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COMMENTARY

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Illuminating dinosaurs under the aurora borealis—A commentary on the creation of the Arctic cover for Dinosaurs: New Ideas from Old Bones

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For the cover of this third Special Issue of *The Anatomical Record* focused on dinosaurs, honoring Peter Dodson—a ceratopsian lover of arguably unrivaled proportions, the piece appeared destined to center on the Arctic *Pachyrhinosaurus* (Fiorillo & Tykoski, 2012)—a fascinating ceratopsian—and *Nanuqsaurus*—its probable antagonist and a taxon first described by former student and current Arctic dinosaur explorer (and coauthor of this piece) Fiorillo (with colleague Tykoski; Fiorillo & Tykoski, 2014) with the editorial support of Dodson himself. Beyond this obvious subject and setting choice, the artistic decision process posed a more difficult problem: how could we depict these potential ecological rivals in a new and interesting way to honor both the scientific fidelity that such an Issue would hold prime and Dodson's decades of evidence-based contributions to our field? More specifically, how could we depict these taxa differently and with greater scientific accuracy than their previous depictions—mostly centered on *Nanuqsaurus* fully fledged in down feathers attacking *Pachyrhinosaurus* during an Arctic snow storm (e.g., by PBS, 2020; Apple TV+, 2022). Beyond trying to avoid the cliché of a tyrannosaurid in physical confrontation with a ceratopsian (grounded in Knight's own classic kangaroo-like *Tyrannosaurus* menacingly squaring off against his tail-dragging Triceratops depicted more than a century ago; Milner, 2012; Paul, 1996), we also wanted to avoid a wooly depiction of *Nanuqsaurus* given the lack of evidence that this taxon (or any large tyrannosaurid) was thickly covered in feathers (Bell et al., 2017; Ksepka, 2020) and to depict a warmer scene given that the Arctic was substantially warmer year round and more seasonal than it is today (though it would have been cold enough in the *winter* for snow to be present; Fiorillo et al., 2016). While snow and mammal-like white fur may be the quickest visual shortcuts to signify the Arctic, we chose a subtler and still aesthetically exciting feature, even more specific to the Arctic: our scene is lit not only by a late-Cretaceous sunset, but by the aurora borealis. Although we cannot be sure of many of our artistic decisions about their appearance in life, we are certain that these two Arctic species were illuminated by the same aurora that lights the sky today millions of years later.

1 | THE CRETACEOUS ARCTIC

While the aurora was undoubtedly a night-sky phenomenon for millions of years, the rest of the Arctic Cretaceous would be largely unrecognizable to us today. It was substantially warmer (Fiorillo et al., 2022), and although it was therefore more hospitable to more animals and plants, many of the plant species that we think of as boreal or temperate flora had not yet evolved; more specifically, the grasses that cold-adapted herbivorous Arctic megafauna rely on today (Wilson & Mittermeier, 2011) had not evolved yet in the Cretaceous. Rather, the palynological samples of the Prince Creek formation, where our focal dinosaurs were excavated, contained records of 32 taxa of shrubs and mosses, as well as ferns and trees, including *Metasequoia* (Fiorillo et al., 2016; Flaig et al., 2013)—both depicted in our foreground—plants that, today, thrive only in substantially lower latitudes.

2 | THE ANATOMY OF PACHYRHINOSAURUS AND NANUQSAURUS

Thankfully, the fossil record is replete with impressively complete specimens of *Pachyrhinosaurus*—a ceratopsian that mostly follows the standard ceratopsian bauplan in that it was a heavy-set quadruped with prominent frill. While its frill was surrounded by small conical horns like those seen in other ceratopsians, *Pachyrhinosaurus* had a prominent nasal boss most similar to the anchoring structures underneath the boss of the horns of muskoxen (*Ovibos moschatus*)—anatomy very different than the conical nasal and supraorbital horn cores prevalent in most large ceratopsians (Hieronymus et al., 2009). Beyond this prominent feature and unlike the smooth-skinned reconstructions that predominate ceratopsian visualizations, our reconstruction also emphasizes highly scaled skin as is evident throughout the numerous skin impressions found in the ceratopsian fossil record (Bell et al., 2022), including on the otherwise bird-like or turtle-like beak (Brown & Schlaikjer, 1940).

Unfortunately, the fossil record for *Nanuqsaurus* is substantially more depauperate. While enough cranial material was found to describe this derived tyrannosaurid as relatively small but still likely impressively dangerous—including the type dentary with robust tooth roots (Fiorillo & Tykoski, 2014), little else is known of the anatomy of this animal as only fragmentary postcranial material has been found (Fiorillo et al., 2016). Thus, our reconstruction of the dorsal cranial profile (fitted to the extrapolated cranial profile provided in the type paper) is conjecture based on our understanding of the more complete skulls of its closer (though notably all larger) relatives. While there are variations in the supraorbital region and general markers of robusticity (including ontogenetic; Woodward et al., 2020), the shape of the skull shown in Fiorillo and Tykoski (2014) is clearly within the morphological range of the lineage. What is less certain is whether this fearsome Arctic theropod should be depicted in feathers. Even assuming that feathers would not have been molted in this depiction of a warmer season, the presence of feathers in adult tyrannosaurids is highly debated. The most thoroughly researched exhibition of the lineage (American Museum of Natural History, 2019) depicted the adult tyrant king with a thin sprout of hair-like filaments on the top of its head and neck, but there seems to be little evidence to support even this amount of plumage (Bell et al., 2017; Ksepka, 2020). With that said, though we chose not to depict feathers in our reconstruction, if any tyrannosaurid had feathers for warmth, they most likely would have been found on this northernmost taxon.

3 | FLESHING OUT THE BONES

On top of the reconstructed cranial profile of *Nanuqsaurus* (from Fiorillo & Tykoski, 2014) and the numerous skulls and skeletons of *Pachyrhinosaurus* (note: the featured animal on the right side of the cover image is mostly built onto the skeletal composite displayed at the Perot Museum of Nature and Science in Dallas, TX), we layered anatomy and skin textures from many sources. Phylogenetically, we pulled photographic textures and structures from birds, but due to all the evidence of scaly integument, we ended up using predominantly source material from reptiles. We mostly used images of varanids for *Nanuqsaurus* given the similarity in scale shape and pattern as depicted by Bell et al. (2017), and we pulled materials more widely for *Pachyrhinosaurus* finding that the scales (as depicted by Bell et al., 2022) and frills were most easily reconstructed from images of chameleons and the more conical horn-like scales were most readily reconstructed from images of agamids, especially *Pogona*. Interestingly, although we tried to stretch reptilian horns over the *Pachyrhinosaurus* horn cores (e.g., those found in some of the *Trioceros* species) and even some of the beak and casque structures of birds (e.g., from bucerotids), we found that the reptilian textures looked implausible scaled to dinosaur proportions and that the bird structures, when removed from their broader context looked so photographically similar to mammalian horns in texture and light reflectivity, that it was easier to use imagery of mammalian horns to begin with, given their more similar overarching shape. To this end, the frill horns on the *Pachyrhinosaurus* were modified from those of cape buffalos (*Syncerus*). The nose horn of *Pachyrhinosaurus* was, as recommended (Hieronymus et al., 2009), reconstructed from the boss of a muskox (*Ovibos*). For the fighting dinosaurs in the background, references were used of fighting birds and lizards (there are some particularly dramatic records of Komodo dragons fighting), but several studies (Farlow & Dodson, 1975; Fiorillo & Tykoski, 2022; Sternberg, 1950) suggest more similarity to the pushing of mammalian megafauna, though whether dinosaurs pushed or crashed heads in this manner is still hotly debated (Farke, 2010; Goodwin & Horner, 2004; Moore et al., 2022; Nabavizadeh, 2023; Snively & Cox, 2008; Snively & Theodor, 2011). Although initial references of multiple taxa were used to imagine this combat, in the end, the only elements that were integrated into the actual reconstructions of the bodies came from lizards (again, mostly varanids) and bird feet (predominantly *Struthio*).

4 | USING MODERN PHOTOGRAPHS FOR PALEORECONSTRUCTION

Although copyright laws allow copyrighted work, such as photographs, to be freely used as long as the piece is sufficiently manipulated enough, as artists ourselves, we are committed to paying professional artists for their art. To stay true to this philosophy, we license all stock images that are not originally our own through sites like Shutterstock, AdobeStock, and Unsplash. The cover—including all background elements, foliage, and elements used to reconstruct the animals—was created entirely from our own photographs or images licensed from iStock, a subsidiary of the larger media licensing company Getty Images. Although our approach to photomanipulation and the sometimes infinitesimally small portions of a start image that we sample would almost surely qualify under the fair use clauses of copyright, we have proudly licensed almost all the images that were blended into the final cover piece. The only other start images used that ended up being part of the final cover were photographs that we took ourselves of specimens from our own research collection—most prominently, the muskox horn used to recreate the nasal horn of the *Pachyrhinosaurus* was photographed from the specimen hanging at the entrance to the Hartstone-Rose research lab.

Ultimately, the composition was comprised of literally dozens of stock images. The sky alone is composed of four different photographs, while the background, lake, and shore contain elements from a further three or four photographs. The tree near the *Pachyrhinosaurus* and the rest of the foreground foliage were composed of almost a dozen additional layers of altered photographs.

As might be expected, the dinosaurs themselves required the most start images. Although this composition only includes the top third of the head of *Nanuqsaurus*, that small section is made from six different photographs; most of the cranial shape and skin is warped from two *Varanus* specimens, and the eye is modified from a photograph of an *Iguana* and several other lizard photographs were combined to integrate the eye into the orbit. As one might imagine, if this small portion of a head required a half dozen stock images, the full-bodied ceratopsians required almost an order of magnitude more. In fact, a dozen images of lizard photographs went into the composition of the head alone of the focal animal and to these were added three different photographs of mammal horns and four photographs of *Varanus* stretched to fit the postcranial skeleton.

Although the head of this specimen took almost as long to create as the rest of the composition combined, the feet also required inordinate attention—especially given that only two of the four that were meticulously reconstructed ended up in the final piece! As the large ceratopsians had more robust limbs than any living bird or lizard—and structures markedly different than those of heavy crocodilians or chelonians, we initially tried to find appropriate images of rhinoceros, hippopotamus and tapir feet that seemed to fit on the distal skeletons. In the end, the solution was more obvious: the mesmerizingly ancient-looking feet of ostriches (*Struthio*) could be manipulated onto the toes of *Pachyrhinosaurus* with care taken to manipulate proportions, claw shape and, of course, toe number. At the risk of breaking the photorealism that we strive for, an unshaded, unblurred draft of the reconstruction (Figure 1) reveals the anatomical work that goes into a single specimen like this before its integration into the broader composition.

All of these photographs of modern animals, plants, and environments are blended together in Photoshop (Adobe) in documents that ultimately consist of more than 100 layers of anatomical elements and shading and color adjustments. Some of these were blended directly from the photographs—trees and leaves—and could be trimmed from their backgrounds and used largely as photographed. Others required more subtle layering—a lake added onto another's shoreline. Although some skin layers could simply be laid onto skeletal shapes (padded with our understanding of myology—the actual professional expertise of our lab), most of the images of animals required not only trimming of specific elements but also stretching them onto dinosaurian proportions; a lizard's scales may approximate those of *Pachyrhinosaurus* but simply enlarging elements from small animals seldom results in realism. The ceratopsian shield is not merely a giant version of a chameleon's. Rather, the photographs are stretched over the underlying reconstructed anatomy using Photoshop's myriad manipulation tools—especially "warp," "puppet warp," and "liquify."

Once these textures are pulled and pushed onto their underlying shapes, shading and highlighting are used to further add depth and contour. The orange sunset and teal aurora were not only chosen for their beauty (and in

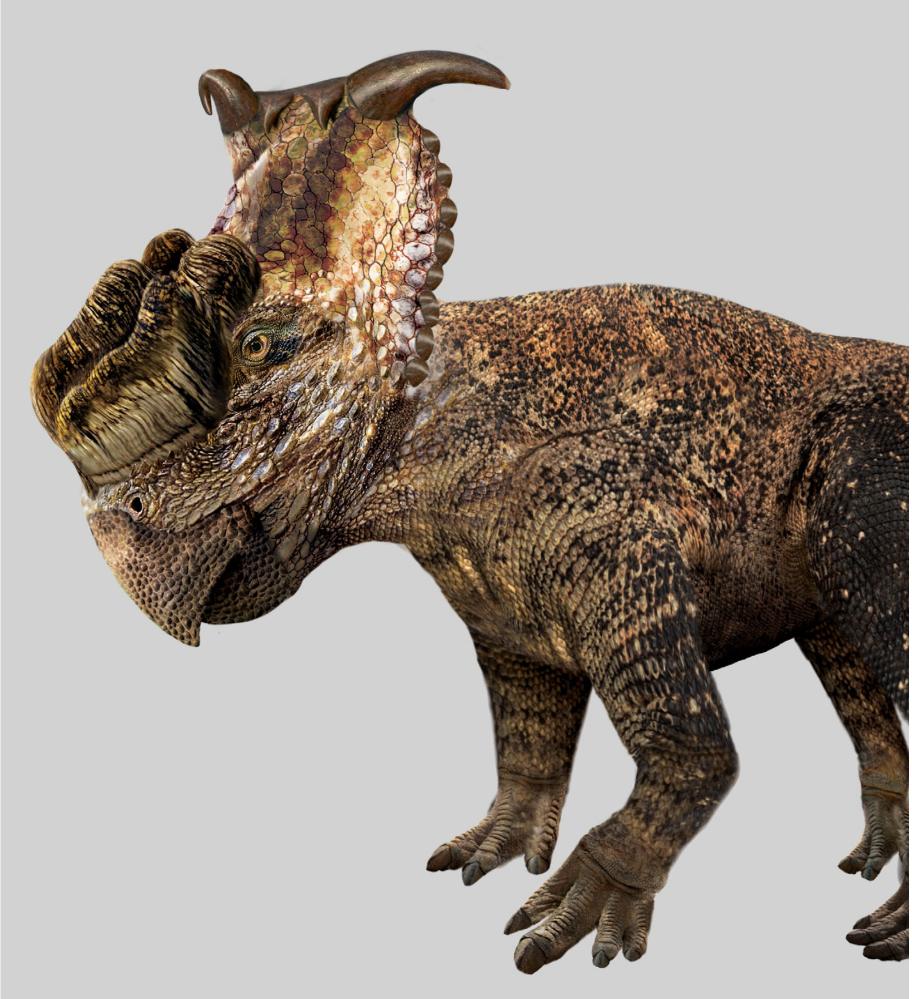

FIGURE 1 Draft of focal *Pachyrhinosaurus* prior to shading, blurring and final blending into full composition. Note that while some details of this composition are rather careless—for instance the scale patterns on the body do not match very well since almost all this detail was destined to be lost during final shading—other elements like the feet are far more anatomically detailed despite this work ultimately being mostly lost in the final blend. A similar display of the *Nanuqsaurus* with a wider crop would embarrassingly reveal that, although we stretched photographs to the morphology of most of the skull, we ultimately left out many details saving us not only the effort of detailing more portions of the anatomy that ultimately would go unseen, but also from having to weigh in on controversies like whether tyrannosaurids had lips (e.g., Bouabdellah et al., 2022).

the case of the latter, for its use as a geographic signifier), but also because they allowed a specific trick of shading: the sunset illuminates the *Nanuqsaurus* from behind, metaphorically silhouetting a taxon that we know rather little about (further obscured by its foliated hiding place). The sunset also illuminates the *Pachyrhinosaurus* from a sharp horizontal angle—a "rim" lit scenario that is often favored in dramatic studio shots, but rare in nature. The aurora acts as a "fill" light adding a slight green glow from above to areas that would not have been touched by the bright orange of the sun. The interplay between these two lighting tones and intensities not only helps add much needed shape to the focal *Pachyrhinosaurus* but also almost solely defines the combatants in the background. Although the two animals in the back were painstakingly created with anatomical fidelity, by the time they were blurred to help add depth to the image, their anatomy was almost solely defined by this interplay of light.

The composition construction was completed with visual tricks used to pull all of the disparate elements together: final color grading to bring all the orange and green glows into the same ranges, vignetting to frame the entire image and tie it into the darkened spaces for the journal banner, logos, and editor attributions, additions of uniform contrasts and grain—a throwback to the good old days of film photography that still adds a subliminal sense of cohesion. The final addition was a lens flare stretching from the farthest light source through the entire composition ending almost beyond the page itself. The Hartstone-Rose lab has used this cliché previously—notably on the cover of the May/June 2013 issue of the *South African Journal of Science* (which accompanied a paper on ancient South African hyenas; Hartstone-Rose & Stynder, 2013)—to not only use a dramatic element to stitch across all of the layers of composition but also to subtly draw the viewer into the issue.

5 | TENSION AND SERENITY

The serene color grading and lens flare serve another important purpose: they, along with the positioning and apparent behavior of the animals, set a very specific tone.

While almost all reconstructions of fossil taxa portray them in two dichotomous states—either in a scientifically standardized view (usually lateral) emphasizing a full and comprehensive anatomical visualization (like the reconstruction that we did of *Eomellivora* that was featured in our description of a key specimen from Batallones, Spain, and on the accompanying July 2015 cover of The Journal of Vertebrate Paleontology; Valenciano et al., 2015) or in the most dramatic state of combat—those of us that have spent time watching modern animals in the wild know that they spend the majority of their lives *not* in these states. Seldom do animals stand in anatomical positions relative to the viewer in normal planes, and, although memorable when a lucky observer catches them, true interspecific combat is also rarely experienced by a viewer. Rather, species spend more of their time doing humble activities; grazers and browsers spend most of their time grazing and browsing, and contrary to conception, most predators spend most of their time resting. Often there are tussles between animals (usually maturing juveniles) to test the subtle hierarchies in a group, but most of the time animals are doing mundane activities and generally avoiding unnecessary exertion. In fact, another paper in this volume (by Fiorillo & Tykoski, 2022) finds that *Pachyrhinosaurus* remains to display remarkably little evidence of pathology—suggesting a potentially even calmer lifestyle than that of other ceratopsians and modern herbivores.

Naturalists understand that to really appreciate species, it is imperative to find the beauty in these serene moments—to seek out animals during that golden hour—the tension between day and night when the temperature and light start shifting. Wildlife observers put themselves at environmental edges—between forest and lake margin—to try to catch animals risking a break from their herbivory for a drink. And we know that sometimes we are not the only ones taking advantage of the margin between day and night, cover and exposure; potentially, we can catch a glimpse of a predator catching a glimpse of its potential prey.

It was this moment at the intersection of tension and serenity that we tried to capture on this cover. An illustration at the intersection of our appreciation for nature

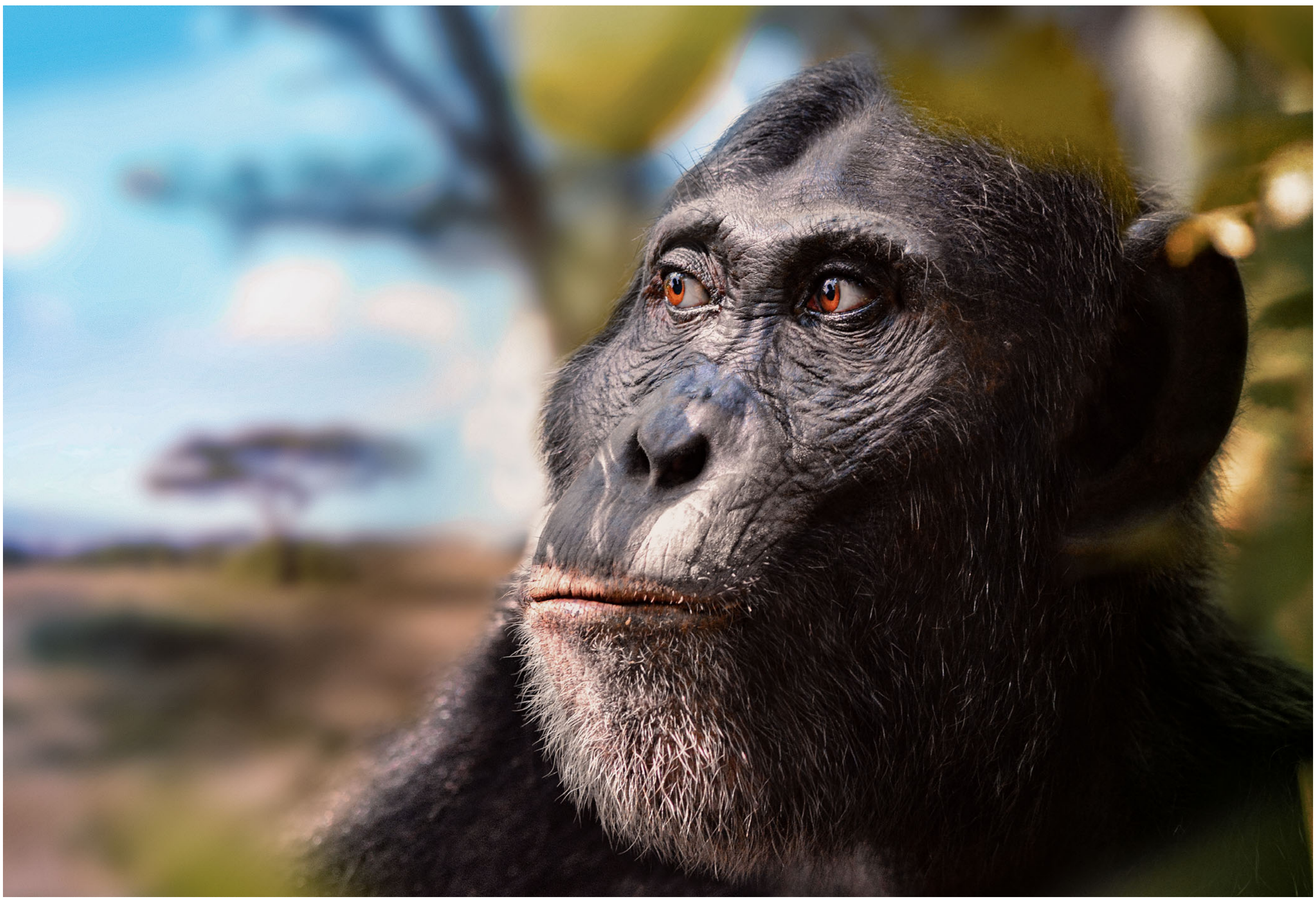

FIGURE 2 A reconstruction of *Paranthropus aethiopicus* by Hartstone-Rose (with consultation by Ashley R. Deutsch) created for an upcoming edited volume on the genus.

FIGURE 3 A dinosaur examining a man who spent a career examining dinosaurs.

at the point when it flips between calm and excitement—and of our scientific understanding of the taxa that our colleagues have introduced to the world through their work. This is the kind of tone we most often seek to exemplify in our work (e.g., Figure 2)—a reconstruction of a long-lost species that draws the viewer in not because of the kind of dramatic activity that is so rarely actually experienced but because of the intensity that manifests in calm intimacy allowing the viewer to think not about fighting or splashing, but to consider how these animals thought and breathed and existed in the landscape in those quiet moments.

6 | ACKNOWLEDGEMENTS - HONORING PETER DODSON

As other commentaries in this volume attest, Peter's contributions to our field are clearly worthy of honor. As this Special Issue is dedicated to him, so too is its cover. He has spent decades gazing at these amazing creatures and in this piece, we have envisioned them gazing right back at him (Figure 3). For all the illumination you shed, both casting light on this important science and, more importantly, illuminating the way for the next generation of students through your enthusiasm of the dinosaurs, we thank you, Dr. Peter Dodson.

AUTHOR CONTRIBUTIONS

Adam Hartstone-Rose: Conceptualization; software; investigation; formal analysis; funding acquisition; project administration; writing – original draft; methodology; data curation; supervision; visualization; resources; writing – review and editing. **Arin Berger:** Formal analysis; writing – original draft; visualization; writing – review and editing. **Mot Tuman:** Formal analysis; writing – original draft; visualization; writing – review and editing. **Anthony R. Fiorillo:** Conceptualization; resources; writing – review and editing.

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