Fire-Breathing Dinosaurs? The Hilarious History of Creationist Pseudoscience at Its Silliest

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This book is meant to slay dragons, in a manner of speaking. It is therefore dedicated to a dragon slayer, St. George the Megalomartyr, illustrated below in a nineteenth-century Russian icon at the Antiochian Heritage Museum (Bolivar, Pennsylvania). Χαῖρε, μεγαλομάρτυς καὶ θαυματουργὲ Γεώργιε!

TABLE OF CONTENTS

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INTRODUCTION

DARING HERALDS OF HILARITY

Warning: For readers who know a thing or two about dinosaurs, the following paragraph may cause perplexed grimacing.

> The helpless watermelon sits unmoving in the sand as its mortal enemy rises from the dark depths, smoke pouring from its glowing nostrils. Towering in the twilight, the hungry tyrannosaur shakes its glistening hide, its armor plating gleaming in the last rays of the setting sun as seawater drips from its dangling breasts. The still air seethes, heavy with the pregnant aura of impending doom. Suddenly, the giant reptile lunges, snatching its immobile prey into its mighty jaws, and with a horrifying crunch, the watermelon is no more. The tyrannosaur heaves a triumphant howl into the sky, splitting the night with a glorious stream of flame from its victorious mouth in a spectacular display that dares the primordial world to challenge its massive bulk to an aimless duel. The silent forest's edge offers no defiant foe. Gratified, the reptilian titan turns and launches itself back into the brine, sinking into the black abyss to pester seals and sailors. In the distance, a mighty sea-lizard spreads its flippers, lifts its snout, and spits a blazing beacon into the inky sky. It is answered in kind from above, as a flying reptile with a fearsome crest casts a fiery flare toward the restless waves. Meanwhile, within the wooded shores, anxious villagers watch and marvel, relieved at the departure of the melon-eating apparition and thanking their Maker that they have survived another day in a world of dragons.

Dinosaurs have a cult following, and some of their most ardent enthusiasts would have you believe that the fan fiction in the paragraph above is a realistic portrayal of the dinosaurs' ancient world. Streaming like insane racehorses from the brains of such fans come confident pronouncements that tyrannosaurs ate melons[1] and pumpkins,[2] howled,[3]

[1] Unfred 1990, 42; Ham 2009, 31.
[2] Ham 2009, 31.
[3] Goertzen 1993.

had armor plating[4] and mammary glands,[5] and swam the ancient seas.[6] Every item in that list is enough to generate a stern rebuke from any six- to ten-year-old dinosaur expert and to paint quizzical expressions that silently say "You *can't* be serious" on the befuddled faces of professional paleontologists. Nonetheless, such confident pronouncements continue to stream forth, unbridled and undaunted, racing their way through countless printed pages, many of which assert that ancient reptiles breathed fire.

Who are these daring heralds who dauntlessly declare that dinosaurs and other fossil reptiles really, truly, actually spat flame? They are the brilliant minds of the dinosaur information unit of an enormous army of authors who have bravely paved an unintended road to hilarity with good intentions. In the next few chapters, we shall follow their fascinating story. Chapter 1 introduces the solemn motives of the curious collective, chapter 2 relates the background that birthed it, and chapters 3 through 5 chronicle the history of its well-meaning but disastrous march from error unto error and its earnest erection of the singularly silly pillars of its controversial stance. The chapters that follow explore several of its dinosaur-related claims, try them in a court of science, and find them hilarious.

To its credit, the publishing army in question has only ever tried to spread truth and to get its facts as straight as possible. Unfortunately, its authors have failed miserably in that endeavor and have instead—in full and innocent sincerity—placed before the public a vast and ever-growing body of literature that misinforms its readers on a titanic scale.

Forgive them. They know not what they do.

---

[4] Cooper 1992.

[5] Goertzen 1993.

[6] McGowen 2002, 110-11. McGowen did not explicitly state that tyrannosaurs swam the seas, but it follows from his identification of the marine monster Leviathan as *Tyrannosaurus rex*.

CHAPTER ONE

ZOMBIE DUCKLINGS AND BAD TEXTBOOKS

> By his sneezings a light shines, and his eyes are like the eyelids of the morning.
> Out of his mouth go burning lamps, and sparks of fire leap out.
> Out of his nostrils goes smoke, as out of a seething pot or cauldron.
> His breath kindles coals, and a flame goes out of his mouth.
>
> *Anonymous* (Job 41:18-21).

Centuries before the birth of Christ, an anonymous poet wrote the lines above. He was describing Leviathan, a supernatural being that the ancient Hebrews envisioned as a mighty serpent that God had imprisoned beneath the sea.[7] Little did the poet know what mayhem his lines would eventually inspire. The lines were meant figuratively, but not all readers understood that.

The misunderstanding of the Leviathan lines has now led to the notion that ancient people witnessed dinosaurs breathing fire. Although its staggering absurdity should perhaps be self-evident, that notion is taken seriously by a stupendously large number of people who seem otherwise quite intelligent. Some of them even write science textbooks, and they have put that blithering flapdoodle into those textbooks, teaching seventh-graders that the dragon legends of old were inspired by human encounters with live, fire-breathing dinosaurs.[8] Those are actual textbooks that are used in schools, to teach children science. Creating such textbooks is about as sensible as creating marine biology textbooks that are based on televised cartoons about a certain talking sponge who dwells in a pineapple beneath the ocean. Nevertheless, the flabbergasting fact is that the textbooks' authors actually believe what they wrote. Equally flabbergasting is the enormity of the mountain oysters necessary to put such things into print, thereby risking ridicule by publicly declaring endorsement of the notion that fire-breathing dragons were real. Also flabbergasting (with a side order of frightening) is the sheer number of such risk-takers. They are

[7] See chapter 16 of this book for further details.
[8] Batdorf and Porch 2007, 133-134; Lacy 2013, 161.

myriad, and they have authored a recent publication explosion that has pelted consumers with a hailstorm of books and articles that promote the same crackpot fantasy. Several such authors have even hypothesized specific mechanisms for fire production by dinosaurs and other prehistoric reptiles. None of those hypotheses are viable, and all of them are sufficiently half-baked to be great fun to explore and then to mercilessly flatten by raining science upon them like a gentle afternoon shower of Acme safes upon a cartoon coyote, as we shall see in chapters 6 – 14.

The publications that endorse the fire-breathing dinosaur madness are products of the young-Earth creationist movement, a thorn in the flesh of mainstream scientists and science educators. The young-Earth creationist movement is founded upon acceptance of the biblical book of Genesis as a literal and accurate record of past events. If one accepts Genesis in such a way, then one accepts the biblical timeline according to which the Earth and the rest of the universe were created only about six thousand years ago, and all kinds of organisms were created independently of each other on days three, five, and six of the Earth's first week. In contrast, mainstream scientists accept the abundant physical evidence that the Earth is billions of years old and that the organisms on it evolved from a common ancestor over a timespan of billions of years.[9] Mainstream scientists also accept the fossil evidence that the dinosaurs (except the one lineage that evolved into birds) died out over 60 million years ago and that the earliest members of the human species, *Homo sapiens*, came into existence about 0.3 million years ago.[10] They therefore accept that live dinosaurs and humans cannot have encountered each other, because they are separated by millions of years. The fire-breathing dinosaur madness is part of a young-Earth creationist effort to cast doubt upon the separation of dinosaurs and humans by millions of years and, by extension, to cast doubt upon the passage of millions of years, thereby casting doubt upon the evolution of the Earth's organisms from a common ancestor (a process that took millions of years).

The self-defeating nature of the young-Earth creationist movement is baffling to observe but fascinating to study. Ostensibly, the movement is based on loyalty to the words of the Bible, but in reality it violates that very loyalty. As we shall see in chapter 17, the young-Earth creationist movement is disloyal to the words of the Psalms, the Prophets, and the New Testament, all of which preach that the Torah (which includes Genesis) is not to be taken literally.[11] In addition, the movement regularly

[9] Isaak 2007; Prothero 2007; Ogg et al. 2016.
[10] Hublin et al. 2017.
[11] Senter 2016, 2017a.

makes its adherents look ridiculous by spawning absurd biological and geological claims with high entertainment value but little or no factual content. Such claims, like a macabre petting zoo of zombie animals—amusing but disappointing at the same time—grotesquely yodel a weird siren song from books, magazines, and the internet, summoning vulnerable brains to bite. Those cerebral scourges, like horrid but adorable zombie ponies and ducklings, make the movement a riveting phenomenon to follow and chronicle.

For the past few years, some colleagues and I have been studying the evolution of the movement[12] and investigating the various dinosaur-related claims that its proponents have put into print.[13] As a vertebrate paleontologist with a specialty in dinosaurs, I find such claims particularly entertaining. Most are so nutty that they could sprout an entire macadamia plantation, which makes them tons of fun. The young-Earth creationist literature on dinosaurs is so delightfully daffy that it makes for very mirthful reading. I therefore feel a profound responsibility to share with the rest of the world the existence of such literature, so that others who might enjoy it can do so. But as a scientist, I also feel a profound responsibility to set the record straight, whilst shedding tears of simultaneous laughter and dismay.

To understand the origin of the horrid yet adorable zombie duckling that is the fire-breathing dinosaur fallacy, it will be helpful to introduce the creatures and concepts upon which it is based. Let us therefore briefly review a century of discovery, an age of wonder, a time of monsters.

[12] Senter and Mackey 2017a, 2017b; Senter, 2017d.

[13] Senter 2010a, 2010b, 2011a, 2011b, 2012a, 2012b, 2013a, 2013b, 2017b, 2017c; Senter and Cole 2011; Senter and Wilkins 2013; Siebert 2013; Senter and Klein 2014; Senter et al. 2015.

CHAPTER TWO

A TIME OF MONSTERS: THE DISCOVERY OF "DRAGONS"

> The modern discoveries of geology have shewn us…monsters…far more gigantic and horrible than romance ever feigned.
>
> *William Howitt.*[14]

Monsters of the Skies

The Mesozoic Era was a time of monsters.

So was the nineteenth century.

A pint-sized little monster kicked off the discoveries. About two decades before the century began, limestone quarry workers in Bavaria found the robin-sized fossil skeleton of a long-snouted, short-tailed reptile that sported one elongated finger on each hand, as if permanently flinging rude gestures (Figure 2-1). The specimen fell into the possession of a local count, who added it to his collection of natural curiosities. The curator of this collection, the Italian naturalist and historian Cosimo Alessandro Collini, published a description of the specimen in 1784.[15] The little reptile skeleton generated much curiosity and captured attention among naturalists across Europe. The French zoologist Georges Cuvier recognized that the elongated finger must have supported a flight membrane, and in an 1809 publication he said so and dubbed the creature *ptero-dactyle* ("wing finger").[16] In 1819, he gave it the proper taxonomic name *Pterodactylus*,[17] which the English-speaking general public shortened to the nickname "pterodactyle" or "pterodactyl."

Before long, the flying reptiles got more monstrous, as bigger and toothier species were uncovered. A specimen from England, of the sort

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[14] Howitt 1842, 271.

[15] Collini 1784.

[16] Cuvier 1809. Unfortunately, the typesetter misspelled it as *petro-dactyle*, which translates as "stone finger."

[17] Cuvier 1819.

Pterodactylus

Scaphognathus

Rhamphorhynchus

Pteranodon

Figure 2-1: Four examples of pterosaurs.[18] The *Pterodactylus* shown here is a cast of the specimen that Collini described in 1784. In the *Rhamphorhynchus* specimen, note the impressions of flight membranes in the sediment.

that would later be named *Dimorphodon*—an animal with a stork-sized wingspan of four and a half feet—was described in 1829.[19] German specimens of the kinds that would later be named *Scaphognathus* and *Rhamphorhynchus* were described in 1831[20] (Figure 2-1). Their mouths

[18] The illustration of Scaphognathus is from Goldfuss (1831).
[19] Buckland 1829b.
[20] Goldfuss 1831.

were full of elongate teeth that were much more intimidating than the dainty little pegs in the beak of *Pterodactylus*, which were almost cute by comparison. *Scaphognathus*, the size of a gull, sported a widely-spaced set of horrifying fangs that resembled a row of finishing nails. The beak of its larger cousin *Rhamphorhynchus*, the largest specimens of which had wingspans of over five feet,[21] bore a ghoulish, forward-pointing array of interdigitating teeth that jutted outward from the snout like the projections around the rim of a Venus flytrap but were sharper and creepier and capable of making any fish that dared to leap toward its mouth immediately regret that decision. By the end of the century, two specimens of *Rhamphorhynchus* confirmed Cuvier's suspicion that the elongated finger supported a flight membrane. The two specimens, which preserved imprints of the flight membrane, were described in 1882.[22]

The assortment of flying reptiles was given the taxonomic name Pterosauria in 1834,[23] and by the end of the century the group was known to include truly enormous species. The American paleontologist Othniel Marsh and his team discovered an immense pterosaur from the American west in the 1870s, a monster with a 20-foot wingspan that must have cast an ominous shadow, an aerial apparition sufficiently chilling to make even the most intrepid birdwatcher switch to an indoor hobby such as knitting or philately or quaking in a fetal position under the bed while frantically trying to calm himself by reading paperboard baby books about bunnies.[24] In 1876, Marsh named the beaked behemoth *Pteranodon*[25] (Figure 2-1). Little did he suspect that 135 years later, *Pteranodon*, along with the dinosaurs, would be accused of breathing fire.[26]

Monsters of the Seas

In addition to monsters of the skies, the nineteenth-century explosion of discoveries of extinct reptiles included giants from the ancient seas, for some of which the colossal *Pteranodon* would have been a mere appetizer. In 1808, Cuvier published an identification of a pair of large specimens from the Netherlands, each of which consisted of a skull nearly four feet long, as those of a gigantic species of lizard. The skulls had been

[21] Wellnhofer 1991, 85.
[22] Marsh 1882; Zittel 1882.
[23] Kaup 1834.
[24] *Busy Bunnies* by John Schindel and Steven Holt is an excellent choice. I turn to it for comfort every time I find myself hiding from a large pterodactyl.
[25] Marsh 1876.
[26] Gilmer 2011, 49, 67-68; Gilmer 2013, 83. See chapter 14 of this book.

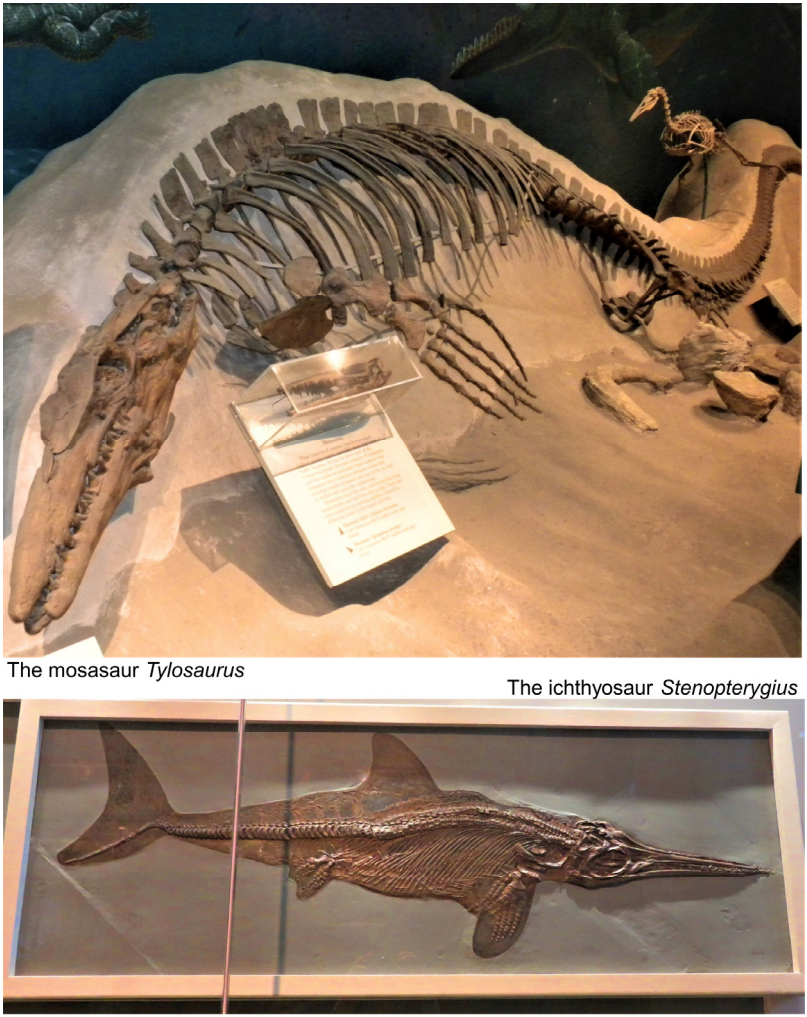

Figure 2-2: Ancient sea reptiles. A mosasaur and an ichthyosaur.

discovered in the 1760s and 1770s and had previously been thought to be those of whales or crocodiles. In 1822, the English geologist William Conybeare named the great lizard genus *Mosasaurus*.[27] Over the course of the century, related species were discovered and classed within the family

[27] Parkinson 1822, 298.

Mosasauridae. Specimens with more complete skeletons showed that the elongate bodies of these marine lizards were astonishingly vast. The mosasaur *Tylosaurus* (Figure 2-2) was found to attain a length of about 40 feet,[28] and subsequent specimens of *Mosasaurus* showed that it exceeded 50 feet.[29] As with *Pteranodon*, mosasaurs would eventually be suspected of fire-breathing.[30]

In 1814, Sir Everard Home published a description of a fish-shaped fossil reptile from England with limbs modified into flippers and with a head that was four feet long.[31] Conybeare gave a similar, smaller species (with a total length of about six feet) the name *Ichthyosaurus* in 1821,[32] and the French zoologist Henri de Blainville named the group Ichthyosauria in 1835.[33] By the end of the century, several different species of ichthyosaurs had been discovered (Figure 2-2). The gigantic ichthyosaur *Temnodontosaurus*, represented by Home's monster with the four-foot head, grew nearly 40 feet in length.[34]

In addition to including reptilian monsters, the Ichthyosauria are of importance for a more entertaining reason, at least as far as giggling schoolchildren are concerned. Their fossilized droppings, containing undigested bones and mollusk parts, were among the first fossilized feces to be recognized as fossilized feces. In several specimens discovered in the early nineteenth century, un-dropped droppings were preserved in the abdominal regions of ichthyosaur skeletons,[35] whose bowels remain full to this day, having suffered millions of years of constipation. After studying the fossilized dung of ichthyosaurs and other marine animals, the English geologist William Buckland coined the term "coprolite"[36] for fossilized feces.[37]

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[28] Lydekker 1889, 1144.
[29] Grigoriev 2014.
[30] Gilmer 2011, 92-95. See chapter 16 of this book.
[31] Home 1814.
[32] Conybeare 1821.
[33] de Blainville 1835, 271.
[34] Lydekker 1889, xi, 1126.
[35] Buckland 1836, 190-192.
[36] This literally translates as "sh*t rock"—not to be confused with sheetrock, which is usually not made of coprolites, but might become a coprolite if you eat some and then are fossilized while it is still in your intestine, although I wouldn't recommend eating it, because it needs a lot of flavoring to be palatable (so I've been told) and will constipate you like geological matrix in a fossilized ichthyosaur's abdomen.
[37] Buckland 1829a.

The long-necked plesiosaur *Thalassomedon*

A short-necked plesiosaur of the family Pliosauridae

Figure 2-3: Two examples of plesiosaurs.

Conybeare gave the name *Plesiosaurus* to a fragmentary reptile skeleton in 1821[38] and published a description of a nearly complete skeleton three years later.[39] The animal had flippers for limbs and was about ten feet long, nearly half of which was neck, at the end of which was a small head, the combined effect of which was to make the animal look like the reptilian love child of a giraffe and an oar-propelled dinghy, the perfect premise for a best-selling forbidden-romance novel if there ever was one. Its remarkable neck had at least 35 vertebrae, more than are in the entire human spine.[40] By the end of the century, a variety of

[38] Conybeare 1821.
[39] Conybeare 1824.
[40] The human spine has seven cervical (neck) vertebrae, twelve thoracic vertebrae, five lumbar vertebrae, five sacral vertebrae, and usually two to four coccygeal

plesiosaurs were discovered. Some were immense. In 1870, the American paleontologist Edward Cope published a detailed description of the giant plesiosaur *Elasmosaurus*. The animal was over 40 feet long, with a neck nearly twice as long as the entire body of *Plesiosaurus*. That enormous neck housed more than 60 vertebrae.[41] Short-necked plesiosaurs with big heads were also discovered and classed in the family Pliosauridae (Figure 2-3). Some pliosaurids were quite colossal. In one specimen of *Pliosaurus*, described in 1869, the jaw alone was nearly six feet long.[42] As with the pterosaurs and mosasaurs, the plesiosaurs were doomed not only to become extinct but to eventually fall under suspicion of oral arson.[43]

The nineteenth century witnessed the discovery of numerous huge, bizarre, and extinct fishes, amphibians, mammals, and other creatures in addition to the reptilian giants. The public gasped in amazement at species after species in an unending train of fossil discoveries, a train that continues to roll on and to surprise and amaze to this day. But, astounding as every new set of fossil finds was, there was one category of fossil monsters that captured the hearts of the public like no other. In 1842, the eminent English paleontologist Sir Richard Owen gave them the name Dinosauria.[44]

The Dinosaurs

The dinosaurs were towering beasts. Most reptiles have limbs that sprawl out to the side, so that the animal's belly contacts the ground. Not so the dinosaurs. They are distinguished from other reptiles by a suite of anatomical traits of the pelvis and hindlimb that make the hindlimbs erect, keeping the belly far off the ground. Likewise, the shoulders of dinosaurs are built to orient the forelimb so that it extends downward, not spread out to the side in a lizardlike gesture of surrender.

("tail-bone") vertebrae. If, like *Plesiosaurus*, you had 35 cervical vertebrae, you could lick the roof of an ice cream van without standing on your tippy-toes. But, as with sheetrock, I wouldn't recommend it. That is because, to the great astonishment of ice cream van roof-lickers worldwide, an ice cream van roof does not taste like ice cream.

[41] Cope 1870.

[42] Owen 1869, 3.

[43] Baugh 1987, 92-94; Phillips 1994, 55, 62-63; Ham 1998, 43-46; Ham 2006, 159; Ham 2009, 27; Isaacs 2010, 162-163; Woetzel 2012, 70. See chapter 16 of this book.

[44] Owen 1842, 103.

The earliest dinosaur to be named and described in a scientific publication was the 20-foot carnivore *Megalosaurus* (Figure 2-4). William Buckland described its partial skeleton in 1824.[45] In the following year, his countryman Gideon Mantell described the teeth of the 30-foot herbivore *Iguanodon*[46] (Figure 2-5). Almost no sooner had the existence of these animals been made public than they were accused of being the biblical Leviathan and Behemoth, the pair of primeval monsters described in Job 40 and 41.[47] That charge was leveled by the reform-minded politician Thomas Thompson in 1835. It appears that his hypothesis was espoused but little in his day, but some creative minds from later generations would not only adopt a revised version of his view but would elaborate upon it with incendiary enthusiasm, insisting that Leviathan was a fire-breathing dinosaur (see chapters 5, 11, and 16).

Mantell described more of the skeleton of *Iguanodon* in 1833,[48] and in the same book he introduced and described the spiky, 15-foot herbivore *Hylaeosaurus*[49] (Figure 2-6). When Owen named the Dinosauria, only those two and *Megalosaurus* were known to be part of the group. But by the end of the century, fossil hunters would discover dozens of new dinosaurian species in several different categories.

Megalosaurus belonged to the dinosaurian group called the Theropoda (Figure 2-4). Theropods were bipedal, and most were carnivorous. Some were gigantic. In 1877, Othniel Marsh announced the discovery of *Allosaurus*[50] (Figure 2-4) a theropod that is now known to have reached a length of 30 feet. Theropods that were larger still—including the famous *Tyrannosaurus rex* (Figure 2-4), which weighed about as much as an African elephant[51]—were described in the twentieth and twenty-first centuries. Many of the smaller theropods, including the Dromaeosauridae (the family to which the famous *Velociraptor* belongs), are now known to have been covered in feathers.[52] Their skeletons are remarkably birdlike, and the earliest fossil birds are nearly identical to them. Theropod dinosaurs were, indeed, the stock from which birds sprang,[53] a pedigree

[45] Buckland 1824.
[46] Mantell 1825.
[47] Thompson 1835.
[48] Mantell 1833, 304-316.
[49] Mantell 1833, 316-333.
[50] Marsh 1877a.
[51] Hutchinson et al. 2014.
[52] Xu et al. 2003; Lü and Brusatte 2015.
[53] The young-Earth creationist objection that feathered theropods cannot be ancestral to birds because all known feathered dinosaurs are from deposits that are

Megalosaurus

Allosaurus

Tyrannosaurus

Velociraptor

Figure 2-4: Four examples of theropod dinosaurs.

that nineteenth-century scientists astutely deduced by examining dinosaurian skeletal anatomy[54] more than a hundred years before the first feathered dinosaur fossil was found.

Iguanodon belonged to the herbivorous dinosaurian group called the Ornithopoda (Figure 2-5). The ornithopods were beaked bipeds. The largest of them had wide snouts that inspired nicknames such as

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stratigraphically higher (in other words, later) than the earliest birds, is now known to be incorrect. Feathered theropods that are earlier than the earliest fossil birds have recently been discovered (Hu et al. 2009).

[54] Huxley 1870.

Iguanodon

Edmontosaurus

Corythosaurus

juvenile *Lambeosaurus*

Figure 2-5: Four examples of ornithopod dinosaurs. *Edmontosaurus*, *Lambeosaurus*, and *Corythosaurus* are members of the duckbilled dinosaur family (Hadrosauridae).

"duckbills" or "duckbilled dinosaurs." The duckbills are more properly called hadrosaurs or hadrosaurids, because they are classed in the family Hadrosauridae. The family is named after *Hadrosaurus*, the first hadrosaurid to be discovered. It was unearthed in New Jersey in 1858,[55] and its skeleton was the first dinosaur skeleton to be mounted for public display, which occurred at the Academy of Natural Sciences in Philadelphia in 1868.[56]

The hadrosaurids with hollow crests on their heads are classed in the subfamily Lambeosaurinae. *Corythosaurus* (Figure 2-5), the first lambeosaurine to be described, was unearthed in 1912 and described in

[55] Foulke and Leidy 1858.
[56] Carpenter 2012a.

Hylaeosaurus

Euoplocephalus

Stegosaurus

Figure 2-6: Three examples of armored dinosaurs: two ankylosaurs (*Hylaeosaurus*, *Euoplocephalus*) and a stegosaur (*Stegosaurus*).

1914.[57] Although this subfamily of monsters is one that was unknown in the nineteenth century, the lambeosaurines are important to mention in our list of dinosaurs, because they would eventually be equated with the biblical Leviathan and would be accused of fire-breathing.[58]

Hylaeosaurus belonged to the herbivorous dinosaurian group called the Ankylosauria (Figure 2-6). The ankylosaurs were quadrupeds whose backs and tails were covered in bony armor. As with many members of the family, the shoulders of *Hylaeosaurus* bore robust, bony spikes. The

[57] Brown 1914.

[58] Gish 1977; Petersen 1986, 145; Morris 1988, 118; Niermann 1994, 86–87; DeYoung 2000, 118.

later members of the ankylosaurian family Ankylosauridae lacked the shoulder spikes but sported a bony club at the end of the tail.[59]

The Stegosauria were another group of armored, quadrupedal dinosaurs. Their backs and tails bore the ornamentation that have made the profile of their best-known representative, *Stegosaurus*, instantly recognizable (Figure 2-6). *Stegosaurus* was the beastie with the pentagonal plates that made it look like it had pasted a row of American school-crossing signs onto its back for some reason.[60] A monstrous beast the size of an Indian elephant, *Stegosaurus* was unearthed in the American west and was announced by Marsh in 1877.[61] By the end of the century, immense European stegosaurs were also discovered.[62]

Members of the Ceratopsia were herbivores with spiked cheeks (Figure 2-7). The earliest ceratopsians were small, hornless bipeds.[63] Many of the later ceratopsians were huge quadrupeds with facial horns and a large, bony frill that protected the neck, making them look like gigantic rhinoceros beetles wearing an oversized garden shovel blade for a bonnet.[64] One of the largest, the well-known *Triceratops*, was about the size of an elephant. It was first described by Marsh in 1889.[65]

Members of the Pachycephalosauria were small, bipedal herbivores with a thick skull roof ringed by bony knobs. In some cases, the skull was topped by a rounded dome of solid bone, as if the animal had stuffed half a bowling ball beneath its scalp (Figure 2-7). The internal structure of the dome indicates that it could absorb strong impact,[66] and patterns of healed injury on pachycephalosaur domes show that they had indeed been used to strike hard objects,[67] possibly other pachycephalosaurs' heads in the manner of bighorn sheep. As any good bowler knows, you get more points by aiming your ball at the pins than at other bowling balls, but the magnitude of the damage in injured pachycephalosaur skulls suggests that

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[59] Carpenter 2012b.

[60] Probably because it was concerned about the safety of schoolchildren.

[61] Marsh 1877b.

[62] Galton 1985.

[63] Hailu and Dodson 2004.

[64] Odd fashion choice, but who am I to criticize? After all, I had a mohawk in high school. I had thought that it would make me look like a ferocious bad-@ss, but I ended up looking like I should be clucking and pecking at grain in a barnyard and passing eggs out my cloaca. Lesson learned.

Now I've got male pattern baldness and couldn't grow a mohawk if I wanted to. Thanks, genes.

[65] Marsh 1889.

[66] Snively and Theodor 2011.

[67] Peterson and Vittore 2012; Peterson et al. 2013.

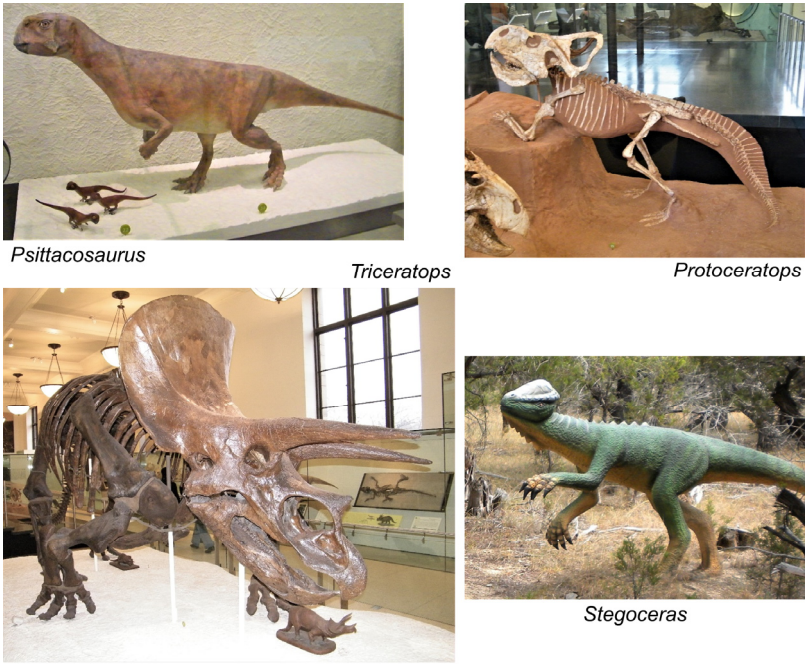
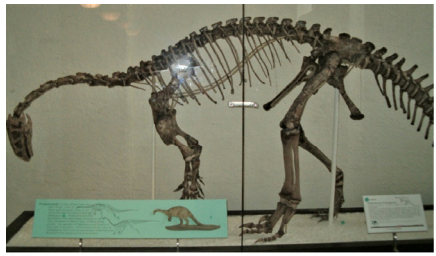


Figure 2-7: Three examples of ceratopsian dinosaurs and one example of a pachycephalosaur: a bipedal ceratopsian (*Psittacosaurus*), two quadrupedal ceratopsians (*Protoceratops*, *Triceratops*), and a pachycephalosaur (*Stegoceras*).

they were less interested in scoring points legally than in being bowling-ball-bashing brawlers, settling disputes by banging brain-bins. *Stegoceras*, the first pachycephalosaur to be discovered, was unearthed in 1898.[68]

The largest dinosaurs were members of the Sauropodomorpha, a group consisting of long-necked, small-headed herbivores (Figure 2-8). Early sauropodomorphs were bipeds that ranged from the size of a turkey (e.g. *Thecodontosaurus*, announced in 1836[69]) to sizes more like that of a rhinoceros (e.g. *Plateosaurus*, announced in 1837[70]). But even those were dwarfed by the quadrupedal sauropodomorphs of the group called the Sauropoda. Truly monstrously-sized sauropods such as the famous *Brontosaurus* (over 70 feet long), *Apatosaurus* (over 70 feet long), and

[68] Lambe 1902.
[69] Riley and Stutchbury 1836.
[70] Meyer 1837.



Plateosaurus

Apatosaurus

Diplodocus

Brontosaurus

Figure 2-8: Four examples of sauropodomorph dinosaurs: one bipedal sauropodomorph (*Plateosaurus*) and three sauropods.

Diplodocus (over 80 feet long) were discovered in the 1870s.[71] *Brontosaurus* was once considered synonymous with *Apatosaurus*, but the two are now thought to be distinct.[72]

Deep Time

Early in the nineteenth century, it had become evident from the collected work of numerous geologists that vast ages had passed on the Earth before

[71] Marsh 1877b, 1878, 1879.
[72] Tschopp et al. 2015.

the first human ever walked it. That collected work also showed that Earth's previous ages had been full of lifeforms that no longer exist today, and that no two slices of ancient time contained the same set of lifeforms. By the 1820s, fossil finds had revealed a curious pattern: the older geological strata (rock layers) contained fossils that were unlike today's organisms, and the fossil organisms became more and more similar to today's organisms in the later and later strata. The closer one got to the present day, the more closely the organisms resembled today's lifeforms.[73] Decades before the 1859 publication of Charles Darwin's famous book *On the Origin of Species*, some biologists had explained the pattern of fossil succession as evidence of evolution: the idea that ancient organisms had evolved, over vast stretches of time, to become today's organisms. Biologists such as Jean-Baptiste de Lamarck and Richard Owen, and other authors such as Richard Chambers, had endorsed that idea in print in the early decades of the nineteenth century,[74] as had Erasmus Darwin (Charles Darwin's grandfather) in the 1790s.[75] Contrary to the misconceptions of those who view evolution as an atheistic conspiracy, all those authors—including both Darwins—stated in writing the opinion that the Divine Creator had set evolution into motion.[76]

The saga of evolution required vast stretches of time, but no one would know exactly how vast those stretches were until the twentieth century. Radiometric dating, the use of radioactive isotopes to date rocks, was introduced by the American physicist Bertram Boltwood in 1907. The concept was rather straightforward: measure the speed with which a radioactive parent substance decays into its daughter substances (that is, its radioactive decay products), then measure the ratio of parent to daughter substances in a rock to determine how long the rock had been accumulating the daughter substances. Using uranium and its radioactive decay products, Boltwood's data showed that some rocks on Earth were billions of years old.[77] Later studies would show that the Earth itself is 4.57 billion years old.[78]

Even before the radiometric dates of Earth's past ages were known, those ages were given names (Figure 2-9). In 1838, the English geologist

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[73] Charles Lyell's 1826 article neatly summarizes the accumulated data that revealed this pattern.
[74] Lamarck 1809; Chambers 1844; Owen 1846, 86; Owen 1849, 86.
[75] Darwin 1794, 498-509.
[76] Darwin, 1794, 509; Lamarck 1809, 67; Chambers 1844, 152-156, 163; Owen 1849, 86; Darwin 1860, 432; Owen 1861, 450-451.
[77] Boltwood 1907.
[78] Brown et al. 2005.