A PHOTOGRAPHIC ATLAS OF THE PES FROM A HADROSAURINE HADROSAURID DINOSAUR

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ABSTRACT

Hadrosaurid dinosaurs are abundantly represented in terrestrial deposits from the Late Cretaceous, as isolated elements, associated specimens, and articulated skeletons with soft tissue. However, identification of isolated elements can be difficult in the absence of adequate reference material. Here we present a photographic atlas of the complete pes from a hadrosaurine hadrosaurid (possibly *Edmontosaurus annectens*) collected in the Hell Creek Formation of Montana.

Introduction

Hadrosauridae was one of the most widespread clades of ornithischian dinosaurs during the Late Cretaceous. Commonly referred to as "duck-billed dinosaurs," in reference to their broad, toothless beaks, hadrosaurs have been recovered in Europe, Asia, North and South America, and Antarctica (Horner *et al.*, 2004; Weishampel *et al.*, 2004). Anatomically, hadrosaurs are also among the best-known dinosaurs. Numerous complete, articulated skeletons from all ontogenetic stages, often with extensive soft tissue preservation, are known from throughout the Western Interior of North America. Isolated elements are also quite common.

Consequently, many aspects of the anatomy of hadrosaurids have been thoroughly described and figured for multiple taxa by numerous authors (*e.g.*, Dilkes, 2000; Lull & Wright, 1942; Parks, 1920). Surprisingly, however, the pes has never been comprehensively figured in a publication, even though numerous articulated and isolated pedal phalanges and metatarsals are known. Detailed written descriptions exist (*e.g.*, Parks, 1920; Prieto-Márquez, 2007; Suzuki *et al.*, 2004), but most published illustrations only

present one or two views of the entire foot (*e.g.*, Lull & Wright, 1942; Parks, 1920) or selected elements. Thus, these papers are of limited utility for identifying isolated or incomplete bones.

Here we present a comprehensive photographic atlas of the hadrosaur foot, with multiple views and measurements for each individual bone (figures 1-7, tables 1-2). The specimen in question, possibly pertaining to *Edmontosaurus annectens,* was preserved in partial articulation with skin impressions (Wideman & Lofgren, 2001). All elements are uncrushed, and rarely identified bones, such as a tarsal IV, were also found with the specimen. Thus, it presents an ideal examplar of a hadrosaurine hadrosaurid pes. Our hope is that these figures will be a useful aid for researchers, preparators, collections managers, and curators identifying specimens in the absence of a reference collection.

Institutional Abbreviations

RAM, Raymond M. Alf Museum of Paleontology, Claremont, California, USA.

Systematic Paleontology

Dinosauria Owen, 1842
Ornithischia Seeley, 1888
Hadrosauridae Cope, 1869
Hadrosaurinae Lambe, 1918
Gen. et sp. indet.

Material – RAM 7150, a partial, mostly articulated skeleton preserving the right hindlimb complete below the mid-shaft of the femur, right ischium, 77 caudal vertebrae, 23 chevrons, and skin impressions. The pes and tarsals were entirely articulated, except for two pedal unguals (II-3 and IV-5), which were disarticulated but associated within 10 cm and 50 cm of their digits, respectively.

Locality – RAM V97048, McCone County, Montana, USA. Detailed locality data are on file at the RAM and available to qualified researchers upon request.

Stratigraphic Horizon and Lithology – Hell Creek Formation, late Maastrichtian (Brown, 1907; Hicks *et al.*, 2002). The specimen is preserved at the base of a sandstone channel cutting into an underlying siltstone, approximately 8 meters below the contact between the Hell Creek Formation and the overlying Tullock Formation.

Discussion – RAM 7150 is identified as a hadrosaurine hadrosaurid (Saurolophinae of Prieto-Márquez, 2010) based on the rod-like morphology of the distal end of the ischium, which is distinct from the expanded distal end of the ischium seen in lambeosaurine hadrosaurids and many non-hadrosaurid iguanodontians (Horner *et al.*, 2004). Although the specimen cannot be unambiguously identified more precisely (particularly in the absence of a skull), it might pertain to *Edmontosaurus annectens*; this is the only currently recognized hadrosaurid taxon in the Hell Creek Formation (Campione & Evans, 2011).

Most aspects of the pes of RAM 7150 (figures 1-7) coincide closely with previously described examples from hadrosaurines (*e.g.*, Parks, 1920; Maryańska & Osmólska, 1984; Prieto-Márquez, 2007, 2010), particularly in the proportions and surface morphology of the individual elements. The only major departure concerns the anomalous ungual on digit IV (figures 1-6). The lateral margin of the distal end of the ungual is truncated. In dorsal view, most of the bone texture is normal in appearance with a slight raised ridge trending proximo-distally (potentially representing a fracture callus). In ventral view, the bone of the lateral half of the phalanx is considerably eroded, with a finished texture proximally and a more porous texture distally. The articular surface is unaffected. Selected measurements of all elements are presented in tables 1 and 2.

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	AP	ML	PD
Astragalus	150	206	98
Calcaneum	115	108	70
Tarsal IV	45	38	16

Table 1. Measurements of tarsals from the right pes of a hadrosaurine hadrosaurid dinosaur, RAM 7150, in millimeters. Length is maximum length; other measurements are at the proximal end and distal end. *indicates maximum width of ungual. Abbreviations: AP, maximum anteroposterior length; ML, maximum mediolateral width; PD, maximum proximodistal height.

		Proximal End		Distal End	
	Length	ML	DP	ML	DP
MT II	281	85	207	167	107
Ph. II-1	153	147	105	100	98
Ph. II-2	68	97	72	94	50
Ph. II-3	100	89	51	-	*98
MT III	397	89	203	141	157
Ph. III-1	151	160	106	143	73
Ph. III-2	52	132	50	139	75
Ph. III-3	34	118	57	106	106
Ph. III-4	109	111	57	-	*126
MT IV	279	139	100	118	115
Ph. IV-1	114	143	106	116	83
Ph. IV-2	38	102	76	100	66
Ph. IV-3	29	89	65	93	57
Ph. IV-4	33	82	57	78	51
Ph. IV-5	95	87	61	-	*102

Table 2. Measurements of metatarsals and phalanges from the right pes of a hadrosaurine hadrosaurid dinosaur, RAM 7150, in millimeters. Length is maximum length; other measurements are at the proximal end and distal end. Only one measurement at the distal end is provided for the distal terminal phalanges, due to their complex shape. *indicates maximum width of ungual. Abbreviations: DP, maximum dorsoplantar height; ML, maximum mediolateral width; MT, metatarsal; ph, phalanx.

Figure 1. Right pes from a hadrosaurid dinosaur, RAM 7150, with individual elements in dorsal view. Note that metatarsals II and III are preserved in articulation; the arrow associated with phalanx IV-5 indicates a possible fracture callus. Minor differences in coloration between elements in this and subsequent figures reflect weathering as well as lighting during photography. Photography by the authors. Courtesy of RAM.

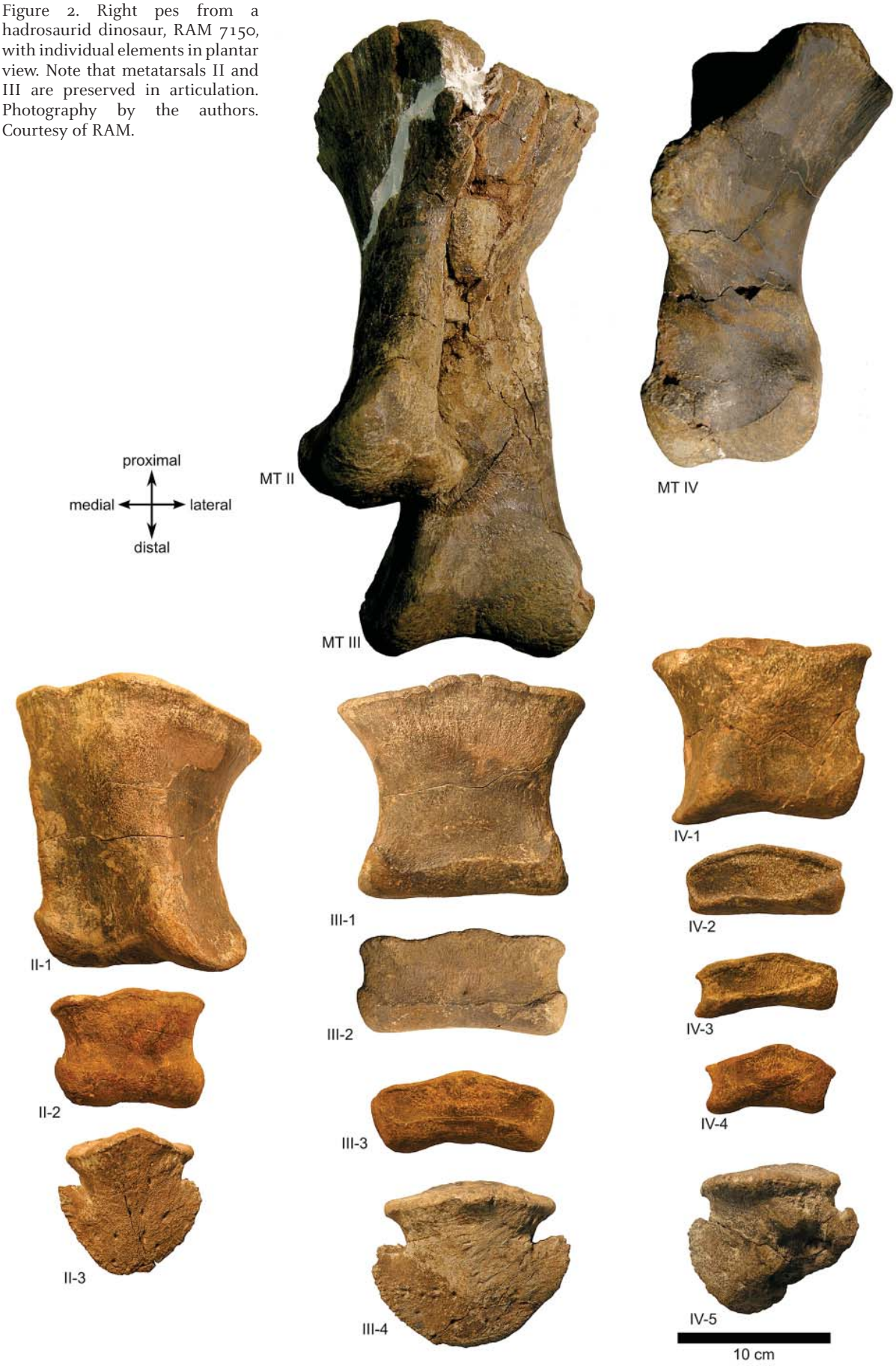

Figure 2. Right pes from a hadrosaurid dinosaur, RAM 7150, with individual elements in plantar view. Note that metatarsals II and III are preserved in articulation. Photography by the authors. Courtesy of RAM.

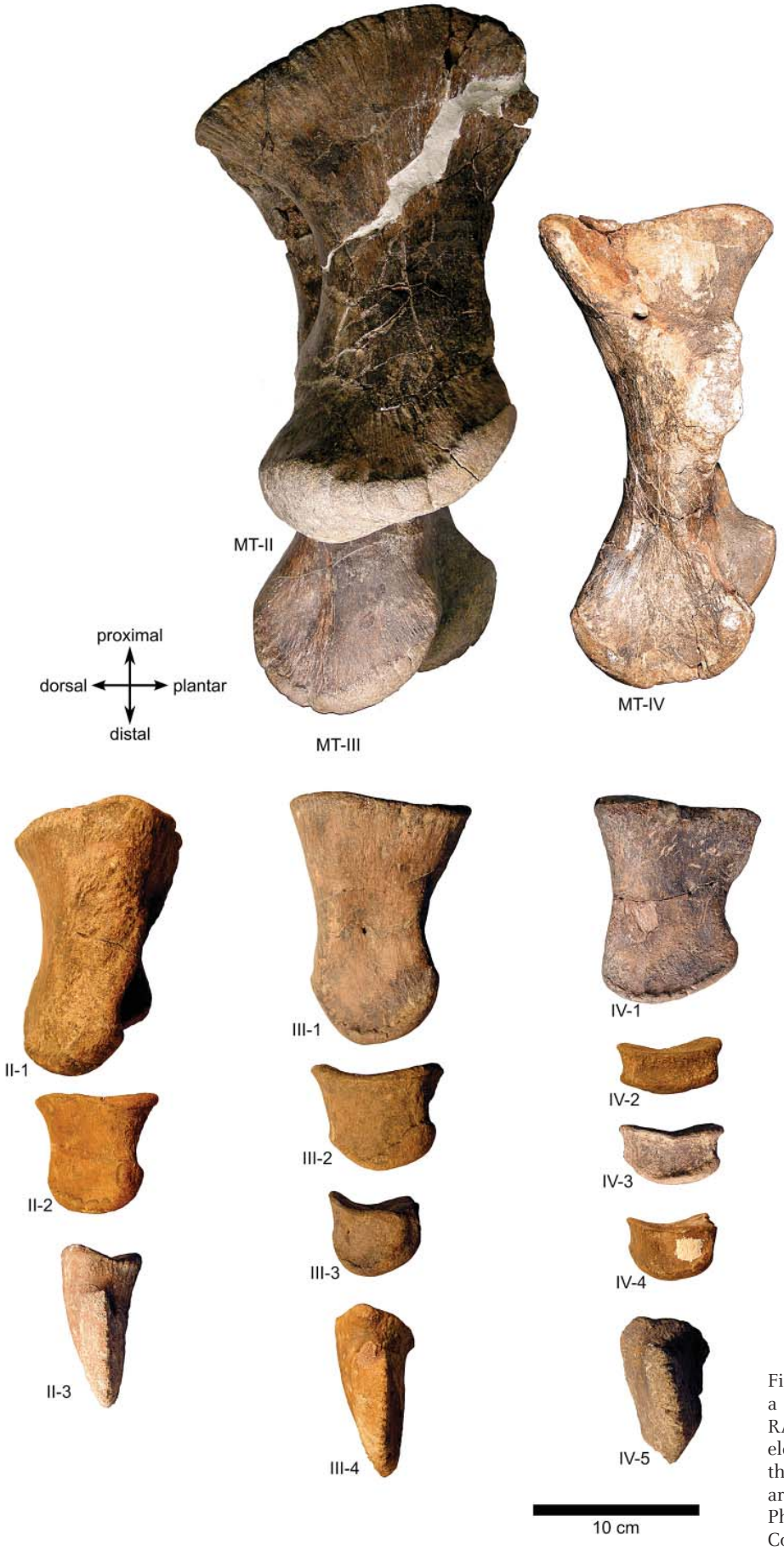

Figure 3. Right pes from a hadrosaurid dinosaur, RAM 7150, with individual elements in medial view. Note that metatarsals II and III are preserved in articulation. Photography by the authors. Courtesy of RAM.

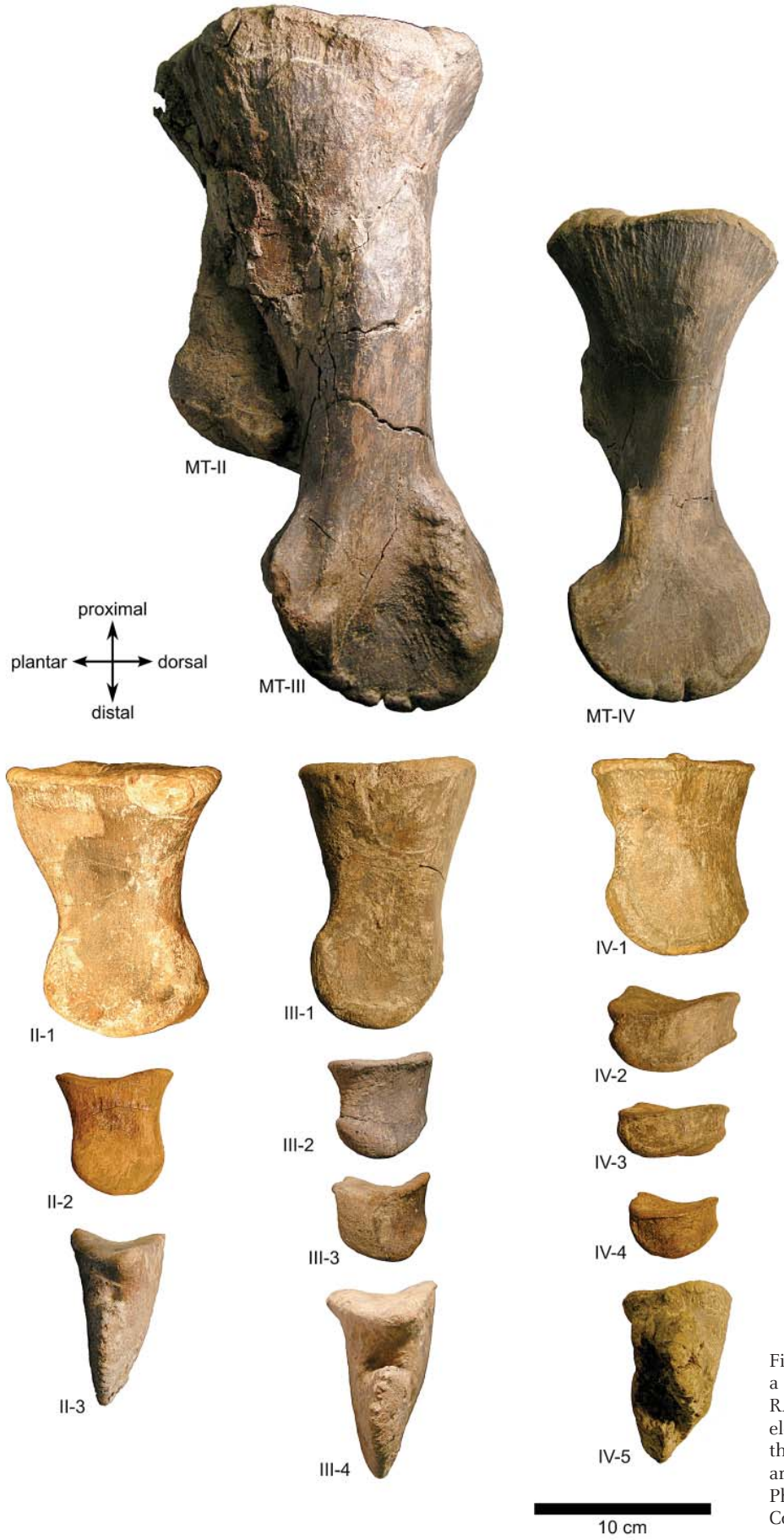

Figure 4. Right pes from a hadrosaurid dinosaur, RAM 7150, with individual elements in lateral view. Note that metatarsals II and III are preserved in articulation. Photography by the authors. Courtesy of RAM.

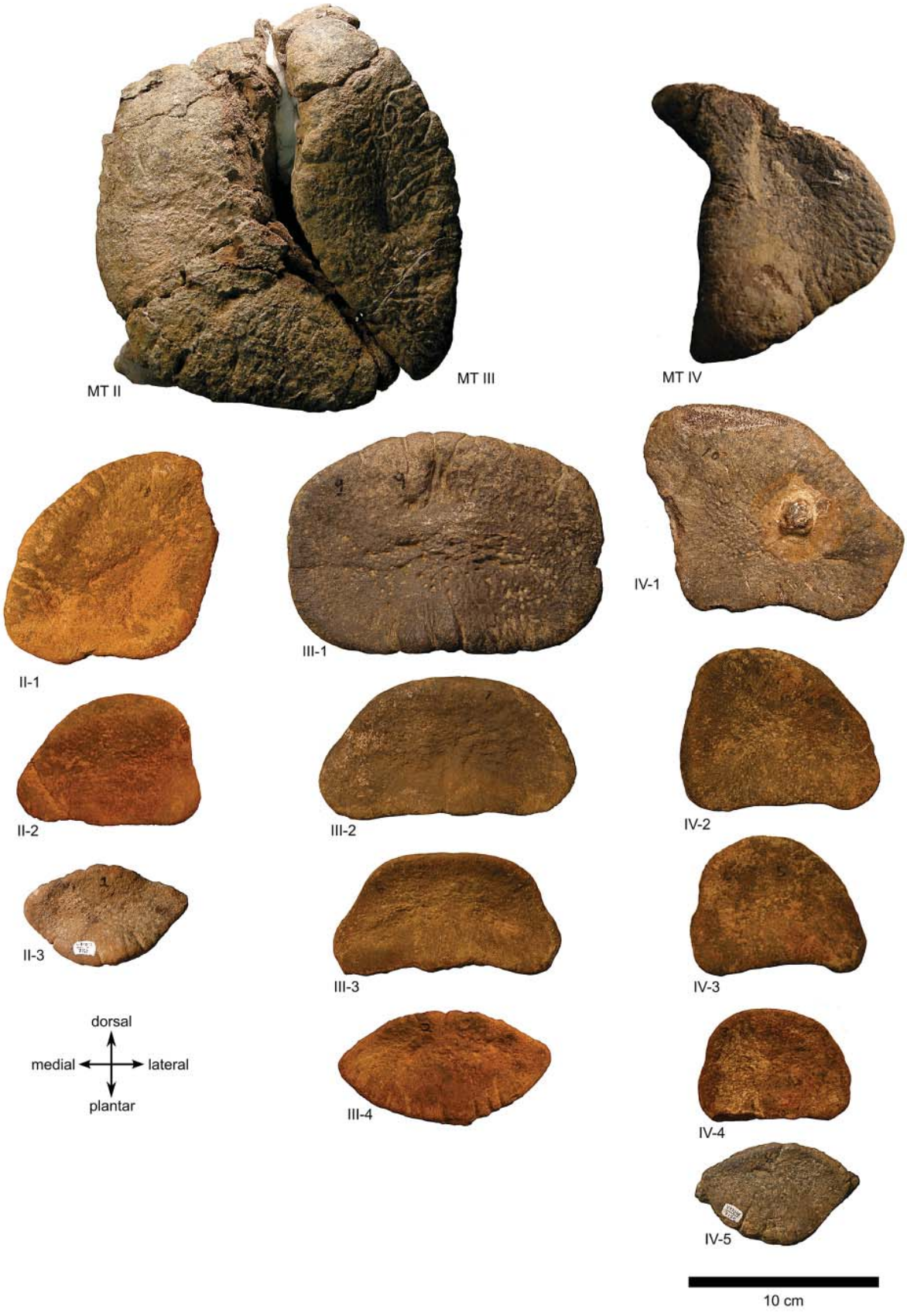

Figure 5. Right pes from a hadrosaurid dinosaur, RAM 7150, with individual elements in proximal view. Note that metatarsals II and III are preserved in articulation. Photography by the authors. Courtesy of RAM.

Figure 6. Right pes from a hadrosaurid dinosaur, RAM 7150, with individual elements in distal view. The arrow associated with phalanx IV-5 indicates a possible fracture callus. Photography by the authors. Courtesy of RAM.

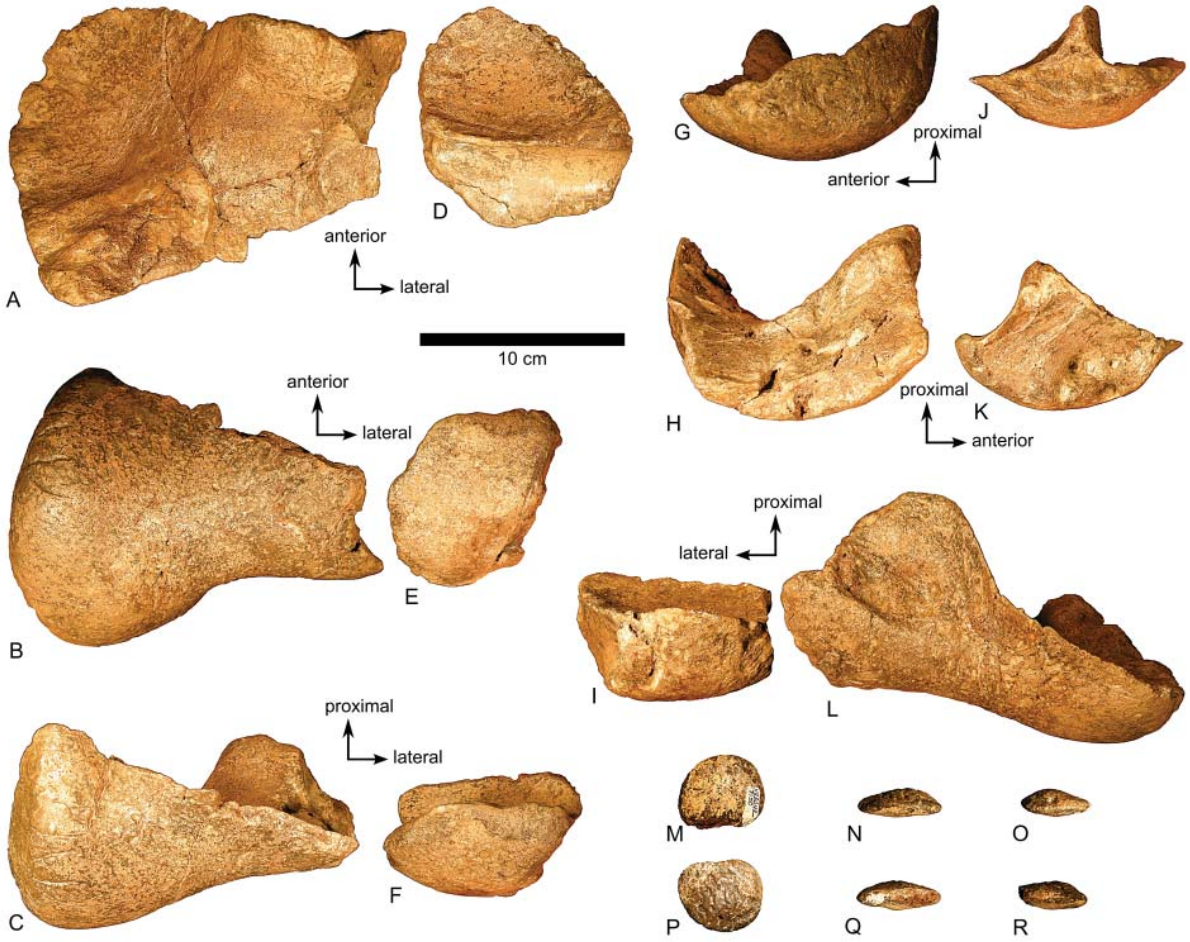

Figure 7. Right tarsals from a hadrosaurid dinosaur, RAM 7150. The astragalus is shown in A) proximal, B) distal, C) posterior, G) medial, H) lateral, and L) anterior views. The calcaneum is shown in D) proximal, E) distal, F) posterior, J) medial, K) lateral, and I) anterior views. The astragalus/calcaneum pairs in A-F and I-L are shown with a slight separation between their contacting surfaces, and the arrows indicate anatomical directions for each pair. M-R) tarsal IV; M and P show proximal and distal views, respectively; the precise orientation of the other views is not known due to disarticulation of the tarsal from the metatarsals after preparation. Photography by the authors. Courtesy of RAM.