'Magisterial ... part historical account, part scientific detective story. Switek's elegant prose and thoughtful scholarship will change the way you see life on our planet.'
Neil Shubin, author of *Your Inner Fish*

BRIAN SWITEK

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THE HIDDEN SECRETS OF FOSSILS AND THE STORY OF LIFE ON EARTH

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For Tracey

PRAISE FOR **WRITTEN IN STONE**

"Brian Switek's … pithy accounts explain how the fossils of everything from Archeopteryx to Tyrannosaurus to Zinjanthropus came to be discovered and interpreted [and his] stories of 19th-century fossil-finders often shed light on current controversies. … [An] excellent book."

—MICHAEL SHERMER, ***Wall Street Journal***

"In this thoroughly entertaining science history, Switek combines a deep knowledge of the fossil record with a Holmesian compulsion to investigate the myriad ways evolutionary discoveries have been made. It's poetry, serendipity, and smart entertainment because Switek has found the sweet spot between academic treatise and pop culture, a literary locale that is a godsend to armchair explorers everywhere."

—COLLEEN MONDOR, ***Booklist***

"Highly recommended."

—Library Journal

"Rocks are full of stories. They contain the petrified remains of long-dead animals and in every fossilized bone, scale and track, there are awe-inspiring accounts of the history of life on this planet. Of course, fossils themselves are poor narrators. To uncover their tales, you need a storyteller with an expert's knowledge and a writer's flair. Brian Switek is that storyteller. This is science narrated with maturity, reverence and grace; the epilogue alone is worth the asking price. *Written in Stone*, quite simply, rocks."

—ED YONG, ***Discover Magazine***

“Notions of evolution have, for lack of a better word, evolved, and with wonderfully broad strokes science writer and long-time paleontology blogger Switek takes readers on a fascinating historical, scientific and cultural tour of the theory’s various incarnations.”

—Sid Perkins, ***Science News***

“Switek’s engaging account may tempt the uncommitted to appreciate how interesting is the underground world, and how the vast storehouses of Earth’s strata further our understanding of how life developed. … *Written in Stone* is a fine guide to the four-dimensional tapestry of life—the bony bits of it, at least.”

—Jan Zalasiewicz, ***Nature***

“This book will change the minds of those who believe quality science writing is vanishing. Switek has produced prose and paleontological inspiration comparable to the work of the late Stephen Jay Gould. … Highly recommended.”

—M. A. Wilson, ***Choice***

FIGURE 1 – The skeleton of the forty-seven-million-year-old fossil primate *Darwinius masillae*.

Introduction:
Missing Links

> About thirty years ago there was much talk that geologists ought only to observe and not theorise; and I well remember some one saying that at this rate a man might as well go into a gravel-pit and count the pebbles and describe the colours. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service!
>
> —Charles Darwin in a letter to Henry Fawcett, 1861

> Let us not be too sure that in putting together the bones of extinct species … we are not out of collected fossil remains creating to ourselves a monster.
>
> —Samuel Best, *After Thoughts on Reading Dr. Buckland's Bridgewater Treatise*, 1837

Embedded in a slab of forty-seven-million-year-old rock chipped from a defunct shale quarry in Messel, Germany, the chocolate-colored skeleton lay curled up on its side as if its owner had peacefully passed away in its sleep. Even the outline of the creature's body could be seen, set off in dark splashes against the soft tan of the surrounding stone, but the hands were what immediately drew my attention. Stretched out in front of the body, as if the skeleton was clutching at its slate tomb, each hand bore four fingers and an opposable thumb, all of which were tipped in

compressed nubs of bone that would have supported flat nails in life. These were the hands of a primate, one of my close extinct relatives, but was it one of my ancestors?

I had been waiting for days to get a good look at the fossil. My curiosity was initially piqued on May 10, 2009, when the British newspaper the *Daily Mail* announced that the venerable natural history documentary host David Attenborough was preparing to unveil the "Missing Link in human evolution." The full details would be presented in a forthcoming BBC program, the article promised, but as a teaser the piece included a caricature of where our new ancestor fit into our family history. Its lemur-like silhouette stooped at the beginning of a short parade of human evolution conducted through our primate antecedents to us.

Further details about the fossil were difficult to dig up. A May 15, 2009, piece by the *Wall Street Journal* provided little new information other than that the discovery would be unveiled the following Tuesday during a New York City press conference coordinated with the release of a descriptive paper in the journal *PLoS One*. This made sense of a nauseatingly overhyped press release I had received the day before which shouted "WORLD RENOWNED SCIENTISTS REVEAL A REVOLUTIONARY SCIENTIFIC FIND THAT WILL CHANGE EVERYTHING." The fossil would be presented with all the pomp and circumstance due a newly discovered and long-lost family member, but I did not care as much about the public ceremonies as the scientific paper. I wanted to know if the evidence supported the fantastic claims being bandied about in the newspapers.

I had hoped that *PLoS One* would send out an embargoed version of the paper so that science writers like me could brace for what was promised to be an earthshaking announcement. This is a standard practice in which a journal distributes papers to science writers a few

days early so that stories can be prepared (with the understanding that no one will break the story until the embargo lifts), and *PLoS One* had used it for many of its major publications. No such luck. Science writers would have to wait for the grand unveiling like everyone else.

When the paper was finally released I felt simultaneously overjoyed and underwhelmed. The petrified skeleton—named *Darwinius masillae* by the authors of the study in honor of Charles Darwin—was the most beautifully preserved primate fossil ever discovered. The remains of prehistoric primates are rare to begin with; most of the time paleontologists find only teeth and bone fragments. But *Darwinius* was exquisitely preserved with hair impressions and gut contents in place. Even the famous skeleton of our early relative "Lucy" was far less complete. By any estimation, this first specimen of *Darwinius* was a gorgeous fossil.

Despite the intricate nature of the fossil's preservation, however, the evidence that *Darwinius* was even close to our ancestry was flimsy. The paper confirmed that it was a type of extinct primate called an adapiform, and while they were once thought to be good candidates for early human ancestors more recent research showed that lemurs, lorises, and bush babies are their closest living relatives. In order to change this consensus *Darwinius* would have to exhibit some hitherto unknown characteristic that affiliated it more closely with early anthropoid primates (monkeys and apes, including us), but the authors did not make a good case for such a connection. There was no trait-for-trait comparison of *Darwinius* with other living and fossil primates that would have supported the status of "ancestor" that early reports had given it.

None of this hindered the fossil's bombastic media debut. In public the fossil was called "Ida" after the daughter of one of the paper's authors, paleontologist Jørn Hurum, and Hurum introduced Ida as our unquestionable

ancestor. He proclaimed that *Darwinius* was "the first link to all humans … the closest thing we can get to a direct ancestor." Some of his co-authors were equally given to hyperbole. Paleontologist Philip Gingerich compared *Darwinius* to the Rosetta Stone, and lead author Jens Franzen stated that the effect of their research would "be like an asteroid hitting the Earth." A pair of high-profile documentaries, a top-notch Web site, a widely read book, and dozens of early media reports drove home the same message; Ida was the "Missing Link" that chained us to our evolutionary history.

New York Times journalist Tim Arango beautifully described this tidal wave of publicity as "science for the Mediacene age." In an instant Ida was everywhere. After seeing the fossil plastered all over the news and even in a customized Google logo I half expected to find promotional "The Link" breakfast cereal at the supermarket. The premiere was just as well orchestrated as that of any Hollywood blockbuster, but unlike most big-budget films there was no buzz leading up to the big event. Outside of the early reports from the *Daily Mail* and *Wall Street Journal* barely a peep was heard about Ida before her debut.

Scientists and journalists who were not content with regurgitating the approved press releases scrambled to dig up the glorified lemur's backstory. Something was not right. The public was being sold extraordinary claims about Ida before anyone had a chance to see if the science held up to scrutiny. It was the scientific equivalent of not screening a film for review by critics but promoting the movie as the greatest since *Casablanca*. Hurum was unapologetic about this media strategy. "Any pop band is doing the same thing," he dodged. "Any athlete is doing the same thing. We have to start thinking the same way in science." But, as Hurum well knew, there was much more to it than that. As reports started to trickle in from

independent sources it quickly became apparent that Ida had been groomed for stardom almost from the very start.

When the fossil pit in Messel, Germany, coughed up Ida it was on its way to becoming a garbage dump. The quarry had been a shale mine for years. Numerous exquisitely preserved fossils had been discovered there, but after the mining operations stopped in 1971 the government made preparations to turn it into a landfill. Amateur fossil hunters knew their time was limited. They picked over the site to remove whatever they could, and in 1983 one of the rock hounds split open a slab of shale to discover Ida's skeleton.[1] There were two parts: a mostly complete main slab; and a second slab that, because of the angle of the split, was missing some of the bones of the head, leg, and torso. Rather than stitch them back together, Ida's discoverer hired a fossil preparator to fill in the details of the "lesser half," using the more complete slab as a guide.

Such a discovery was too valuable to just give away to science, and the half-real, half-fabricated slab was sold to the Wyoming Dinosaur Center in 1991. Perhaps the fossil should have been called "*Caveat emptor*" at this point; not only was the purchased slab partially faked, but the parts that were real were not especially helpful in determining what kind of primate it might have been. The specimen sat virtually unnoticed in the Wyoming museum. The other slab stayed in private hands. Scientists had no idea it existed.

By 2006, however, it was time to sell Ida's better half. Her owner (who has remained anonymous) sold it to the German fossil dealer Thomas Perner, who in turn offered it to two German museums, but Perner's asking price was so high that neither institution could afford the fossil. Private collectors have deeper pockets than museums, though, so Perner decided to bring a few high-resolution photos to the Hamburg Fossil and Mineral Fair to show to some of his previous clients, including University of Oslo paleontologist Jørn Hurum.

Upon seeing the fossil, Hurum was instantly enthralled. He had to have it. The trick would be raising the $1,000,000 Perner was asking. He could not afford this on his own but hoped his university could help foot the bill. Eventually they reached a deal. The college would dole out a total of $750,000 in two payments: half the asking price once the fossil was in Hurum's hands and the other half when he were sure of its authenticity. The tests confirmed that, unlike its complement, the slab had not been forged, and by the beginning of 2007 Hurum finally had his fossil "Mona Lisa."

But Hurum was not a primate expert. Most of his scientific work had focused on dinosaurs and extinct marine reptiles. To make up for this lack of expertise he put together what he would later call an international "dream team" of fossil primate specialists; Jens Franzen, Philip Gingerich, Jörg Habersetzer, Wighart von Koenigswald, and B. Holly Smith. Each scientist brought different strengths to the team, but the inclusion of Franzen was especially important. Franzen had described the other half of Ida's skeleton during the 1990s, and once it was realized that the two slabs were halves of the same fossil they were reunited.

Hurum also had bigger things in mind. At the time he acquired Ida, Hurum was working with the media company Atlantic Productions on a documentary about the remains of a 147-million-year-old, fifty-foot-long carnivorous marine reptile given the B-movie moniker "Predator X." The company had jumped at the chance to document the study of one of the largest marine predators that ever lived, and Hurum approached them about Ida. The company reps were just as taken with the primate fossil as Hurum was. Sea monsters were interesting, but a potential human ancestor was even better. Plans for the two documentaries, the mass market book, and all the other details of the public release began to coalesce.

Team member Philip Gingerich would later lament, “It’s not how I like to do science.” With the May 19, 2009, debut date set far in advance the scientists had to rush to get their description of *Darwinius* completed in time. This presented a substantial hurdle. To be published in a reputable scientific journal research must go through a process of peer review in which the original paper is sent for comment to academics in the same field. Based upon these independent assessments the journal then decides to either publish or reject the paper, and even if the paper is not rejected it might still require changes prior to final acceptance. The process can drag out for months or even years, and since the first complete version of the *Darwinius* paper was completed in the early months of 2009 the researchers did not have much time left.

As the open-access journal *PLoS One* had earned a reputation for a speedy review process, it seemed like the best choice. The manuscript was submitted in March, but it could not immediately be accepted. According to one of the reviewers, fossil primate expert John Fleagle, the paper made the extraordinary claim that *Darwinius* was a human ancestor without supplying sufficient evidence. This conclusion was toned down, and in the next draft the authors suggested that *Darwinius* might be closely related to the ancestors of anthropoid primates instead. Nevertheless, the plans to herald Ida as the “missing link” to the public remained in place, and despite the heavy involvement of the media companies, the scientists declared no competing interests in the paper.

The paper was finally accepted on May 12, 2009, just one week before it was set to be released. With the contents of the paper finalized, the *PLoS One* employees went into overdrive to get the paper prepared for Ida’s debut. They managed to finish their work by May 18, but on behalf of the media companies the authors asked that the paper not be released to anyone until the press

conference the next day.[2] The journal acquiesced. Atlantic Productions was given full control over how Ida would be presented.

When this convoluted tale of black market fossil deals, pervasive media control, and overhyped conclusions burst onto the public scene scientists were aghast. There were so many controversial points it was difficult to know where to start, but the most prominent was Ida's being hailed as our great-great-great-great- … -grandmother. By all appearances *Darwinius* had been believed to be a human ancestor from almost the start. This was not good science and, in truth, the peer review of Ida had only just begun.

A hypothesis or conclusion announced in a scientific paper is not ironclad law. Publication is just an intermediate step in fostering our understanding of nature, and a hypothesis will stand or fall according to the ensuing debate. The case of *Darwinius* was no exception. It was clear that the team of scientists had not done the essential work to support the claims they were making in public, and within a few months a new study would put Ida in her proper place.

In 2001, five years prior to the sale of *Darwinius* to Hurum, paleontologist Erik Seiffert and his colleagues were searching for fossils in the thirty-seven-million-year-old sediments of the Fayum desert of Egypt. During that part of earth's history the Fayum hosted a lush forest inhabited by a mix of early anthropoids and representatives of other now-extinct primate groups. Among the fossil scraps Seiffert and his peers collected in 2001 were the jaw fragments and teeth of a lemurlike primate. The distinctive shape of a mammal's teeth is so closely tied to its feeding habits that a handful of teeth can be more useful in determining its closeness to another mammal than scattered bits of ribs, limbs, or vertebrae.

The Fayum team spent years piecing together the bits of the primate they had found, but in the wake of the Ida

fallout Seiffert and colleagues Jonathan Perry, Elwyn Simons, and Doug Boyer resolved to do what "team *Darwinius*" had not. They compared 360 characteristics across 117 living and extinct primates, including *Darwinius*, through a methodology known as cladistics.

The logic behind the technique is simple. The goal is to create a tree of evolutionary relationships based upon common ancestry, and to do this scientists select the organisms to be scrutinized, choose the traits to be compared, and document the character state of each trait (i.e., whether the trait is present or absent). Once all this information is compiled it is placed into a computer program that sifts through the data to determine which organisms are most closely related to each other on the basis of shared, specialized characteristics inherited from a common ancestor. Anthropoid primates and tarsiers, for example, have a partition of bone which closes off the back of the eye, whereas lemurs and lorises lack this closure. The fact that *Darwinius* lacked this distinctive plate of bone behind its eye, among other characteristics, associated it closer with lemurs and lorises than anthropoid primates.

No single trait overrides all the others, though. Some traits evolve more than once in different lineages or are secondarily lost among some members of a group, so it is better to select numerous traits rather than just a handful. Each evolutionary tree produced is a hypothesis that will be tested against additional evidence, but cladistics has the advantage of forcing scientists to fully present the data they use in the process. Even if the resultant tree is thought to be incorrect, scientists can at least look at the data to pinpoint what might have skewed the results. This kind of self-correction is not possible when ancestors and descendants are lined up simply on the basis of what looks right.

The results of the analysis Seiffert and his team conducted were published in the journal *Nature* on October

21, 2009, just over five months after *Darwinius* was announced. There were a few surprises. Despite living thousands of miles and ten million years apart, the primate from the Fayum, which they named *Afradapis longicristatus*, was a very close relative of *Darwinius*. They were definitely both adapiforms, but they were unusual ones.

Both *Darwinius* and *Afradapis* had traits that had traditionally been thought to be indicative of anthropoid primates, such as the fusion of the lower jawbones where they meet in the middle. This is a key trait seen in living monkeys, not lemurs, and if we had only living primates to compare *Darwinius* to then we might think that adapiforms really were ancestors of anthropoids. The problem is that some of the earliest anthropoid primates known, such as *Biretia* and *Proteopithecus*, do not share these same "anthropoid features." These traits evolved independently among later anthropoids in a case of convergent evolution. For *Darwinius* to be an anthropoid ancestor its descendants would have had to lose some traits, such as the fused lower jawbones, only to have those same traits evolve again later among its descendants. There was no evidence to suppose that such a thing had happened.

This conclusion was supported by the evolutionary tree Seiffert's team produced. Not only did *Darwinius* and *Afradapis* group closely together on the basis of their shared characteristics, but they were about as distantly related to early anthropoids as it was possible to be. Their closest living relatives are the lemurs and lorises, not monkeys. (Though they actually were most closely related to other forms of primate that are now entirely extinct.) As expected, it was the tarsiers and their extinct relatives that were most closely related to anthropoids. Ida had unceremoniously been dethroned.[3]

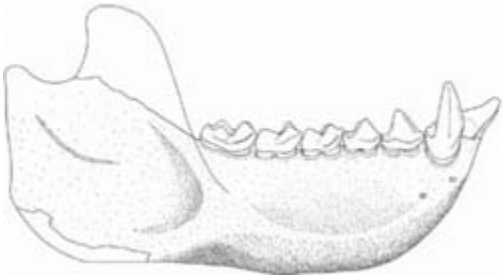

FIGURE 2 – The lower jaw of *Afradapis longicristatus*, reconstructed on the basis of multiple specimens. So far, it is all that is known of this fossil primate.

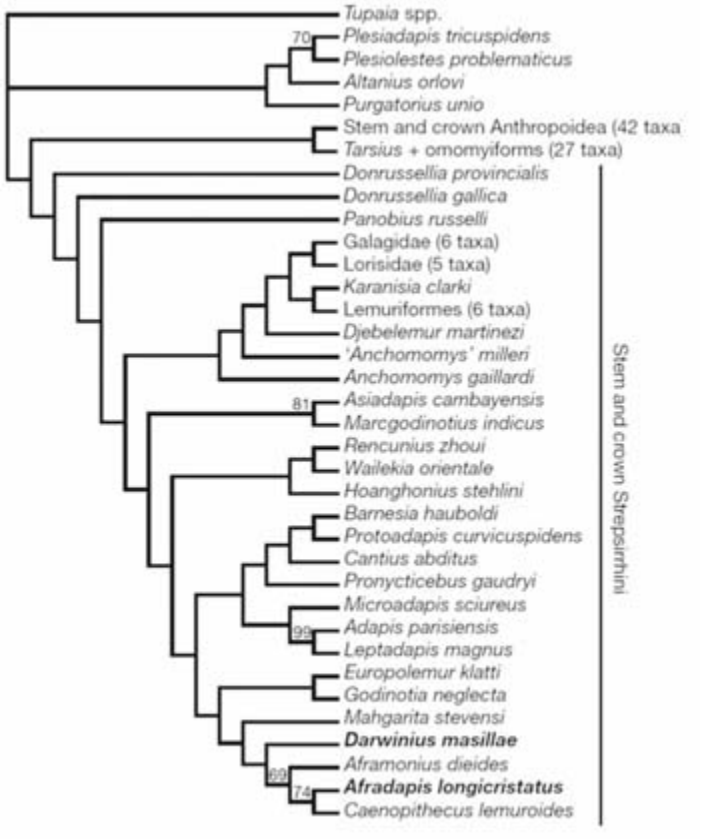

FIGURE 3 – A family tree of primates as produced by the cladistic analysis run by Seiffert and colleagues. Not only does *Darwinius* fall near *Afradapis*, but both are confirmed as extinct relatives of lemurs far removed from anthropoid primates.

Her backers were not pleased. Distancing himself from the headline-making claims of a few months before, Hurum stated that *Darwinius* could still belong to a "stem group" from which early anthropoids evolved. After all, the

skeleton of *Darwinius* was much more complete, and according to Hurum it contained some anthropoid characteristics that could not be seen in the incomplete remains of *Afradapis*. Gingerich was similarly unimpressed. He asserted that the anthropoid traits seen in *Darwinius* were not convergences at all; Ida had monkey-like traits because she was closely related to monkeys. Though the *Afradapis* paper presented a much better supported hypothesis for what the primate family tree looks like, it was hardly the last word on the matter, either. Hurum promised that an independent cladistic analysis of *Darwinius* was already being planned.

I watched this back-and-forth from the periphery. As a writer there was not much I could directly contribute to the scientific discourse, but I was hooked by the drama surrounding Ida.[4] I couldn't help but wonder why this petrified primate had caused such a fuss. If Ida had been presented in her proper evolutionary position, as a unique relative of living lemurs, this whole media kerfuffle probably would not have happened. Therein was my answer.

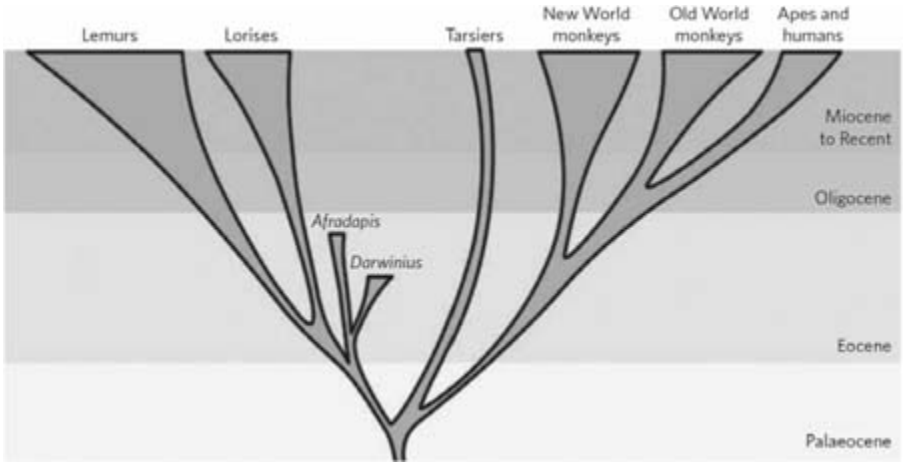

FIGURE 4 – A simplified version of the evolutionary tree produced by Seiffert and colleagues. It shows a deep split among early primates, with *Darwinius* and *Afradapis* being on the side that gave rise to lemurs and lorises, not anthropoids.

No matter how much we learn about nature there are some questions our species continually grapples with. Why are we here? How did we get to be this way? Where are we going? Maybe these questions sound a bit trite, but if that is so it is only because they are timeless queries that have been difficult to answer. We desperately want to know where we came from, where we are headed, and, as phrased by novelist Douglas Adams, the "Ultimate Answer to Life, the Universe and Everything."[5]

The answers to these questions have traditionally been supplied by religion. We have been created and sustained thanks to God's will, so the story goes, making us the most privileged thing in all Creation. Even if we feel lost and isolated we can still believe that there is an inherent purpose and direction to life, a beginning and an ending.

But during the past 150 years these existential questions have taken on new inflections. There might not be a universal answer to "Why are we here?" that provides us with a driving sense of purpose, but an understanding of the quirks and contingencies of evolution allows us to meaningfully understand how we came to be as we are. This was made possible by the work of Charles Darwin in the middle of the nineteenth century. He was not the first person to consider evolution, nor was he the only Victorian naturalist to provide evidence for it, but through his 1859 masterwork *On the Origin of Species* Darwin popularized a new view of life in which a past far beyond the oldest remnants of human history could help us understand our place in nature. We are inextricably tied to what has come before.

Our preoccupation with origins made the search for fossil ancestors among the most pressing preoccupations of naturalists. If life had truly been transforming over an incalculable amount of time, then the bones of our distant ancestors, as well as forerunners of every other living species, should speak to us from the earth. This hypothesis

was a bit of a gamble for Darwin. Geology and paleontology had been essential to the formation of his evolutionary theory, yet the records of deep time had, prior to 1859, failed to provide the continuous, graded chains of fossils linking the present to the past. While Darwin was correct that the fossil record was an archive “imperfectly kept,” full of gaps and discontinuities, ultimately it would have to provide the solid proofs of the theory he had based on observations of living animals.

The rarity of these fossil proofs of evolution vexed naturalists. In an 1868 address on the evolution of birds from reptiles Darwin’s ally Thomas Henry Huxley likened the state of affairs to a landowner who, despite his claims, could not produce hard evidence that he really owned the property at all:

> If a landed proprietor is asked to produce the title-deeds of his estate, and is obliged to reply that some of them were destroyed in a fire a century ago, that some were carried off by a dishonest attorney, and that the rest are in a safe somewhere, but that he really cannot lay his hands upon them; he cannot, I think, feel pleasantly secure, though all his allegations may be correct and his ownership indisputable. But a doctrine is a scientific estate, and the holder must always be able to produce his title-deeds, in a way of direct evidence, or take the penalty of that peculiar discomfort to which I have referred.

Naturalists would have to supply these “title deeds” if the fact of evolution was to be established. The theoretical question of whether evolution was driven by natural selection or some other force would be debated for decades, but the fossil record held the most immediate potential of supplying solid evidence that evolution was real.

This want of ancestors is what allowed the *Darwinius*-for-ancestor lobby to enthrall the public. The fossil record does not contain a complete roll of every living thing that ever lived. It is rare that a living thing dies in circumstances amenable to fossilization, and even among this fossil pool the remains of many organisms are destroyed by geological processes. Of this fraction of a fraction only a very few specimens exist in rocks accessible to scientists, and of that tiny slice fewer still are collected and studied. The discovery of any fossil with transitional features that helps us understand the transformation of one form into another is cause for celebration, and most celebrated of all are those that connect familiar animals to their extinct forerunners.

The fossil forms which bridge the gap between one group of organisms and another have popularly been called "missing links" (and this is especially true of the search for our own ancestors). This is an unfortunate misnomer that reveals the ancient origin of the phrase as well as the biases that run though it. Indeed, the idea of missing links originally did not contain any evolutionary significance at all. During the Middle Ages Christian scholars thought that life was organized according to a hierarchical scale of natural productions ranked from "lower" to "higher." This was the Great Chain of Being, and it was a static arrangement that reflected the virtues of Creation: plentitude, continuity, and gradation.

Since God was benevolent and omnipotent He had created everything that was possible.[6] Ours was the best of all possible worlds, one of magnificent plenitude, but there was an order to the diversity of nature. In the continuous, unbroken hierarchy anything in nature could be linked to another by recognizing their shared characteristics. A rock had existence, while a plant had both existence and life, and the ability of animals to move around on their own placed them above plants. And so the rankings went, all the

way from pebbles up to the Almighty, with humans representing the highest point of the “animal Creation.” Our kind was a step above other animals but one below angels, beings possessed of a heavenly infused soul but still subject to animal urges.

Despite the certainty that God had ordered creation according to these laws, however, there were breaks in the chain. Among the most troublesome was the one between humans and the vulgar monkeys (which, for many medieval Christians, represented what a life of sin could lead to). Monkeys were clearly similar to humans but far too low to be on the rung right below us. Between us and them there should have been a humanlike being that lacked a soul, but for centuries this missing link remained elusive.

This view of nature was later co-opted into ideas about evolution. By the beginning of the nineteenth century the Great Chain of Being ceased to be a useful concept to organize nature, but vestiges of it still remained. The vertical dimension of the hierarchy, rather than representing only the rank of living organisms, was impressed onto the geological timeline. Fish appeared before amphibians, which preceded reptiles, which in turn gave way to an Age of Mammals capped by the appearance of our own species. The story of evolution still presented a chain of beings connected through a series of intermediate links, and it was among fossil vertebrates that the first of these intermediate forms were found. In his 1870 address as president of London’s Geological Society, Huxley stated that “when we turn to the higher *Vertebrata*, the results of recent investigations, however we may sift and criticize them, seem to me to leave a clear balance in favour of the doctrine of the evolution of living forms one from another.” Fossil vertebrates provided some of the most compelling evidence for evolutionary change, and it was not surprising that some scientists interpreted the succession of these forms to represent life’s progress.

This underlying thread has given rise to some of our most iconic evolutionary images. The March of Progress from early primate to human is one, but the same imagery has been employed for the evolution of horses, elephants, the earliest terrestrial vertebrates, early mammals, birds, and whales. As transitional forms have been found they have been strung up in temporal sequences to show the progressive transformation of the archaic into the modern. This interpretation might not be explicit, and perhaps it is even outright denied by the presenters of these diagrams, but such illustrations leave little doubt that the biases inherent in the Great Chain of Being remain with us even today.

And this drive toward progress implies the question of what might come next, particularly for our own species. What might our descendants be like a thousand, a million, or ten million years from now? If the past presents us with a tale of progress from “primitive” to “advanced,” then what might the future hold for us? What is the next evolutionary step? There is no way to tell. It is impossible to predict how our species might be adapted, but the annals of science fiction reveal our expectations. It is no coincidence that in popular culture, from Hollywood films to discussion boards run by UFO conspiracy nuts, technologically superior aliens are envisaged as having large heads stuffed with enormous brains and frail humanoid bodies.[7] They are species that have advanced to the point where body is sublimated to mind, and they act as proxies for what many expect our species to become given enough time. As hypothetical creatures that live more in the mental realm than the physical, they occupy the place once inhabited by angels, above humans but below God, on the Great Chain of Being.

The irony of this view is that Darwin envisioned evolution as producing a wildly branching tree of life with no predetermined path or endpoint. It is significant that the

only illustration in *On the Origin of Species* is not a revised version of the Great Chain of Being, but a series of branches embedded within greater branches, all connected by common ancestry. With a sufficiently complete fossil record it is possible to trace the evolution of particular forms according to direct lines of descent, but doing so requires that neighboring branches containing close relatives be lopped off. And the further back in time we go, the more relatives we have to ignore.

Any paleontologist worth their salt knows this well. Yes, it is possible to line up a series of forms representing what our direct ancestors looked like at different points over the last six million years or so, but to do so would require that we ignore other types of early humans that lived alongside our ancestors such as the heavy-jawed robust australopithecines and our sister species, the Neanderthals. Even before that, our anthropoid ancestors were just one twig of a more diverse evolutionary bush that coexisted with other kinds of primates such as *Afradapis* and tarsiers. To focus solely upon our ancestors is to blind ourselves to our own evolutionary context.

But why consider fossils at all? In the introductory chapters of his 2004 tome *The Ancestor's Tale* Richard Dawkins stressed that "dead men tell no tales." We might be just as well off in our understanding of evolution if not a single fossil even existed:

> In spite of the fascination of fossils, it is surprising how much we would still know about our evolutionary past without them. If every fossil were magicked away, the comparative study of modern organisms, of how their patterns of resemblances, especially of their genetic sequences, are distributed among species, and of how species are distributed among continents and islands, would still demonstrate, beyond all sane doubt, that our history is

evolutionary. Fossils are a bonus. A welcome bonus, to be sure, but not an essential one.

But this dim view of paleontology is not accurate.[8] During the past thirty years scientists have seen the emergence of a new, synthetic paleontology that is giving us an unprecedented look at the machinations of evolution.

Scientists such as Stephen Jay Gould, Niles Eldredge, Steven Stanley, Elisabeth Vrba, David Raup, and Jack Sepkoski led the charge. Starting in the 1970s these paleontologists questioned the popular interpretation of evolution as a slow and steady process in which species were constantly evolving by tiny steps. Their research was not in conflict with evolution by means of natural selection, but the patterns of the fossil record were far more haphazard than had been expected on the basis of genetics. This precipitated a 1980 conference in Chicago where some of these ideas could be hashed out with biologists, such as John Maynard Smith, who favored a smoother evolutionary pattern. The tension was felt by all. After a presentation by embryologist George Oster about how developmental quirks constrain the forms organisms can take, Maynard Smith responded that scientists like himself had already considered the idea and dispensed with it as being of little importance. The paleontologists and other biologists who were questioning what was commonly accepted were only reinventing the wheel. To this Oster retorted, “You may have had the wheel, John, but you didn’t ride away on it.”

Paleontologists were ready to hop on and see where they could go, and while relations between paleontologists and neontologists (biologists who work with living organisms) were tense to start with, the debates between them started to feed cross-disciplinary collaborations. Slowly, paleontologists began to incorporate discoveries from molecular biology, genetics, and embryology into their

work. This allowed paleontologists not only identify to patterns of change, but to begin to understand how such changes in form might have been caused. The discovery of preserved soft tissues from prehistoric creatures from Neanderthals to mammoths to *Tyrannosaurus* have even opened a new field of study centered on the recovery and study of ancient molecular materials. Comparative anatomy and geology still form the core of paleontology, but the science has embraced information and techniques from a variety of disciplines, thus allowing scientists to test their ideas about life's history through the combination of multiple lines of evidence.

The coalescence of this new paleobiological synthesis coincided with the discovery of many new transitional fossils and the reappraisal of many old ones. Fossils that scientists knew had to exist but had been missing, such as land-dwelling whale ancestors and feathered dinosaurs, were found, while well-known lineages, such as horses and elephants, were revealed to show a wildly branching pattern of diversity rather than a straight line of progress. Even among our own ancestors, what had once been supposed to be a single chain of ancient humans was suddenly split and split again by new discoveries, so much so that at the turn of the twenty-first century no less than three fossils were in competition for the designation "earliest human." With the development of the new paleobiology and more complete collections of transitional fossils, paleontologists began to piece together a better understanding for how life changed through time. Paleontology is not just a bonus; it is among the most essential of evolutionary disciplines.

Fossils do not speak for themselves, however, and the history of science fleshes out the context in which new discoveries have been made and interpreted. The standard story that Charles Darwin's theory of evolution by means of natural selection was so brilliant that everyone but

religious zealots agreed with him is only a caricature of the truth. Darwin's 1859 book proposed more questions than it provided answers, and the scientific endeavor to answer some of those questions has been affected just as much by contingency and chance as the history of life. The places paleontologists looked for fossils and how those fossils have been interpreted have been influenced by politics and culture, reminding us that while there is a reality that science allows us to approach the process of science is a human endeavor.

The following pages tie together the complementary narratives of life's history and our changing understanding of that history. Walking whales, amphibious elephants, feathered dinosaurs, land-dwelling fish, mammals that listened with their jaws, multi-toed horses, and upright apes will be presented through the eyes of the scientists who puzzled over their origins, culminating in what we now understand about the evolution of such creatures. The perspective these stories provide has changed how we interpret the past, and leads us to question some of our most cherished beliefs about our place in the universe.