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Redescription of Arundel formation Ornithomimosaur material and a reinterpretation of *Nedcolbertia justinhofmanni* as an "Ostrich Dinosaur": Biogeographic implications

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The fossil record of dinosaurs from the Early Cretaceous of eastern North America is scant, and only a few sediments to the east of the continent are fossiliferous. Among them is the Arundel Formation of the east coast of the United States, which has produced among the best dinosaur faunas known from the Early Cretaceous of eastern North America. The diverse dinosaur fauna of this formation has been thoroughly discussed previously, but few of the dinosaur species originally described from the Arundel are still regarded as valid genera. Much of the Arundel material is in need of review and redescription. Among the fossils of dinosaurs from this formation are those referred to ornithomimosaurs. Here, I redescribe ornithomimosaur remains from the Arundel Formation which may warrant the naming of a new taxon of dinosaur. These remains provide key information on the theropods of the Early Cretaceous of Eastern North America. The description of the Arundel material herein along with recent discoveries of basal ornithomimosaurs in the past 15 years has allowed for comparisons with the coelurosaur *Nedcolbertia justinhofmanni*, suggesting the latter animal was a basal ornithomimosaurian dinosaur rather than a "generalized" coelurosaur. Comparisons between the Arundel ornithomimosaur and similar southeast Asian ornithomimosaurian material as well as ornithomimosaur remains from western North America suggest that a lineage of ornithomimosaurs with a metatarsal condition intermediate between that of basal and derived ornithomimosaurs was present through southeast Asia into North America, in turn suggesting that such animals coexisted with genera having a more primitive metatarsal morphology as seen in *N. justinhofmanni*.

Redescription of Arundel Formation Ornithomimosaur Material and a Reinterpretation of *Nedcolbertia justinhofmanni* as an "Ostrich Dinosaur": Biogeographic Implications.

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Abstract.

The fossil record of dinosaurs from the Early Cretaceous of eastern North America is scant, and only a few sediments to the east of the continent are fossiliferous. Among them is the Arundel Formation of the east coast of the United States, which has produced among the best dinosaur faunas known from the Early Cretaceous of eastern North America. The diverse dinosaur fauna of this formation has been thoroughly discussed previously, but few of the dinosaur species originally described from the Arundel are still regarded as valid genera. Much of the Arundel material is in need of review and redescription. Among the fossils of dinosaurs from this formation are those referred to ornithomimosaurs. Here, I redescribe ornithomimosaur remains from the Arundel Formation which may warrant the naming of a new taxon of dinosaur. These remains provide key information on the theropods of the Early Cretaceous of Eastern North America. The description of the Arundel material herein along with recent discoveries of basal ornithomimosaurs in the past 15 years has allowed for comparisons with the coelurosaur *Nedcolbertia justinhofmanni*, suggesting the latter animal was a basal ornithomimosaurian dinosaur rather than a "generalized" coelurosaur. Comparisons between the Arundel ornithomimosaur and similar southeast Asian ornithomimosaurian material as well as ornithomimosaur remains from western North America suggest that a lineage of

ornithomimosaurs with a metatarsal condition intermediate between that of basal and derived ornithomimosaurs was present through southeast Asia into North America, in turn suggesting that such animals coexisted with genera having a more primitive metatarsal morphology as seen in *N. justinhofmanni.*

Introduction.

The fossil record of dinosaurs from eastern North America during the Cretaceous is sparse compared that of the west of the continent. One of the best dinosaur faunas known from eastern North America comes from the Arundel Formation. This formation, which is Aptian in age (Kranz, 1998), has yielded specimens of sauropod dinosaur *Astrodon johnstoni*, the ornithopod *Tenontosaurus sp.*, the nodosaur *Priconodon crassus,* the tooth of a ceratopsian, and a number of theropods including *Deinonychus sp.* and the dubious theropods *Allosaurus medius*, *Creosaurus potens,* and *Coelurus gracilis* (Kranz, 1998; Weishampel et. al., 2004: Weishampel, 2006). The most recent review of the Arundel dinosaur material found the theropod fauna to contain *Deinonychus sp.*, an *Acrocanthosaurus*-like allosauroid known from a few teeth, and an indeterminate ornithomimosaur in addition to a few indeterminate species (Weishampel, 2006).

The Arundel ornithomimosaur material has been the subject of some taxonomic confusion (Weishampel, 2006). Originally found by Lull (1911) to be an ornithopod, the ornithomimosaur specimens from the Arundel have been described as a species of *Ornithomimus* ("*O." affinis*), referred to the genus *Archaeornithomimus*, regarded as a small theropod of indeterminate affinities, and finally regarded as an ornithomimosaur of indeterminate affinities (Gilmore, 1920; Russell, 1972; Smith & Galton, 1990; Makovicky, Kobayashi & Currie, 2004;

Weishampel, 2006). The remains were also referred to as *Ornithomimus sp*. or *Ornithomimus affinis* by Serrano-Brañas et. al. (2016). Gilmore (1920) originally described the Arundel material as then a new species of ornithomimosaur based on some pedal elements and caudal vertebrae. Weishampel and Young (1996) noted that pedal elements and the proximal portion of a tibia were retrieved in 1992. However, Weishampel & Young (1996) only figured the proximal end of the tibia and the location of the pedal elements discovered in 1992 is unknown to the author. Most recently, an astralagus was recovered from Prince George's County, Maryland in 2010 (USNM PAL540727).

Early Cretaceous ornithomimosaur remains have been retrieved from from Western North America (Ostrom, 1970; Galton & Jensen, 1975), Europe (Sanz & Wenz, 1988; Perez-Moreno et. al., 1994; Neraudeau & Allain, 2012; Allain et. al., 2014), Asia (Maleev, 1954; Dmitriev, 1960; Kalandadze & Kurzanov, 1974; Hasegwa & Manabe, 1986; Xu & Wang, 1999; Boonchai & Grote, 2009; Molnar & Obata, 2009; Buffetaut, Suteethorn & Tong, 2009; Makovicky et. al., 2010; Liyong, Jun & Godefroit, 2012), and Africa (Choiniere, Forster & De Klerk, 2012). The rich fossil record of Early Cretaceous ornithomimosaurs which has developed in the past decade has allowed for comparisons of the Arundel specimens with a multitude of new taxa.

Here, I redescribe the Arundel ornithomimosaur remains retrieved from the Arundel Formation of Maryland and housed in the collections of the United States National Museum. The majority of these specimens, including those described by Gilmore (1920), are from a locality numbered 41615 in museum's collections and are referred to the same indeterminate ornithomimosaur taxon. Additionally, a phalanx of pedal digit IV retrieved from another location was referred to this Arundel taxon (then "*O*" *affinis*) by Gilmore (1920). Along with an

additional phalanx interpreted from coming from digit IV, the former phalanx described by Glimore (1920) is that of an ornithomimosaur based on its anteroposteriorly short length and is tentatively referred to the same ornithomimosaur taxon which left remains at site 41615.

This new ornithomimosaur has implications for the evolution of more derived members of the ornithomimosauria, suggesting that they were present across North America during the Early Cretaceous. However, the paucity of material from this animal warrants that further specimens are recovered before a new genus name is erected. Additionally, a reinterpretation of *Nedcolbertia justinhofmanni* from the Early Cretaceous of Utah as an ornithomimosaur is provided, showing that taxa with no arctometatarsalian pes and a likely near-arctometatarsalian pes coexisted during relatively the same time in North America as they did in Asia. The biogeographic and ecological implications of ornithomimosaurs with likely different metatarsus morphologies coexisting in North America are discussed, though the paucity of material from these North American forms during the Early Cretaceous makes any conclusions limited.

Methods.

Permits.

No permits were required for the described study, which complied with all relevant regulations. Help in accessing the specimens was given by Mr. Thomas Jorstad of the Smithsonian Institution.

Institutional Abbreviations.

I use the term USNM V to refer to the vertebrate zoology collections and USNM PAL to refer to the paleontology collections of the United States National Museum, within both of which the specimens discussed herein are stored.

Results.

Geological Setting.

The best record of the Arundel ornithomimosaur comes from a site numbered 41615 in the USNM collections. This site, along with the locations of the recovery of a few other elements referred to the Arundel ornithomimosaur, is in Prince George's County, Maryland and pertains to the Arundel Formation. This lithology of this formation was often described as "blue charcoal clays with iron carbonate nodules" (Kranz, 1998). However, some have doubted the placement Arundel sediments as a formation and instead have suggested that the Arundel constitutes as deposits from oxbow swamps. This interpretation is based on field observations that the clays of the Arundel appear as discontinuing elongated sediments (Kranz, 1998). Others have discussed that the palynomorphs of the Patuxent and Arundel Formations cannot be distinguished (Brenner, 1963; Doyle & Hickey, 1976; Doyle & Robbins, 1977; Robbins, 1991; Kranz, 1998), providing further evidence against the designation of the Arundel as a formation. Regardless, the sediments referred to as the Arundel are Aptian in age and have produced a diverse vertebrate fauna, including saurischian & ornithischian dinosaurs, testudines, anurans, and aquatic vertebrates like

111 the shark *Hybodus* and the lungfish *Ceratodus* (e. g. Kranz, 1998; Weishampel et. al., 2004;
112 Weishampel, 2006).
113
114 Systematic Paleontology.
115 Dinosauria Owen 1852 sensu Padian and May 1993
116 Theropoda Marsh 1881 sensu Gauthier 1986
117 Ornithomimosauria Barsbold 1976 sensu Choiniere, Forster & De Klerk, 2012
118 Ornithomimosauria gen. et. sp. indet.
119 Material: USNM V8454, a dorsal vertebral centrum; USNM V5701 & USNM V6116, two
120 caudal vertebra; USNM 5652 and USNM PAL5407, left and right astragali; USNM V5684, the
121 distal portion of metatarsal III; USNM V5704, the distal portion of metatarsal II; USNM V6108
123 & USNM V5453, pedal phalanges II-1; USNM V5703, pedal phalanx III-2; USNM V6115,
124 phalanx from pedal digit IV; USNM V6107, a pedal ungual; ?USNM V8456 & ?USNM
125 V16748, two phalanges from pedal digit IV recovered elsewhere in Prince George's County.
126 Additional material, including a tibia, a pedal ungual, and pedal elements were recovered in 1992
127 and noted by Weishampel & Young (1996), though the author is unaware of the location of these
128 specimens. The partial tibia, however, was figured in Weishampel & Young (1996), and as they
129 noted that the tibia shares similarities with ornithomimosaurs in having a large proximodorsal
130 crest. Additionally, Weishampel & Young (1996) likened some of the new pedal material to
131 ornithomimosauria based on the pedal unguals found which were flat in lateral and medial view.
132 Description: The single dorsal vertebral centrum (figure 1A-B) that was recovered and assigned
133 to an ornithomimosaur by Gilmore (1920) is slightly worn and opisthocoelus. The vertebra

measures 7.6 cm long anteroposteriorly and 49.5 millimeters wide as measured mediolaterally along its distal face (Gilmore, 1920). The neural spine of USNM V8454 was broken off right at the neurocentral suture, the outline of which is still completely visible in lateral and dorsal view on the dorsal face of the vertebra. The condition of the dorsal face suggests that the suture was not fused and therefore that the dinosaur to which USNM V8454 pertains was a juvenile or subadult during the time of its death.

Both caudal vertebra (figure 2A-B) are elongate. USNM V5701 is opisthocoelus and has an elongated neural spine which is eroded in its middle, and measures 68.7 mm anteroposteriorly, while USNM V6116 is 67. 5 mm long (Gilmore, 1920). Two elongated zygapophyses extend distally past the border of the vertebral centrum. the ventral surface of USNM 5701 arches slightly in the middle of the ventral face. USNM V6116 is similar to USNM V5701, but is stouter and its zygapophyses do not extend past the distal end of the centrum.

The left and right astragali (figure 3A-D) retrieved from site 41615 are similar in form in having an ascending process which is square in posterior and anterior views which is separated by a very shallow oval depression from the condylar bodies of the astragali. USNM V5652, the left astragalus, is slightly longer than the right astragalus USNM PAL5407 at 78 mm long anteroposteriorly and 56 mm tall, though this can be attributed to the erosion present on the latter 70 mm long, 40.125 mm tall specimen. A sulcus also separates the astragalar condyles in USNM V5652. As Makovicky, Kobayashi & Currie (2004) discussed, an oval depression separating the ascending process from the condylar bodies and a shallow sulcus separating the astragalar condyles are features found in ornithomimosaurs. Both these features, however, are faint or absent from USNM PAL5407, likely due to weathering.

The distal portions of metatarsals II & III (figure 4A-B) were also recovered from site 41615 and described by Gilmore (1920). Metatarsal III is elongate and measures 139.5 mm long proximodistally (Gilmore, 1920), and both collateral ligament pits are large and teardrop-shaped.. The presence of an arctometatarsalian condition in the Arundel ornithomimosaur is supported by the thinning of the bone immediately after this diaphysis "bulge". At its distal end, metatarsal III measures 43 mm, while 75 mm towards its proximal end, it measures only 29 mm (Gilmore 1920). Ventrally, the distal condyles are separated, though in dorsal view they are fused. The distal end of metatarsal II was also recovered and described by Gilmore (1920). This element also preserves collateral ligament pits and curves outward from the center of the pes to allow room for the articulation of metatarsal III. This portion of metatarsal II measures 54 mm proximodistally and is distally 33 mm wide.

A number of phalanges are preserved, including two which Gilmore originally believed to both have been from the second digit of the right pes of ornithomimosaurs. If so, they would affirm the presence of the fossils of two ornithomimosaur individuals at site 41615. These two specimens (figure 5A-) are similar in being elongate, having distal condyles noticeably separated by a groove, having circular collateral ligament pits, having a slight depression at the distal end of their dorsal faces, and finally having a concave proximal articular facet bordered by a slight rim, though this last feature is less noticeable in USNM V6108. USNM V5453 and USNM V6108 measure 82 mm and 79 mm at their centers and 34 mm and 32 mm wide as measured mediolaterally along their proximal faces, respectively (Gilmore, 1920).

Additionally, a pedal phalanx regarded as III-2 by Gilmore (1920) was recovered (figure 5). The specimen is elongate and both collateral ligament pits were preserved and are teardrop-

shaped. As in phalanges II-1 of the Arundel ornithomimosaur, a slight depression appears at the distal end of the dorsal face of USNM V5703. This phalanx is very slightly curved and has a noticeably expanded rim surrounding the proximal articular facet, which Gilmore (1920) regarded as warranting the phalanx's position as III-2. Indeed, the phalanx is similar to III-2 of *Ornithomimus* (Gilmore, 1920) and *Struthiomimus,* but not to that of the basal taxon *Harpymimus* (figure 6.5 in Makovicky, Kobayashi & Currie, 2004), suggesting that the presence of expanded rim around the proximal articular facet on an elongate pedal phalanx III-2 is a derived trait among ornithomimosaurs. The specimen has an anteroposterior length of 69 mm and is 32 mm wide as measured mediolaterally along its proximal face (Gilmore, 1920).

A partial phalanx, USNM V6115 (figure 5), was recovered from site 41615 and is interpreted as coming from digit IV of the pes of the Arundel ornithomimosaur due to the immediate proximodorsal curvature of the dorsal and ventral faces of the specimen in lateral and medial view suggesting an anteroposteriorly short phalanx. The collateral ligament pits are not well-preserved though still are somewhat visibly circular. The specimen is 31 mm long anteroposteriorly.

Finally, USNM V6107, a pedal ungual (figure 5) , was recovered from site 41615. In lateral and medial views, USNM V1607 is very slightly curved. Additionally, the pedal ungual bears a flexor fossa on the proximal end of its ventral face, a synapomorphy of ornithomimosauria (Choiniere, Foster & De Klerk, 2012). The grooves for the claw sheath are well-defined and curve anteromedially towards the distal tip of the ungual. This pedal claw measures 55.5 mm long anteroposteriorly and 17 mm wide as measured lateromedially along its proximal articular facet (Gilmore, 1920).

The two phalanges discovered elsewhere in Prince George's County, Maryland (figure 5) are both interpreted as phalanges of digit IV of an ornithomimosaur as they are both anteroposteriorly short and therefore characteristic of digit IV of ornithomimosaurs (Choiniere, Foster & De Klerk, 2012). USNM V8456, which Gilmore (1920) originally referred to the Arundel ornithomimosaur, is 38 mm long anteroposteriorly and 24 mm wide mediolaterally along its proximal face. USNM V16748 is similar in size and complete. Both preserve circular collateral ligament pits and unfused distal condyles, and are tentatively assigned to the Arundel form at site 41615 due to their similarities with the known pedal phalanx from digit IV found at site 41615 and comparatively short geographic distance between the locations where the two phalanges were each found at site 41615.

The Arundel remains are identified as belonging to an ornithomimosaur due to a flexor fossa being present on the ventral surface of the known pedal ungual and having anteroposteriorly short phalanges from digit IV (Choiniere, Foster & De Klerk, 2012). Additionally, the USNM material shares the elongated metatarsals found in ornithomimosaurs and the pedal phalanges of the Arundel ornithomimosaur strongly resemble those of *Kinnareemimus khonkaensis* and other genera (Buffetaut, Suteethorn & Tong, 2009). The astragali of the Arundel form have traits of the astragali of ornithomimosaurs described by Makovicky, Kobayashi & Currie (2004). The caudal vertebrae of the Arundel form are elongated as seen in ornithomimosaurs, though this is also found in other theropods.

222 Discussion.

223

224 The Arundel ornithomimosaur material represents among the most complete records of
225 any dinosaur from the Early Cretaceous of eastern North America. Though more remains are
226 needed to confidently name a new taxon for the Arundel animal, the fossils of the Arundel
227 ornithomimosaur not only display a mix of derived (i. e., metatarsal III & pedal phalanx III-2
228 displaying morphologies similar to those of some ornithomimids including suggesting the
229 presence of a near arctometatarsalian foot) and basal (recurved pedal phalanx) traits, but also
230 have features dissimilar to or absent from the corresponding elements in other ornithomimosaurs.
231 For example, the dorsal surface of the distal end of metatarsal III displays two ridges which
232 migrate towards each other from the lateral and medial ends of the dorsal face of metatarsal III to
233 form a distinct, upside-down V-shaped outline. These ridges then run almost parallel to each
234 other and then depart again to the lateral and medial sides of the dorsal face. The distal condyles
235 of metatarsal III are also fused in dorsal view, unlike the condition found in *Tototlmimus*
236 *packardensis* (figure 6 in Serrano-Brañas et. al., 2016). Additionally, the pedal ungual of the
237 Arundel form does not show a sulcus on its ventral surface in lateral or medial views,
238 differentiating it from *Ornithomimus* and *Struthiomimus*. The pes of the Arundel
239 ornithomimosaur is not nearly as robust as those of the deinocheirids *Beishanlong* &
240 *Deinocheirus* (Makovicky et. al., 2010; Lee et. al., 2014).

241 The geographical distance between the location of the retrieval of specimens of the
242 Arundel ornithomimosaur and those of other Early Cretaceous ornithomimosaurs may also
243 suggest that the Arundel material is indeed from a distinct taxon intermediate between, though

244 further remains will need to be recovered in order to confidently erect a new genus for the
245 Arundel form.

246 Redescription of the Arundel ornithomimosaur and the naming of new basal
247 ornithomimosaur taxa in recent years has allowed for the reinterpretation of the "generalized"
248 North American coelurosaur *Nedcolbertia justinhofmanni* as an ornithomimosaur. *Nedcolbertia*
249 shares two synapomorphies with ornithomimosaurs in having anteroposteriorly shortened
250 phalanges from pedal digit IV and a single flexor fossa on the proximal end of the ventral surface
251 of its pedal unguals (figure 8 & figure 9 in Kirkland et. al., 1998). The proximal end of
252 metatarsal III is restricted mediolaterally slightly less than in *Harpymimus*, and in proximal view
253 the metatarsals are similar in shape to those of *Kinnareeemimus* (figure 8 in Buffetaut,
254 Suteethorn & Tong, 2009). The pedal unguals of *Nedcolbertia* are also triangular in cross-section
255 (Kirkland et. al., 1998), similar to those of some ornithomimosaur taxa and listed as a
256 synapomorphy of ornithomimosaurs by Barsbold & Osmólska (1990). The astralagus of *N.*
257 *justinhofmanni* is also similar to the left astralagus, USNM PAL5407, of the Arundel
258 ornithomimosaur.

259 Unlike some ornithomimosaurs, the flexor tubercle of the first manal ungual is extremely
250 pronounced, the manal unguals are likely differentiated, and the dorsal vertebrae are simplistic
251 and pneumatic (Kirkland et. al., 1998). *N. justinhofmanni* can be differentiated from the Arundel
252 ornithomimosaur by having straighter, more elongate pedal unguals and lacking the visibly
253 separated distal condyles seen in phalanx II-1 of the latter taxon (figure 8 & figure 9 in Kirkland
254 et. al., 1998). Additionally, the two forms likely can be differentiated in the morphology of their
255 metatarsus, as the known portion of metatarsal III of the Arundel ornithomimosaur suggests the

form had a near-arctometatarsalian condition similar to that of *Kinnareemimus*, while in *Nedcolbertia* the dorsal face of metatarsal III is still completely visible along the entire portion of the metatarsus. *Nedcolbertia* is therefore considered as a basal ornithomimosaur due to its non-arctometatarsalian pedal condition where the shaft of metatarsal III is at least partially visible along its entire run in dorsal view.

The similarities between the Arundel ornithomimosaur and *Kinnareemimus* suggest that ornithomimosaurs with a metatarsal morphology intermediate between that of the basal *Nqwebasaurus thwazi* and the derived condition seen in ornithomimids were present in southeast Asia and through the whole of North America. Both *Kinnareemimus* and *Nedcolbertia* come from post-earliest Cretaceous pre-Aptian (possibly Barremian) and Barremian sediments, respectively (Kirkland et. al., 1998; Buffetaut, Suteethorn & Tong, 2009), while the Arundel Formation from which the ornithomimosaur discussed herein pertains is Aptian in age (Kranz, 1998). This temporal frame suggests that both basal ornithomimosaurians lacking an arctometatarsalian or near-arctometatarsalian pes and ornithomimosaurs with a pedal morphology closer to the arctometatarsalian condition may have coexisted in North America during the mid-Early Cretaceous. Additionally, ornithomimosaur metatarsals from the Late Aptian to Early Albian Cloverly Formation of the American west (Ostrom, 1970) have morphologies consistent with a near-arctometatarsus or arctometatarsus, supporting the presence of an ornithomimosaurian lineage with a near-arctometatarsalian or arctometatarsalian pes in western North America. However, only portions of metatarsals II & III of this Cloverly Formation form are known (Ostrom 1970).

Though the possibility of two distinct lineages of ornithomimosaurs coexisting during the Early Cretaceous is an enticing prospect, more specimens will have to be recovered and analyzed in a biogeographic frame to further understand the spread of lineages of Early Cretaceous "ostrich dinosaurs". Material from the forelimbs, neck, and skull of different lineages of North American Early Cretaceous ornithomimosaurs may show morphological disparities between near-arctometatarsalian/arctometatarsalian and forms with the dorsal surface of metatarsal III completely visible in dorsal view of the metatarsus which could have allowed ornithomimosaurs of different lineages to coexist. Indeed, the dissimilarities between the manus of *Nedcolbertia* and ornithomimids (Kirkland et. al., 1998) suggest that *N. justinhofmanni* employed its forelimbs differently than more derived ornithomimosaurs. It would not surprise the author if future discoveries did reveal that North American ornithomimosaurs with only a slightly-pinched proximal end of metatarsal III possessed different morphologies to carry out daily activities such as food consumption. Unfortunately, the poor record of Early Cretaceous North American dinosaurs has still to yield such remains.

Conclusions.

The Arundel ornithomimosaur is one of the most well-known theropods from the Early Cretaceous of eastern North America and may represent a new taxon. Furthermore, it has provided evidence for the placement of *Nedcolbertia justinhofmanni* as an ornithomimosaur. Both species have implications for the biogeography of Early Cretaceous ornithomimosaur lineages, suggesting that clades with near-arctometatarsalian and non-arctometatarsalian metatarsus morphologies coexisted in Early Cretaceous North America.

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Figure 1(on next page)

Dorsal Vertebra of the Arundel Ornithomimosaur

Figure 1. Dorsal vertebra of the Arundel ornithomimosaur in lateral (A), and dorsal (B) views. Scale bar = 50 mm. Courtesy of Smithsonian Institution. Photos by M. Brett-Surman.

Figure 2(on next page)

Caudal Vertebrae of the Arundel Ornithomimosaur

A.

B.

Figure 2. Caudal vertebra of the Arundel Ornithomimosaur in lateral (A, B) view. Scale bar = 60 mm. USNM V5701 pictured in A; USNM V6116 pictured in B. Courtesy of Smithsonian Institution. Photos by M. Brett-Surman.

Figure 3(on next page)

Astragali of Arundel Ornithomimosaur

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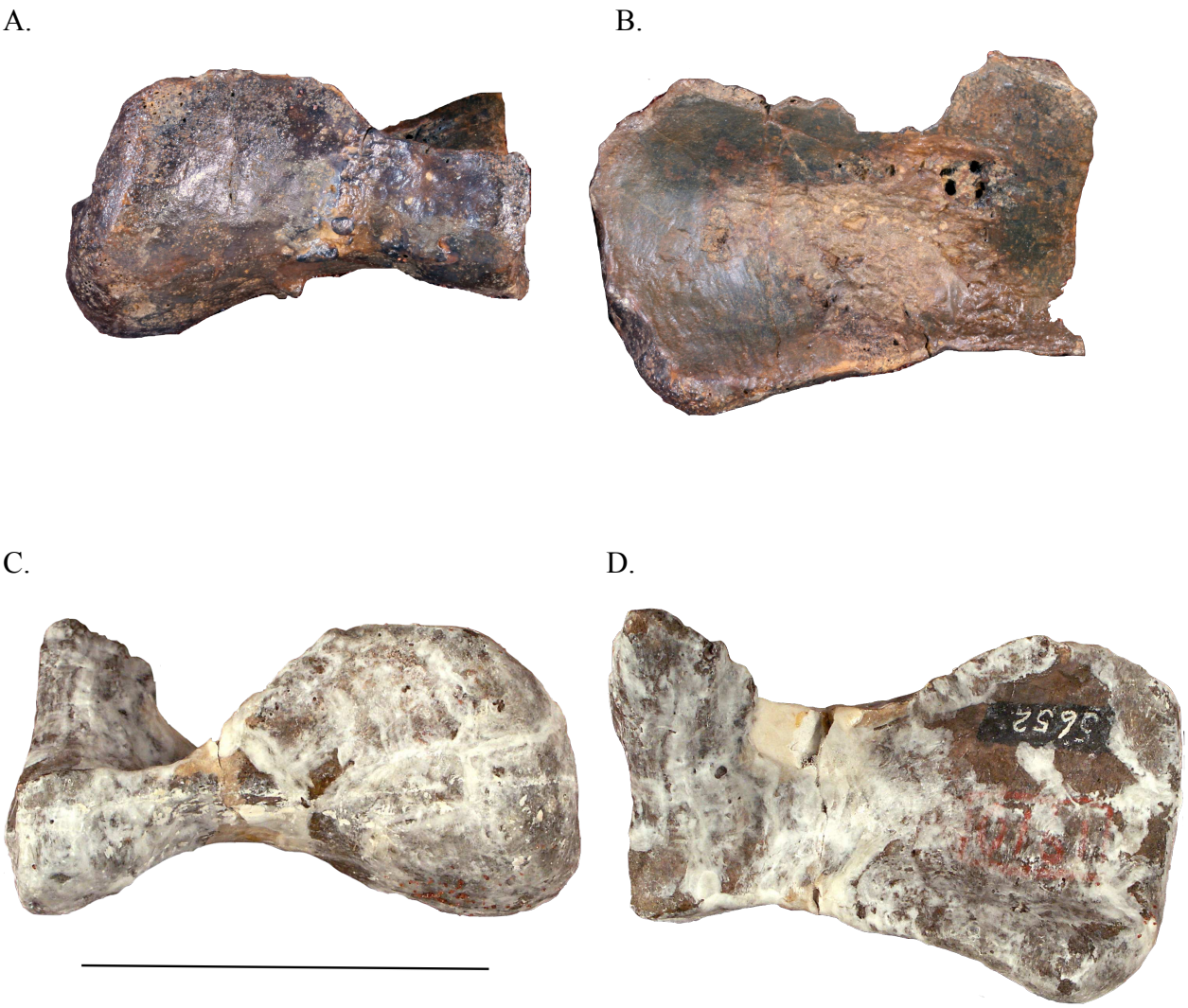

Figure 3. Left and right astralagi of the Arundel ornithomimosaur in medial (A, C) and dorsal (B, D) views. Scale bar = 60 mm. USNM PAL5407 pictured in A-B; USNM V5652 pictured in C-D. Courtesy of Smithsonian Institution. Photos by M. Brett-Surman.

Figure 4(on next page)

Selected Pedal Elements of the Arundel Ornithomimosaur

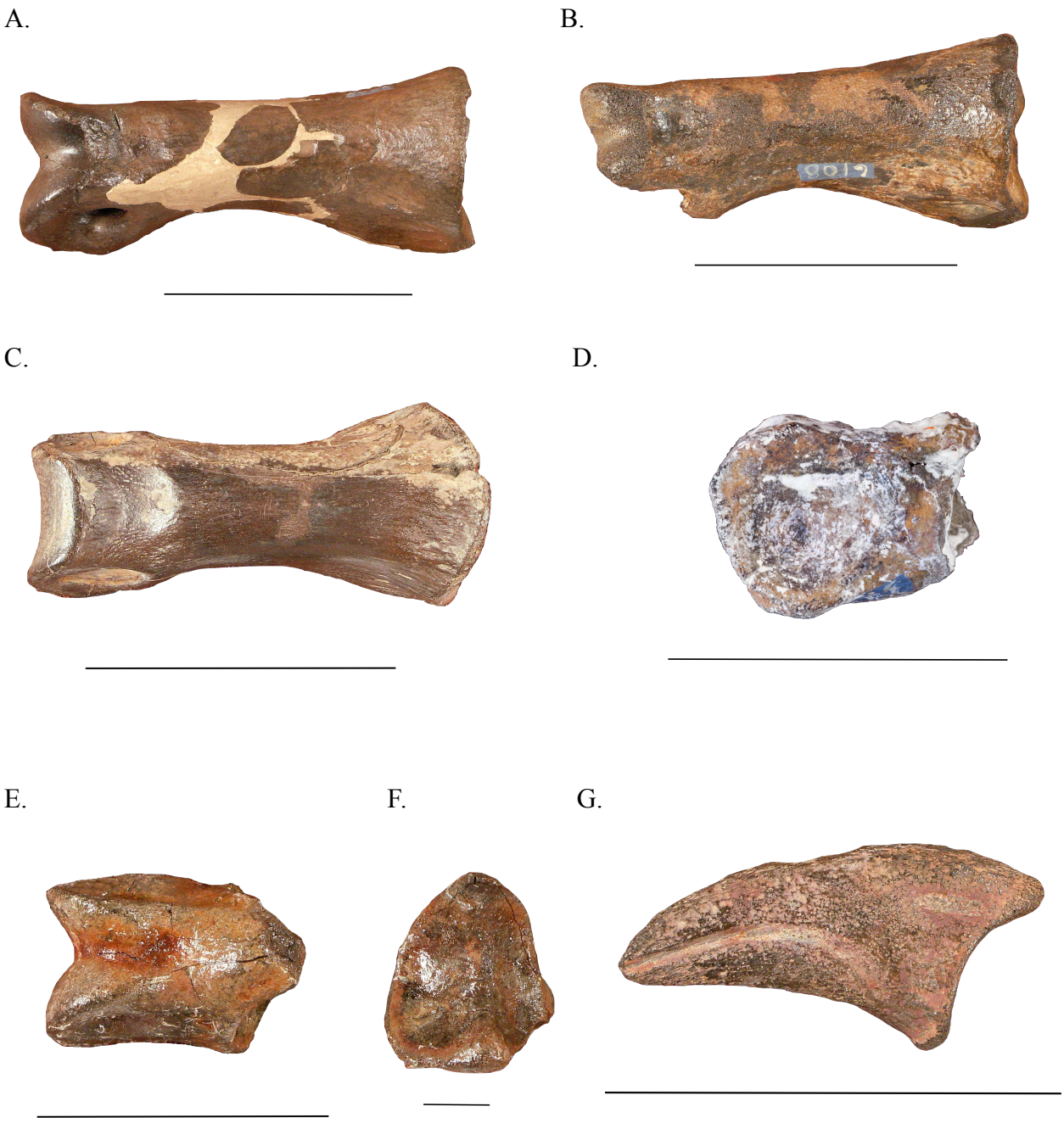

Figure 6. Selected pedal elements from the Arundel ornithomimosaur. USNM V5453, right pedal phalanx II-1, in dorsal view (A); USNM V6108, ?right pedal phalanx II-1, in dorsal view (B); USNM V5703, right pedal phalanx III-2, in dorsal view (C); USNM V6115, pedal phalanx of digit IV, in medial view (D); USNM V8456, pedal phalanx of digit IV, in dorsal (E) and proximal (F) views; USNM V6107, pedal ungual, in medial view (G). Scale bar = 50 mm (A, B, C, G), = 40 mm (D, E,), = 10 mm (F) . Courtesy of Smithsonian Institution. Photos by M. Brett-Surman.