 1988; Jacobs et al., 1996). Diplodocoids are represented by a possible rebbachisaurid scapula from the Cenomanian Baharija Formation of Egypt (Smith et al., 2001). Baharija titanosaurs consist of *Aegyptosaurus* and *Paralititan* (Stromer, 1932; Smith et al., 2001). In addition, titanosaur bones occur in the Albian-Cenomanian Wadi Milk Formation of Sudan (Buffetaut et al., 1990; Werner, 1994; Rauhut and Werner, 1995), the Santonian of Zululand, South Africa (Kennedy et al., 1987), and the Senonian of Niger (Greigert et al., 1954; de Broin et al., 1974). Titanosaur remains have also been reported from the middle to Late Cretaceous of the Turkana Grits of Kenya, but the age of the fossils is under debate (Arambourg and Wolf, 1969; Wescott et al., 1993).

Titanosauriforms, particularly titanosaurs, attained a near-global distribution by the end of the Cretaceous as their remains are known in North and South America, Europe, Asia, Africa, India and Madagascar (see Hunt et al., 1994; Upchurch, 1995, 1998; Wilson and Sereno, 1998; Curry Rogers and Forster, 2001; Wilson, 2002; Powell, 2003 and references). Though the occurrence of a member of Titanosauriformes in the latest Cretaceous of Morocco is not unexpected, this discovery is worthy of consideration because non-titanosaur titanosauriforms are still poorly known and occur preferentially in the Lower Cretaceous formations. Interestingly, the Moroccan specimen, one of the youngest sauropod records worldwide, demonstrates the survival of Titanosauriformes into the Late Maastrichtian of northern Africa.

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