╝

**Darwin's Doubt**

**The Explosive Origin of Animal Life**

**and the Case for Intelligent Design**

**By: Stephen C. Meyer**

****

**نبذة مُختصرة عن الكتاب:**

جاهدت نفسي حتى أكتب هذه النبذة المُختصرة، وقد كنت عازماً على تركها لأنَّها لن تعجب الكثيرين!

كتاب «**شكّ داروين**»، لفيلسوف العلوم المشهور جداً «**ستيفن ماير**»، صاحب الكتاب المشهور «**بصمة في الخلية**». الكتاب يتحدَّث في الأساس عن الانفجار الكامبري، وهو الظُّهُور المُفاجئ لأنواع كثيرة مُختلفة من الحياة الحيوانية، ممَّا يُعدّ من أشهر الإشكاليات التي تُواجه نظرية داروين، والتي اعترف بإشكاليتها «**داروين**» نفسه!

الكتاب مُنقسم إلى ثلاثة أقسام، القسم الأول أغلبه هو الأكثر إثارة ومُتعة في الكتاب بالكامل، والقسم الثاني أشبه بتجميعة من الرُّدُود والاعتراضات، وهو قسم علمي ثقيل جداً ومُملّ، وأكثر الملل جاء من النَّقل المُستمر من مؤلَّفات لأعضاء آخرين من مؤسَّسة «**ديسكفري**»، مثل «**جوناثان ويلز**»، و «**مايكل بيهي**»، و «**ويليام ديمبسكي**»، و «**بول نيلسون**»، ولعلّ سبب رئيسي من شعوري بالملل هو أنَّني قرأت من قبل أغلب ما نقله المؤلِّف من زملائه، فشعرتُ أنَّه لم يُقدِّم شيئاً جديداً، والقسم الثالث يتحدَّث عن ما بعد نظرية داروين، وقد كان في بدايته مُشوِّقاً، إلَّا أنَّه بعد فترة قصيرة جداً صار مُملًّا وثقيلاً.

لا أريد أن أطيل كثيراً، إلَّا أنَّني أحبّ أن أؤكِّد على أنَّ الكتاب مُتخصِّص جداً، وكبير، ويحتوي على مناقشات مُستفيضة للمواضيع المطروحة، ولا ينبغي أن يكون أول ما تقرأ في مجال نقد نظرية التَّطوُّر، وإذا عزمت على قراءته، فتحلَّى بالصَّبر، وجاهد نفسك على إكماله، وإن أخذ منك وقتاً طويلاً، وأُذكِّر على أنَّ القضية ليست مُجرَّد إتمام القراءة، وإنَّما مُحاولة الاستفادة من الطَّرح الموجود في الكتاب قدر المُستطاع، وإلَّا فمُجرَّد القراءة لا شيء فيها!

في النِّهاية، ورغم أنَّ هُناك أجزاء لا بأس بها من الكتاب لم أفهم منها شيئا، وذلك لعمقها في النقد، وتخصُّصها الشَّديد، إلَّا أنَّ أغلب الكتاب مفهوم، بنسبة تصل إلى 70 % أو أكثر، وأظنّ أنَّ الكتاب يستحق تقديراً، بين جيِّد، وجيِّد جدًّا، وأنصح «**ماير**» - وكأن نصيحتي ستصله! – بأن يكُفّ عن الثَّرثرة الكثيرة، والحكايات العجيبة التي يُحبّ أن يحكيها في كُلّ كتبه، وأن يُحاول تبسيط المعلومات المُتخصِّصة بشكل أكبر!

وشكراً!

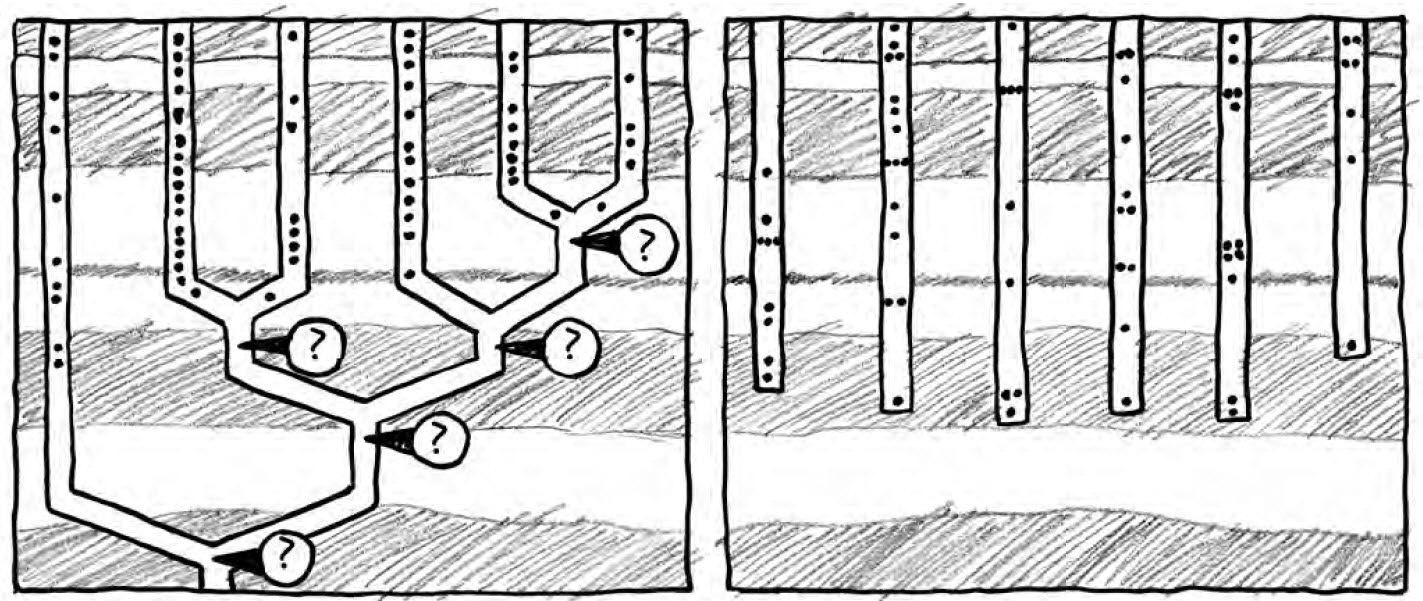
**Prologue**

* As information theorist Henry Quastler observed, “The creation of information is habitually associated with conscious activity.”1 [Quastler, The Emergence of Biological Organization, 16.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 61-63). HarperCollins. Kindle Edition.]
* Since 1980, when Harvard paleontologist Stephen Jay Gould declared that neo-Darwinism “is effectively dead, despite its persistence as textbook orthodoxy,”7 the weight of critical opinion in biology has grown steadily with each passing  year. [Gould, “Is a New and General Theory of Evolution Emerging?” 120.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 115-117). HarperCollins. Kindle Edition.]
* Douglas Futuyma has done, that “just because we don’t know how evolution occurred, does not justify doubt about whether it occurred.”9 [Futuyma asserts, “There is absolutely no disagreement among professional biologists on the fact that evolution has occurred. . . . But the theory of how evolution occurs is quite another matter, and is the subject of intense dispute” (“Evolution as Fact and Theory,” 8). Of course, to admit that natural selection cannot explain the appearance of design is in effect to admit that it has failed to perform the role that is claimed for it as a “designer substitute.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 120-121). HarperCollins. Kindle Edition.]
* The fundamental problem confronting neo-Darwinism, as with chemical evolutionary theory, is the problem of the origin of new biological information. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 124-125). HarperCollins. Kindle Edition.]
* That term has many meanings, and few biology textbooks distinguish between them. “Evolution” can refer to anything from trivial cyclical change within the limits of a preexisting gene pool to the creation of entirely novel genetic information and structure as the result of natural selection acting on random mutations. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 134-136). HarperCollins. Kindle Edition.]
* As a host of distinguished biologists have explained in recent technical papers, small-scale, or “microevolutionary,” change cannot be extrapolated to explain large-scale, or “macroevolutionary,” innovation.11 [See, e.g., Kauffman, 361; Raff, The Shape of Life; Miklos, “Emergence of Organizational Complexities During Metazoan Evolution.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 136-138). HarperCollins. Kindle Edition.]
* For the most part, microevolutionary changes (such as variation in color or shape) merely utilize or express existing genetic information, while the macroevolutionary change necessary to assemble new organs or whole body plans requires the creation of entirely new information. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 138-140). HarperCollins. Kindle Edition.]
* As an increasing number of evolutionary biologists have noted, natural selection explains “only the survival of the fittest, not the arrival of the fittest.”12 The technical literature in biology is now replete with world-class biologists13 routinely expressing doubts about various aspects of neo-Darwinian theory, and especially about its central tenet, namely, the alleged creative power of the natural selection and mutation mechanism. [12. Gilbert et al., “Resynthesizing Evolutionary and Developmental Biology.” 13. Webster, How the Leopard Changed Its Spots, 33; Webster and Goodwin, Form and Transformation, x; Gunter Theissen, “The Proper Place of Hopeful Monsters in Evolutionary Biology,” 351; Marc Kirschner and John Gerhart, The Plausibility of Life, 13; Schwartz, Sudden Origins, 3, 299–300; Erwin, “Macroevolution Is More Than Repeated Rounds of Microevolution”; Davidson, “Evolutionary Bioscience as Regulatory Systems Biology,” 35; Koonin, “The Origin at 150,” 473–75; Conway Morris, “Walcott, the Burgess Shale, and Rumours of a Post-Darwinian World,” R928-R930; Carroll, “Towards a New Evolutionary Synthesis,” 27; Wagner, “What Is the Promise of Developmental Evolution?”; Wagner and Stadler, “Quasi-independence, Homology and the Unity of Type”; Becker and Lönnig, “Transposons: Eukaryotic,” 529–39; Lönnig and Saedler, “Chromosomal Rearrangements and Transposable Elements,” 402; Muller and Newman, “Origination of Organismal Form,” 7; Kauffman, At Home in the Universe, 8; Valentine and Erwin, “Interpreting Great Developmental Experiments,” 96; Sermonti, Why Is a Fly Not a Horse?; Lynch, The Origins of Genome Architecture, 369; Shapiro, Evolution, 89, 128. David J. Depew and Bruce H. Weber, writing in the journal Biological Theory, are even more frank, “Darwinism in its current scientific incarnation has pretty much reached the end of its rope” (89–102).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 140-145). HarperCollins. Kindle Edition.]
* Today modern neo-Darwinism seems to enjoy almost universal acclaim among science journalists and bloggers, biology textbook writers, and other popular spokespersons for science as the great unifying theory of all biology. High-school and college textbooks present its tenets without qualification and do not acknowledge the existence of any significant scientific criticism of it. At the same time, official scientific organizations—such as the National Academy of Sciences (NAS), the American Association for the Advancement of Sciences (AAAS), and the National Association of Biology Teachers (NABT)—routinely assure the public that the contemporary version of Darwinian theory enjoys unequivocal support among qualified scientists and that the evidence of biology overwhelmingly supports the theory. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 147-153). HarperCollins. Kindle Edition.]
* For example, in 2006 the AAAS declared, “There is no significant controversy within the scientific community about the validity of the theory of evolution.”14 The media dutifully echo these pronouncements. As New York Times science writer Cornelia Dean asserted in 2007, “There is no credible scientific challenge to the theory of evolution as an explanation for the complexity and diversity of life on earth.”15 [14. “Statement on Teaching Evolution by the Board of Directors of the American Association for the Advancement of Science,” St. Louis, Missouri, February 16, 2006; www.aaas.org/news/releases/2006/pdf/0219boardstatement.pdf (accessed October 26, 2012). 15. Dean, “Scientists Feel Miscast in Film on Life’s Origin.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 153-157). HarperCollins. Kindle Edition.]
* They attacked the provision by insisting that there was no need to consider weaknesses in modern evolutionary theory because, as Eugenie Scott, spokeswoman for the National Center for Science Education, insisted in The Dallas Morning News, “There are no weaknesses in the theory of evolution.”16 [Eugenie Scott, quoted in Stutz, “State Board of Education Debates Evolution Curriculum”; also requoted in Stoddard, “Evolution Gets Added Boost in Texas Schools.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 163-166). HarperCollins. Kindle Edition.]
* In On the Origin of Species, Darwin openly acknowledged important weaknesses in his theory and professed his own doubts about key aspects of it. Yet today’s public defenders of a Darwin-only science curriculum apparently do not want these, or any other scientific doubts about contemporary Darwinian theory, reported to students. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 170-172). HarperCollins. Kindle Edition.]
* This book addresses Darwin’s most significant doubt and what has become of it. It examines an event during a remote period of geological history in which numerous animal forms appear to have arisen suddenly and without evolutionary precursors in the fossil record, a mysterious event commonly referred to as the “Cambrian explosion.” As he acknowledged in the Origin, Darwin viewed this event as a troubling anomaly—one that he hoped future fossil discoveries would eventually eliminate. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 172-176). HarperCollins. Kindle Edition.]

**Part One: The Mystery of the Missing Fossils**

**1 Darwin’s Nemesis**

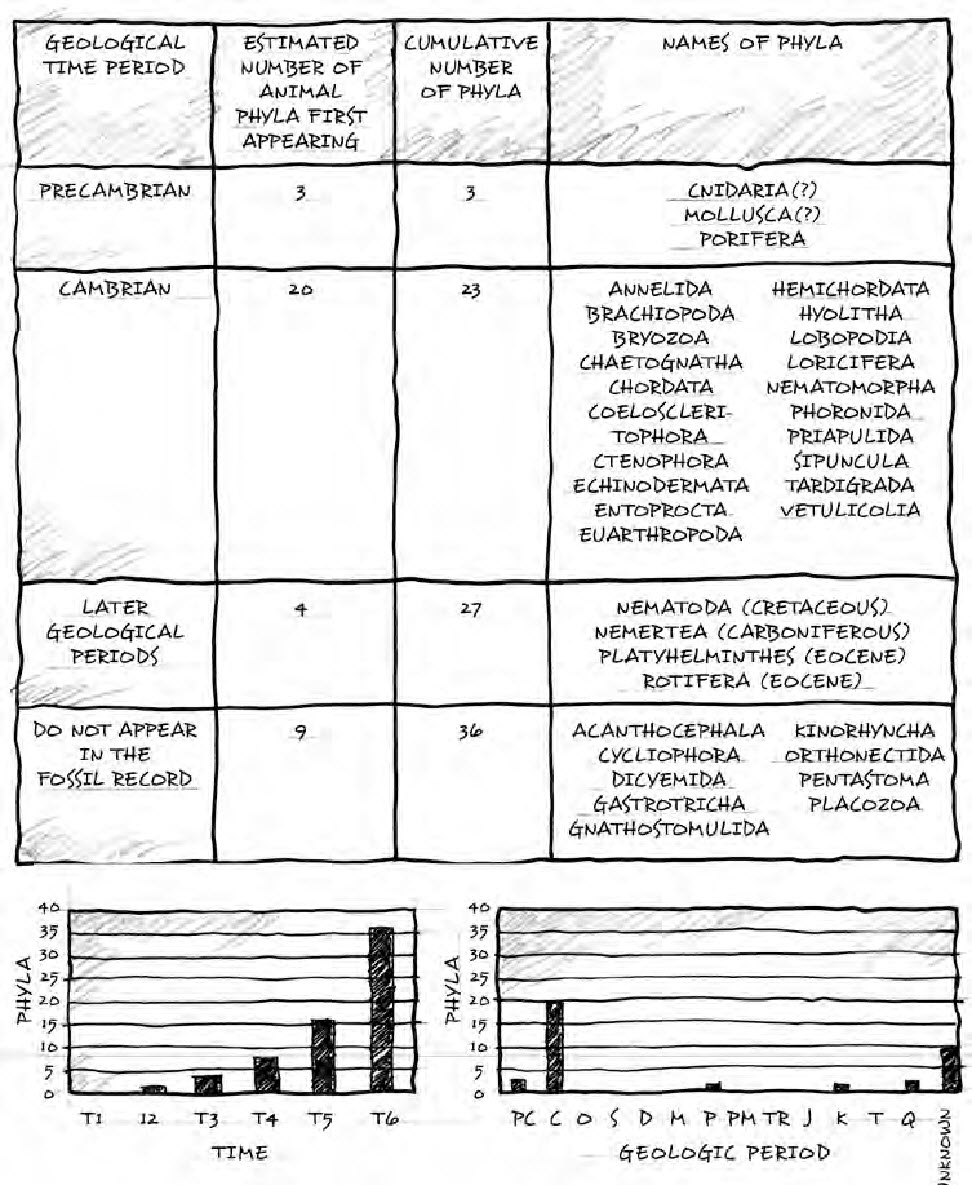
* Darwin’s Origin explained many classes of biological evidence with just two central organizing ideas. The twin pillars of his theory were the ideas of universal common ancestry and natural selection. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 201-203). HarperCollins. Kindle Edition.]
* The first of these pillars, universal common ancestry, represented Darwin’s theory of the history of life. It asserted that all forms of life have ultimately descended from a single common ancestor somewhere in the distant past. In a famous passage at the end of the Origin, Darwin argued that “all the organic beings which have ever lived on this earth have descended from some one primordial form.”1 [Darwin, On the Origin of Species, 484. In other places in The Origin, Darwin hedged his bets, referring to life “having been originally breathed into a few forms or into one.” Darwin, The Origin of Species, 490.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 203-206). HarperCollins. Kindle Edition.]
* Biologists often call Darwin’s theory of the history of life “universal common descent” to indicate that every organism on earth arose from a single common ancestor by a process of “descent with modification.” [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 214-216). HarperCollins. Kindle Edition.]
* The second pillar of Darwin’s theory affirmed the creative power of a process he called natural selection, a process that acted on random variations in the traits or features of organisms and their offspring.2 [Though Darwin emphasized natural selection as the “chief agent of change,” he also emphasized “sexual selection”—the preference that sexually reproducing animals have for some traits over others in prospective mates—as a mechanism responsible for some changes in evolving populations.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 218-220). HarperCollins. Kindle Edition.]
* Despite the scope of his synthesis, there was one set of facts that troubled Darwin—something he conceded his theory couldn’t adequately explain, at least at present. Darwin was puzzled by a pattern in the fossil record that seemed to document the geologically sudden appearance of animal life in a remote period of geologic history, a period that at first was commonly called the Silurian, but later came to be known as the Cambrian. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 253-256). HarperCollins. Kindle Edition.]
* During this geological period, many new and anatomically sophisticated creatures appeared suddenly in the sedimentary layers of the geologic column without any evidence of simpler ancestral forms in the earlier layers below, in an event that paleontologists today call the Cambrian explosion. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 256-258). HarperCollins. Kindle Edition.]
* Darwin frankly described his concerns about this conundrum in the Origin: “The difficulty of understanding the absence of vast piles of fossiliferous strata, which on my theory were no doubt somewhere accumulated before the Silurian [i.e., Cambrian] epoch, is very great,” he wrote. “I allude to the manner in which numbers of species of the same group suddenly appear in the lowest known fossiliferous rocks.”5 [Darwin, On the Origin of Species, 306–7.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 258-261). HarperCollins. Kindle Edition.]
* Agassiz concluded that the fossil record, particularly the record of the explosion of Cambrian animal life, posed an insuperable difficulty for Darwin’s theory. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 269-270). HarperCollins. Kindle Edition.]
* Most dramatic of all were the compound eyes found on even some of the very early trilobites—eyes that afforded these not so primitive animals a 360-degree field of vision.7 The abrupt appearance of such complex anatomical designs presented a challenge to each of the two main parts of Darwin’s theory of evolution. [See www.geo.ucalgary.ca/~macrae/trilobite/siluria.html (accessed October 23, 2012), where Roderick Murchison’s skillful trilobite drawings are reproduced.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 288-292). HarperCollins. Kindle Edition.]
* In an 1874 Atlantic Monthly essay titled “Evolution and the Permanence of Type,” Agassiz explained his reasons for doubting the creative power of natural selection. Small-scale variations, he argued, had never produced a “specific difference” (i.e., a difference in species). Meanwhile, large-scale variations, whether achieved gradually or suddenly, inevitably resulted in sterility or death. As he put it, “It is a matter of fact that extreme variations finally degenerate or become sterile; like monstrosities they die out.”8 [Agassiz, “Evolution and the Permanence of Type,” 99.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 309-313). HarperCollins. Kindle Edition.]
* As University of Washington paleontologist Peter Ward would later explain, Darwin had very specific expectations for what paleontologists would find below the lowest known strata of animal fossils—in particular, “intervening strata showing fossils of increasing complexity until finally trilobites appeared.”9 As Darwin noted, “If my theory be true, it is indisputable that before the lowest Silurian [Cambrian] stratum was deposited, long periods elapsed, as long as, or probably far longer than, the whole interval from the Silurian age to the present day; and that during these vast, yet quite unknown, periods of time, the world swarmed with living creatures.”10 [9. Ward, On Methuselah’s Trail, 29. 10. Darwin, On the Origin of Species, 307. Darwin’s original quotation used the “Silurian” rather than the “Cambrian,” because in Darwin’s time what we now label as the Cambrian period was subsumed within the concept of the lower Silurian. In a later sixth edition of the Origin, Darwin adopted the term “Cambrian” in place of “Silurian.” See Darwin, On the Origin of Species; sixth edition, 286.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 317-322). HarperCollins. Kindle Edition.]
* If Darwin is right, Agassiz argued, then we should find not just one or a few missing links, but innumerable links shading almost imperceptibly from alleged ancestors to presumed descendants. Geologists, however, had found no such myriad of transitional forms leading to the Cambrian fauna. Instead, the stratigraphic column seemed to document the abrupt appearance of the earliest animals. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 334-337). HarperCollins. Kindle Edition.]
* Agassiz thought the evidence of abrupt appearance, and the absence of ancestral forms in the Precambrian, refuted Darwin’s theory.11 Of these earlier forms, Agassiz asked, “Where are their fossilized remains?” He insisted that Darwin’s picture of the history of life “contradict[ed] what the animal forms buried in the rocky strata of our earth tell us of their own introduction and succession upon the surface of the globe. Let us therefore hear them;—for, after all, their testimony is that of the eye-witness and the actor in the scene.”12 [11. Agassiz, Essay on Classification, 102. 12. Agassiz, “Evolution and the Permanence of Type,” 10.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 337-342). HarperCollins. Kindle Edition.]
* At the time, perhaps the best place to investigate the lowest known strata of fossils was Wales, and one of its leading experts was Roderick Impey Murchison, who named the earliest geologic period the Silurian after an ancient Welsh tribe. Five years before On the Origin of Species, he called attention to the sudden appearance of complex designs like the compound eyes of the first trilobites, creatures already thriving at the apparent dawn of animal life. For him, this discovery ruled out the idea that these creatures had evolved gradually from some primitive and relatively simple form: “The earliest signs of living things, announcing as they do a high complexity of organization, entirely exclude the hypothesis of a transmutation from lower to higher grades of being.”13 [Murchison, Siluria, 469.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 345-351). HarperCollins. Kindle Edition.]
* The other pioneering explorer of Wales’s rich fossil record, Adam Sedgwick, also thought that Darwin had leaped beyond the evidence, as he told him in a letter in the fall of 1859: “You have deserted—after a start in that tram-road of all solid physical truth—the true method of induction.”14 [Letter from Adam Sedgwick to Charles Darwin, November 24, 1859.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 351-354). HarperCollins. Kindle Edition.]
* It was these strata that Sedgwick named after a Latinized English term for the country of Wales—“Cambria,” a designation that eventually replaced “Silurian” as the name for the earliest strata of animal fossils. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 356-358). HarperCollins. Kindle Edition.]
* Where in the Ordovician strata, for instance, are many of the families of the trilobites and brachiopods present in the Cambrian just below it?15 These creatures along with numerous other types suddenly disappear. But just as suddenly one finds newcomers in the Ordovician strata like the eurypterans (sea scorpions), starfish, and tetracorals (see Fig. 1.5).16 In a later Paleozoic period called the Devonian, the first amphibians (e.g., Ichthyostega) arise. Much later, many staples of the Paleozoic era (which encompasses the Cambrian, Ordovician, and four subsequent periods) suddenly go extinct in a period called the Permian.17 Then, in the Triassic period that follows, completely novel animals such as turtles and dinosaurs emerge.18 Such discontinuity, Sedgwick argued, is not the exception, but the rule. [15. Between approximately 450 and 440 million years ago, many animal species went extinct. Known as the Ordovician extinction, this event resulted in the disappearance of a huge number of marine invertebrates. This was the second biggest extinction in the history of life, being superseded only by the great Permian extinction (about 252 million years ago). Dott and Prothero, Evolution of the Earth, 259. 16. Mintz, Historical Geology, 146, 153–54, 124–27. 17. Prothero, Bringing Fossils to Life: An Introduction to Paleobiology, 84–85. Dott and Prothero, Evolution of the Earth, 376–79. 18. Dott and Prothero, Evolution of the Earth, 425–26; Li et al., “An Ancestral Turtle from the Late Triassic of Southwestern China”; Gaffney, “The Comparative Osteology of the Triassic Turtle Proganochelys.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 363-371). HarperCollins. Kindle Edition.]
* As Harvard paleontologist Stephen Jay Gould explains, it is the phenomenon of fossil succession that dictates the names of the major periods in the geological column (see Fig. 1.6). “We might take the history of modern multi-cellular life, about 600 million years, and divide this time into even and arbitrary units easily remembered as 1–12 or A-L, at 50 million years per unit,” Gould writes. “But the earth scorns our simplifications, and becomes much more interesting in its derision. The history of life is not a continuum of development, but a record punctuated by brief, sometimes geologically instantaneous, episodes of mass extinction and subsequent diversification.”21 The question that Darwin’s early critics posed was this: How could he reconcile his theory of gradual evolution with a fossil record so discontinuous that it had given rise to the names of the major distinct periods of geological time, particularly when the first animal forms seemed to spring into existence during the Cambrian as if from nowhere? [Gould, Wonderful Life, 54.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 388-395). HarperCollins. Kindle Edition.]
* Of course, Darwin was well aware of these problems. As he noted in the Origin, “The abrupt manner in which whole groups of species suddenly appear in certain formations has been urged by several paleontologists—for instance, by Agassiz, Pictet, and Sedgwick—as a fatal objection to the belief in the transmutation of species. If numerous species, belonging to the same genera or families, have really started into life all at once, the fact would be fatal to the theory of descent with slow modification through natural selection.”22 [Darwin, On the Origin of Species, 302.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 396-400). HarperCollins. Kindle Edition.]
* He suggested that the fossil record may be significantly incomplete: either the ancestral forms of the Cambrian animals were not fossilized or they hadn’t been found yet. “I look at the natural geological record, as a history of the world imperfectly kept, and written in a changing dialect,” Darwin wrote. “Of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page, only here and there a few lines. . . . On this view, the difficulties above discussed are greatly diminished, or even disappear.”23 [Darwin, On the Origin of Species, 311.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 401-405). HarperCollins. Kindle Edition.]
* Agassiz, for his part, would have none of it. “Both with Darwin and his followers, a great part of the argument is purely negative,” he wrote. They “thus throw off the responsibility of proof. . . . However broken the geological record may be, there is a complete sequence in many parts of it, from which the character of the succession may be ascertained.” On what basis did he make this claim? “Since the most exquisitely delicate structures, as well as embryonic phases of growth of the most perishable nature, have been preserved from very early deposits, we have no right to infer the disappearance of types because their absence disproves some favorite [i.e., Darwinian] theory.”25 [Agassiz, “Evolution and the Permanence of Type,” 97.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 407-412). HarperCollins. Kindle Edition.]
* Biographer Edward Lurie describes the Harvard naturalist as a “giant of the nineteenth century . . . a person deeply involved in his surroundings, a man who understood the possibilities of life with an uncommon awareness.”27 Similarly, historian Mabel Robinson says that she long awaited a biography of Agassiz that “would re-create this man of genius and his headlong splendid race through life.” He was, she said, “a man to remember because genius is rare,” “an immortal Pied Piper.”28 [27. Lurie, Louis Agassiz, vii. 28. Robinson, Runner on the Mountain Tops, foreword.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 425-429). HarperCollins. Kindle Edition.]
* So passionate was Agassiz for the particulars of the natural world that he began organizing a system of information-sharing among naturalists, sailors, and missionaries around the world. He collected more than 435 barrels of specimens, among them an extremely rare group of fossil plants.42 In a single year, Agassiz amassed more than 91,000 specimens and identified close to 11,000 new species,43 making Harvard’s natural history museum preeminent among such museums in the world. [42. Lurie, Louis Agassiz, 244. 43. Lurie, Louis Agassiz, 246.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 480-485). HarperCollins. Kindle Edition.]
* He also appears to have gone to great lengths, literally and figuratively, to assess On the Origin of Species empirically, going so far as to make a research voyage retracing Darwin’s trip to the Galápagos Islands. As he explained to German zoologist Carl Gegenbauer, he “wanted to study the Darwin theory free from all external influences and former prejudices.”44 [Quoted in Lurie, Louis Agassiz, 373.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 485-488). HarperCollins. Kindle Edition.]
* Moreover, Agassiz showed himself perfectly willing to accept natural mechanisms where before supernatural intervention had been the preferred explanation. Since he regarded material forces, and the laws of nature that described them, as the products of an underlying design plan, he saw any creative work they did as deriving ultimately from a creator. For instance, he assumed this was the case with the development of embryos: he attributed their natural evolution from zygote to adult as a natural phenomenon and considered this no threat to his belief in a creator.46 He also readily accepted the notion of a naturally evolving solar system.47 He thought a skillful cosmic architect could work through secondary natural causes every bit as effectively as through direct acts of agency. The marginalia in his copy of On the Origin of Species suggest that he had this same attitude concerning biological evolution. “What is the great difference,” he wrote, “between supposing that God makes variable species or that he makes laws by which species vary?” [46. Agassiz, “Evolution and the Permanence of Type,” 92–101. 47. Gray, Darwiniana, 127.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 491-499). HarperCollins. Kindle Edition.]
* Here a direct comparison between Darwin and Agassiz is possible. Each searched for an explanation of a curious geological phenomenon in the Scottish Highlands, the parallel roads of Glen Roy. Glen Roy is the valley of the River Roy and, although it’s a place of breathtaking beauty, what visitors found most intriguing about it over the years were its three parallel roads that wind along the canyon wall on either side of the river (see Fig. 1.7).48 Scottish legend held that they were hunting paths built for use by early Scottish kings or perhaps even for the mythical warrior Fingal. Scientists later argued that the roads were natural rather than artificial. Darwin and Agassiz were both convinced that natural processes were the cause, but they nevertheless arrived at different explanations. What was the end of the matter? In his autobiography, Darwin explained, “Having been deeply impressed with what I had seen of the elevation of the land in S. America, I attributed the parallel lines to the action of the sea; but I had to give up this view when Agassiz propounded his glacier-lake theory.”49 Subsequent investigations in the late nineteenth and early twentieth centuries confirmed that Agassiz’s interpretation was the correct one.50 [48. See the parallel lines on the sides of the hills on either side of the valley in this beautiful picture: www.swisseduc.ch/glaciers/earth\_icy\_planet/icons-15/16.jpg (last accessed Oct. 23rd, 2012). www.uh.edu/engines/epi857.htm (last accessed Oct. 23rd, 2012). See also Tyndall, “The Parallel Roads of Glen Roy.” 49. Darwin, Autobiography, 84. Also, Gertrude Himmelfarb notes that Darwin took more than twenty years to concede his mistake. In his autobiography, Darwin labeled it “one long gigantic blunder from beginning to end. . . . Because no other explanation was possible under our then state of knowledge, I argued in favour of sea-action; and my error has been a good lesson to me never to trust in science to the principle of exclusion.” See Himmelfarb’s discussion in Darwin and the Darwinian Revolution, 107. 50. See Oosthoek, “The Parallel Roads of Glen Roy and Forestry.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 503-513). HarperCollins. Kindle Edition.]
* First, as already noted, Darwin himself accepted the validity of Agassiz’s objection.51 As he acknowledged elsewhere in the Origin, “To the question why we do not find rich fossiliferous deposits belonging to these assumed earliest periods prior to the Cambrian system, I can give no satisfactory answer. . . . The case at present must remain inexplicable; and may be truly urged as a valid argument against the views here entertained.”52 [51. Darwin, On the Origin of Species, 307. 52. Darwin, On the Origin of Species, 308.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 522-526). HarperCollins. Kindle Edition.]



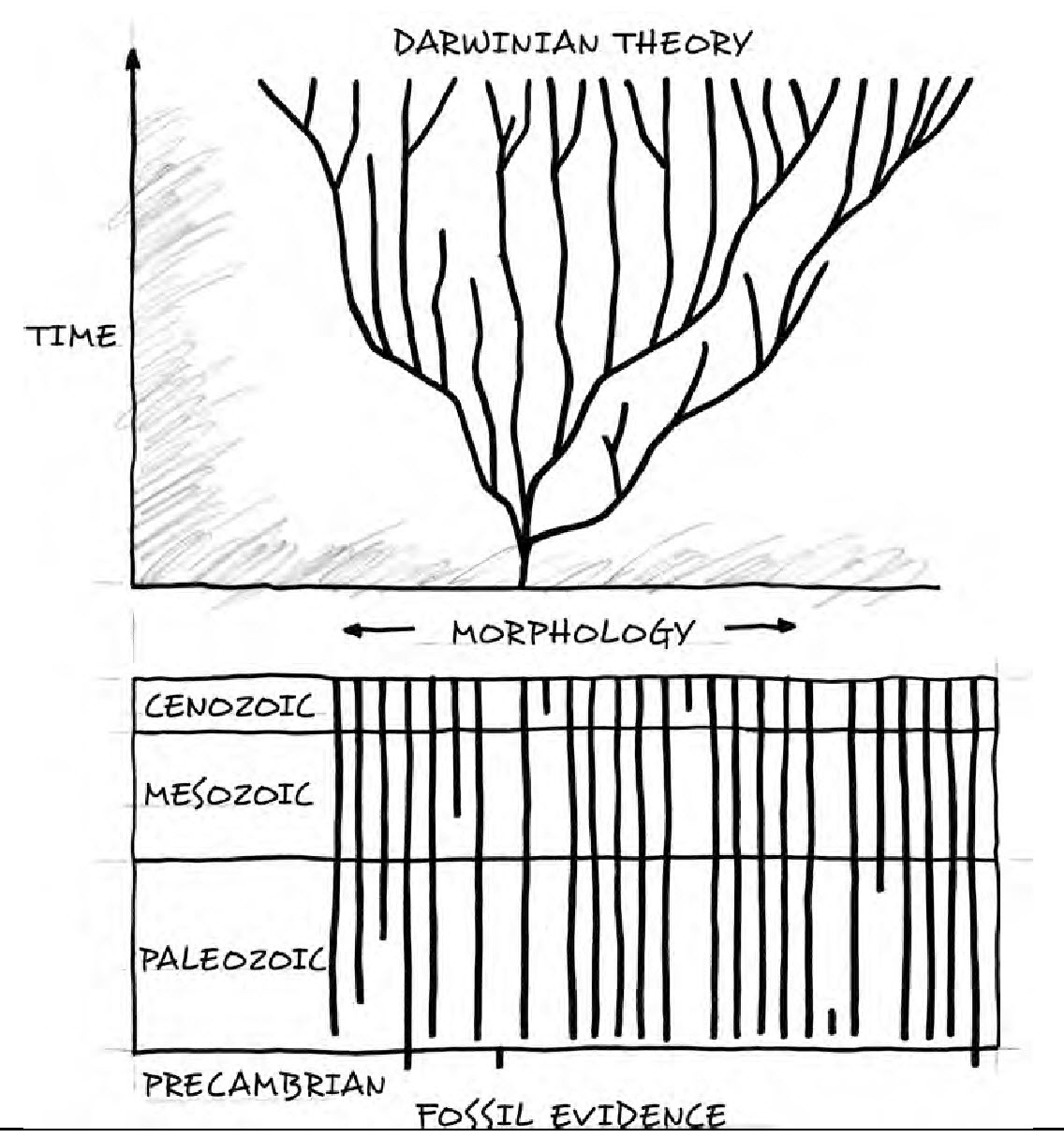
* The vertical lines in these diagrams represent known animal phyla. The dots within the vertical lines represent animals from those phyla that have been found fossilized in different strata. The diagram on the left shows the animal tree of life as expected based upon Darwinian theory. The diagram on the right shows a simplified representation of the actual pattern of the Precambrian–Cambrian fossil record. Notice that fossils representing the internal branches and nodes, but not the terminal branches, are missing. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 540-544). HarperCollins. Kindle Edition.]

**2 The Burgess Bestiary**

* Paleontologist Stephen Jay Gould considered it to have been rendered best in an obituary of Charles Walcott written by Walcott’s former research assistant, Charles Schuchert: One of the most striking of Walcott’s faunal discoveries came at the end of the field season of 1909, when Mrs. Walcott’s horse slid on going down the trail and turned up a slab that at once attracted her husband’s attention. Here was a great treasure—wholly strange Crustacea of Middle Cambrian time—but where in the mountain was the mother rock from which the slab had come? Snow was even then falling, and the solving of the riddle had to be left to another season, but next year the Walcotts were back again on Mount Wapta, and eventually the slab was traced to a layer of shale—later called the Burgess Shale—3000 feet above the town of Field.1 [Gould, Wonderful Life, 71. A slightly different version of this story is found in Charles Schuchert, “Charles Doolittle Walcott,” 124. See also Schuchert, “Charles Doolittle Walcott Paleontologist—1850–1927,” 455–58.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 577-584). HarperCollins. Kindle Edition.]
* Gould quotes the legend to celebrate its archetypal appeal even as he debunks it: “Consider the primal character of this tale—the lucky break provided by the slipping horse, . . . the greatest discovery at the very last minute of a field season (with falling snow and darkness heightening the drama of finality), the anxious wait through a winter of discontent, the triumphant return and careful, methodical tracing of errant block to mother lode.”2 [Gould, Wonderful Life, 71.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 584-588). HarperCollins. Kindle Edition.]
* The term “Cambrian explosion” was to become common coin, because Walcott’s site suggested the geologically abrupt appearance of a menagerie of animals as various as any found in the gaudiest science fiction. During this explosion of fauna, representatives of about twenty of the roughly twenty-six total phyla present in the known fossil record made their first appearance on earth. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 615-618). HarperCollins. Kindle Edition.]
* Other authorities, such as Douglas Erwin at the Smithsonian, arrive at a slightly higher total. By counting groups that some paleontologists count as subphyla or classes as phyla, Erwin argues that about twenty-five phyla first appear in the Cambrian out of about thirty-three total (by his way of counting) phyla known from the fossil record. [See Erwin et al., “The Cambrian Conundrum: Early Divergence and Later Ecological Success in the Early History of Animals,” 1091–97.] I’ve used a slightly more conservative method for estimating the total number of phyla that first appear in the Cambrian (see Fig. 2.5). I came to my count consulting the following sources: Phylum references listed in same order as they appear on the chart. Cnidaria: Chen et al., “Precambrian Animal Life: Probable Developmental and Adult Cnidarian Forms from Southwest China.” Mollusca: Fedonkin and Waggoner. “The Late Precambrian Fossil Kimberella Is a Mollusc-Like Bilaterian Organism.” Porifera: Love, G. D. “Fossil steroids record the appearance of Demospongiae during the Cryogenian period.” Annelida: Conway Morris and Peel, “The Earliest Annelids: Lower Cambrian Polychaetes from the Sirius Passet Lagerstätte, Peary Land, North Greenland.” Brachiopoda: Skovsted and Holmer, “Early Cambrian Brachiopods from North-East Greenland.” Bryozoa: Landing et al., “Cambrian Origin of All Skeletalized Metazoan Phyla—Discovery of Earth’s Oldest Bryozoans (Upper Cambrian, southern Mexico).” Chaetognatha: Szaniawski, H. “Cambrian Chaetognaths Recognized in Burgess Shale Fossils.” Chordata: Chen et al., “A Possible Early Cambrian Chordate”; Chen, “Early Crest Animals and the Insight They Provide into the Evolutionary Origin of Craniates”; Janvier, “Catching the First Fish”; Monnereau, “An Early Cambrian Craniate-Like Chordate”; Conway Morris and Caron, “Pikaia gracilens Walcott, a Stem-Group Chordate from the Middle Cambrian of British Columbia”; Sansom et al., “Non-Random Decay of Chordate Characters Causes Bias in Fossil Interpretation”; Shu et al., “An Early Cambrian Tunicate from China”; Shu et al. “Lower Cambrian Vertebrates from South China.” Coeloscleritophora: Bengtson and Hou, “The Integument of Cambrian Chancelloriids.” Ctenophora: Chen, J. Y. et al. “Raman Spectra of a Lower Cambrian Ctenophore Embryo from Southwestern Shaanxi, China”; Conway Morris and Collins, “Middle Cambrian Ctenophores from the Stephen Formation, British Columbia, Canada.” Echinodermata: Foote, “Paleozoic Record of Morphological Diversity in Blastozoan Echinoderms”; Shu et al., “Ancestral Echinoderms from the Chengjiang Deposits of China”; Zamora et al., “Middle Cambrian Gogiid Echinoderms from Northeast Spain: Taxonomy, Palaeoecology, and Palaeogeographic Implications.” Entoprocta: Zhang et al., “A Sclerite-Bearing Stem Group Entoproct from the Early Cambrian and Its Implications.” Euarthropoda: Cisne, J. L., “Trilobites and the Origin of Arthropods”; Daley, “The Morphology and Evolutionary Significance of the Anomalocaridids”; Grosberg, “Out on a Limb: Arthropod Origins”; Siveter, “A Phosphatocopid Crustacean with Appendages from the Lower Cambrian.” Hemichordata: Shu et al., “Reinterpretation of Yunnanozoon as the Earliest Known Hemichordate”; Shu et al., “A New Species of Yunnanozoan with Implications for Deuterostome Evolution.” Hyolitha: Malinky and Skovsted, “Hyoliths and Small Shelly Fossils from the Lower Cambrian of North-East Greenland”; note that some authors consider Hyolitha to belong to phylum Mollusca, whereas others consider Hyolitha to represent an independent phylum. Lobopodia: Liu et al., “A Large Xenusiid Lobopod with Complex Appendages from the Lower Cambrian Chengjiang Lagerstätte”; Liu et al., “Origin, Diversification, and Relationships of Cambrian Lobopods”; Liu et al., “An Armoured Cambrian Lobopodian from China with Arthropod-Like Appendages”; Ou et al., “A Rare Onychophoran-Like Lobopodian from the Lower Cambrian Chengjiang Lagerstätte, Southwestern China, and Its Phylogenetic Implications.” Loricifera: Peel, “A Corset-Like Fossil from the Cambrian Sirius Passet Lagerstatte of North Greenland and Its Implications for Cycloneuralian Evolution.” Nematomorpha: Xian-guang and Wen-guo, “Discovery of Chengjiang Fauna at Meishucun, Jinning, Yunnan.” Phoronida: Erwin et al., “The Cambrian Conundrum: Early Divergence and Later Ecological Success in the Early History of Animals.” Priapulida: Wills et al., “The Disparity of Priapulid, Archaeopriapulid and Palaeoscolecid Worms in the Light of New Data”; Hu et al., “A New Priapulid Assemblage from the Early Cambrian Guanshan Fossil Lagerstätte of SW China.” Sipuncula: Huang et al., “Early Cambrian Sipunculan Worms from Southwest China.” Some consider sipunculan worms to be a subgroup of the phylum Annelida based on phylogenomic analyses. See Struck et al., “Phylogenomic Analyses Unravel Annelid Evolution.” Tardigrada: Muller et al., “ ‘Orsten’ Type Phosphatized Soft-Integument Preservation and a New Record from the Middle Cambrian Kuonamka Formation in Siberia.” Vetulicolia: Shu, “On the Phylum Vetulicolia.” Nematoda: Erwin et al., “The Cambrian Conundrum: Early Divergence and Later Ecological Success in the Early History of Animals.” Nemertea(?): Schram, “Pseudocoelomates and a Nemertine from the Illinois Pennsylvanian.” Note that the presence of Nemertea in the fossil record is contested. Platyhelminthes: Poinar, “A Rhabdocoel Turbellarian (Platyhelminthes, Typhloplanoida) in Baltic Amber with a Review of Fossil and Sub-Fossil Platyhelminths.” Rotifera: Swadling et al., “Fossil Rotifers and the Early Colonization of an Antarctic Lake.” [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7289-7337). HarperCollins. Kindle Edition.]
* The term “phyla” (singular: “phylum”) refers to divisions in the biological classification system. The phyla constitute the highest (or widest) categories of biological classification in the animal kingdom, with each exhibiting a unique architecture, organizational blueprint, or structural body plan. Familiar examples of phyla are cnidarians (corals and jellyfish), mollusks (squid and clams), echinoderms (sea stars and sea urchins), arthropods (trilobites and insects), and the chordates, to which all vertebrates including humans belong. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 619-623). HarperCollins. Kindle Edition.]



* The variety in the Burgess Shale was so extreme it took several decades for paleontologists to grasp it fully. Walcott, for instance, attempted to fit all of the new forms into existing phyla. However, even in the midst of this attempt, he realized that this revolutionary quarry posed a problem more fundamental than a need to tidy up the existing taxonomy. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 659-661). HarperCollins. Kindle Edition.]
* Over the years, as paleontologists have reflected on the overall pattern of the Precambrian–Cambrian fossil record in light of Walcott’s discoveries, they too have noted several features of the Cambrian explosion that are unexpected from a Darwinian point of view11 in particular: (1) the sudden appearance of Cambrian animal forms; (2) an absence of transitional intermediate fossils connecting the Cambrian animals to simpler Precambrian forms; (3) a startling array of completely novel animal forms with novel body plans; and (4) a pattern in which radical differences in form in the fossil record arise before more minor, small-scale diversification and variations. This pattern turns on its head the Darwinian expectation of small incremental change only gradually resulting in larger and larger differences in form. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 665-671). HarperCollins. Kindle Edition.]



* Of course, the fossil record does show an overall increase in the complexity of organisms from Precambrian to Cambrian times, as Darwin expected. But the problem posed by the Burgess Shale is not the increase in complexity, but the sudden quantum leap in complexity. The jump from the simpler Precambrian organisms (further explored in the next chapters) to the radically different Cambrian forms appears to occur far too suddenly to be readily explained by the gradual activity of natural selection and random variations. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 686-689). HarperCollins. Kindle Edition.]
* According to Darwin’s theory, the differences in form, or “morphological distance,” between evolving organisms should increase gradually over time as small-scale variations accumulate by natural selection to produce increasingly complex forms and structures (including, eventually, new body plans). In other words, one would expect small-scale differences or diversity among species to precede large-scale morphological disparity among phyla. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 749-752). HarperCollins. Kindle Edition.]
* As the former Oxford University neo-Darwinian biologist Richard Dawkins puts it, “What had been distinct species within one genus become, in the fullness of time, distinct genera within one family. Later, families will be found to have diverged to the point where taxonomists (specialists in classification) prefer to call them orders, then classes, then phyla.”17 [Dawkins, Unweaving the Rainbow, 201.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 752-755). HarperCollins. Kindle Edition.]
* He said, “The diagram illustrates the steps by which small differences distinguishing varieties are increased into larger differences distinguishing species.”18 He went on to assert that the process of modification by natural selection would eventually move beyond the formation of species and genera to form “two distinct families, or orders, according to the amount of divergent modification supposed to be represented in the diagram.”19 [18. Darwin, On the Origin of Species, 120. 19. Darwin, On the Origin of Species, 125.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 758-762). HarperCollins. Kindle Edition.]
* In his view, this process would continue until it produced differences in form that were great enough that taxonomists would classify them as new classes or phyla. In short, diversity would precede disparity, and phyla-level differences in body plan would emerge only after species-, genus-, family-, order-, and class-level differences appeared. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 762-765). HarperCollins. Kindle Edition.]
* The actual pattern in the fossil record, however, contradicts this expectation. Instead of more and more species eventually leading to more genera, leading to more families, orders, classes, and phyla, the fossil record shows representatives of separate phyla appearing first followed by lower-level diversification on those basic themes. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 765-767). HarperCollins. Kindle Edition.]
* This is nowhere more dramatically apparent than in the Cambrian period explains Roger Lewin in the journal Science: “Several possible patterns exist for the establishment of higher taxa, the two most obvious of which are the bottom-up and the top-down approaches. In the first, evolutionary novelties emerge, bit by bit. The Cambrian explosion appears to conform to the second pattern, the top-down effect.”20 [Lewin, “A Lopsided Look at Evolution,” 292.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 768-771). HarperCollins. Kindle Edition.]
* Or as paleontologists Douglas Erwin, James Valentine, and Jack Sepkoski note in their study of skeletonized marine invertebrates: “The fossil record suggests that the major pulse of diversification of phyla occurs before that of classes, classes before that of orders, orders before that of families. . . . The higher taxa do not seem to have diverged through an accumulation of lower taxa.”21 [Erwin, Valentine, and Sepkoski, “A Comparative Study of Diversification Events,” 1183. See also Erwin et al., “The Cambrian Conundrum: Early Divergence and Later Ecological Success in the Early History of Animals,” 1091–97; Bowring et al., “Calibrating Rates of Early Cambrian Evolution,” 1293–98.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 771-774). HarperCollins. Kindle Edition.]
* Yet, on a Darwinian view, small-scale variations and differences should arise first, gradually giving rise to larger-scale differences in form—just the opposite of the pattern evident in the fossil record. Thus, the discovery, and later analysis, of the Burgess revealed another puzzling feature of the fossil record from a Darwinian point of view, regardless of which system of classification paleontologists prefer to use. Indeed, Walcott’s discovery turned Darwin’s anticipated bottom-up—or small changes first, big changes later—pattern on its head. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 800-804). HarperCollins. Kindle Edition.]
* Paleontologists think they know the answer. They think the marine animals that were later fossilized in the Burgess Shale lived near the bottom of an ancient sea in front of an underwater cliff or escarpment. Due to tectonic activity, blocks at the edge of this underwater cliff began to break off. These blocks slumped, creating underwater mudflows in their wake. These slumps and flows transported the Burgess animals several kilometers into deeper waters where they were buried in such a way as to leave them not only undamaged, but also protected from scavengers and bacteria. Very probably, the mudflows were highly turbulent, for paleontologists found the creatures dumped and preserved in a variety of angles in relation to the bedding. The speed and pressure of these mudflows quickly produced a preservation-friendly, oxygen-free environment. Then the turbulent and muddy currents pressed fine silt and clay into the crevices of the bodies at just the right consistency and pressure to fossilize them without tearing their delicate appendages, an ideal set of circumstances for ensuring later observation by future paleontologists.23 [For a more technical description of the processes behind the Burgess Shale fossil formation, see Briggs, Erwin, and Collier, The Fossils of the Burgess Shale, 21–32; Conway Morris, The Crucible of Creation, 106–107.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 818-826). HarperCollins. Kindle Edition.]
* Although Walcott conceded that his hypothesis was essentially a negative argument that attempted to explain away the absence of evidence, he insisted that it was a sensible inference from his broad sampling of the paleontological data. “I fully realize that the conclusions above outlined are based primarily on the absence of a marine fauna in Algonkian [Precambrian] rocks,” he wrote, “but until such is discovered I know of no more probable explanation of the abrupt appearance of the Cambrian fauna than that I have presented.”25 [Walcott, “Cambrian Geology and Paleontology II,” 15.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 854-858). HarperCollins. Kindle Edition.]

**3 Soft Bodies and Hard Facts**

* In the spring of 2000, Discovery Institute, where I do my research, sponsored a lecture at the University of Washington geology department by renowned Chinese paleontologist J. Y. Chen (see Fig. 3.1). As the result of his role in excavating a new discovery of Cambrian-era fossils in southern China, Professor Chen’s standing in the scientific world was on the rise. The discovery, near the town of Chengjiang in the Kunming Province, revealed a trove of early Cambrian animal forms. After Time magazine mentioned the Chengjiang discovery in a 1995 cover story about the Cambrian explosion,1 interest in the fossils surged. [Nash, “When Life Exploded,” 66–74.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 891-896). HarperCollins. Kindle Edition.]
* The fossils from the Maotianshan Shale near Chengjiang (see Fig. 3.2) had established an even greater variety of Cambrian body plans from an even older layer of Cambrian rock than those of the Burgess, and they did so with an almost photographic fidelity. The Chinese fossils also helped to establish that the Cambrian animals appeared even more explosively than previously realized. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 901-903). HarperCollins. Kindle Edition.]
* In his presentation, he highlighted the apparent contradiction between the Chinese fossil evidence and Darwinian orthodoxy. As a result, one professor in the audience asked Chen, almost as if in warning, if he wasn’t nervous about expressing his doubts about Darwinism so freely—especially given China’s reputation for suppressing dissenting opinion. I remember Chen’s wry smile as he answered. “In China,” he said, “we can criticize Darwin, but not the government. In America, you can criticize the government, but not Darwin.” [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 909-913). HarperCollins. Kindle Edition.]
* When Walcott proposed his ingenious geological scenario, it could not yet be tested. But with the development of offshore drilling technology in the 1940s, 1950s, and 1960s, oil companies began to drill through thousands of feet of marine sedimentary rock.6 As geologists evaluated the contents of these drill cores, they did not find Walcott’s predicted Precambrian fossils. [See Cloud, “The Ship That Digs Holes in the Sea,” 108. See also a history of offshore drilling on the website of the National Ocean Industries Association, http://www.noia.org/website/article.asp?id=123 (accessed July 8, 2011).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 966-970). HarperCollins. Kindle Edition.]
* As a consequence of this cycle, the maximum age of any marine sediment is strictly limited. And according to modern estimates, the oldest section of oceanic crust has existed only since the Jurassic (or about 180 million years ago8)—far too young to contain fossil ancestors of the trilobites. As the evidence for plate tectonics mounted, scientists discarded Walcott’s artifact hypothesis and Lipalian interval as nonstarters. Paleontologists today do not expect to find any Precambrian ancestors of the trilobites in oceanic sediments, since they realize that there are no Precambrian sediments in the ocean basins. If Precambrian strata are to be found anywhere, continents are the place. [Müller et al., “Digital Isochrons of the World’s Ocean Floor,” 3212.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 980-986). HarperCollins. Kindle Edition.]
* Some scientists claimed, though for different reasons, that the expected Precambrian fossil ancestors had simply not yet been found—that missing fossils were an artifact of the incomplete sampling of the fossil record. Others suggested that Precambrian sedimentary rocks had not preserved the missing fossils—that the incomplete preservation of the Precambrian animals meant the missing fossils were no longer there to be found. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 988-991). HarperCollins. Kindle Edition.]
* Walcott rejected the idea that paleontologists simply had not looked in, or sampled, enough places. He noted that geologists already had extensively investigated “the great series of Cambrian and Precambrian strata in eastern North America.” Though they had looked “from Alabama to Labrador; in western North America [and] from Nevada and California far into Alberta and British Columbia, and also in China” their investigations had turned up nothing of significant interest.9 In Walcott’s view the continents simply had not preserved the fossilized remains of the Cambrian ancestors. [Walcott, “Cambrian Geology and Paleontology II,” 2–4.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 992-996). HarperCollins. Kindle Edition.]
* Before Walcott, some geologists had gone a step farther and suggested that all Precambrian sedimentary rocks had been destroyed via extreme heat and pressure, a process called “universal metamorphism.” Walcott rejected this hypothesis, since he himself had encountered a “great series of pre-Cambrian sedimentary rocks on the North American continent” among other places. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 997-999). HarperCollins. Kindle Edition.]
* Other geologists suggested that major bursts of evolutionary innovation occurred only during periods when sedimentary deposition had ceased, thus again resulting in a lack of fossil preservation. But, as Gould remarked of Walcott’s artifact hypothesis, this explanation also appeared to many scientists “forced and ad hoc . . . born of frustration, rather than the pleasure of discovery.”10 [Gould, Wonderful Life, 275.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 999-1002). HarperCollins. Kindle Edition.]
* Developmental biologist Eric Davidson, of California Institute of Technology, has suggested that the transitional forms leading to the Cambrian animals were “microscopic forms similar to modern marine larvae” and were thus too small to have been reliably fossilized.11 Other evolutionary scientists, such as Gregory Wray, Jeffrey Levinton, and Leo Shapiro, have suggested that the ancestors of the Cambrian animals were not preserved, because they lacked hard parts such as shells and exoskeletons.12 They argue that since soft-bodied animals are difficult to fossilize, we shouldn’t expect to find the remains of the supposedly soft-bodied ancestors of the Cambrian fauna in the Precambrian fossil record. [11. Some have even suggested that the transitional intermediate forms leading to the Cambrian animals only existed in the larval stage. See Davidson, Peterson, and Cameron, “Origin of Bilaterian Body Plans,” 1319. 12. Wray, Levinton, and Shapiro, “Molecular Evidence for Deep Pre-Cambrian Divergences Among Metazoan Phyla.” For other recent expressions of this version of the artifact hypothesis, see Simpson, Fossils and the History of Life, 72–74; Ward, Out of Thin Air, 5; Eldredge, The Triumph of Evolution and the Failure of Creationism, 46; and Schirber, “Skeletons in the Pre-Cambrian Closet.” Though contemporary paleontologists commonly attribute the absence of Precambrian ancestral forms to their alleged lack of hard parts or appreciable size, earlier geologists and paleontologists have also employed this version of the artifact hypothesis. For example, in 1941 Charles Schuchert and Carl Dunbar stated: “We may infer, therefore, that life probably was abundant in the seas of Cryptozoic time and especially during the Proterozoic, but was of a low order and doubtless small and soft-tissued, so that there was little chance for actual preservation of fossils” (Textbook of Geology, Part II, 124). And as early as 1894 W. K. Brooks asserted: “the zoological features of the Lower Cambrian are of such a character as to indicate that it is a decided and unmistakable approximation to the primitive fauna of the bottom, beyond which life was represented only by minute and simple surface animals not likely to be preserved as fossils” (“The Origin of the Oldest Fossils and the Discovery of the Bottom of the Ocean,” 360–61).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1006-1012). HarperCollins. Kindle Edition.]
* University of California, Berkeley, paleontologist Charles R. Marshall summarizes these explanations: [I]t is important to remember that we see the Cambrian “explosion” through the windows permitted by the fossil and geological records. So when talking about the Cambrian “explosion,” we are typically referring to the appearance of large-body (can be seen by the naked eye) and preservable (and therefore largely skeletonized) forms. . . . If the stem lineages were both small and unskeletonized, then we would not expect to see them in the fossil record.13 [Marshall, “Explaining the Cambrian ‘Explosion’ of Animals,” 357, 372. For an authoritative refutation of this version of the artifact hypothesis, see Conway Morris, The Crucible of Creation, 140–44; Conway Morris, “Darwin’s Dilemma: The Realities of the Cambrian ‘Explosion’,” 1069–83.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1012-1017). HarperCollins. Kindle Edition.]
* Paleobiologist J. William Schopf, of the University of California, Los Angeles, has reported an extremely ancient example of these fossils in the Warrawoona Group strata of western Australia. These fossilized cyanobacteria are preserved in 3.465-billion-year-old bedded cherts (microcrystalline sedimentary rocks).14 The same strata have also preserved stromatolite mats, an organic accretionary growth structure usually indicating the presence of bacteria, within slightly younger dolostone sediments of roughly 3.45 billion years in age.15 [14. Schopf and Packer, “Early Archean (3.3-Billion to 3.5-Billion-Year-Old) Microfossils from Warrawoona Group, Australia,” 70; Schopf, “Microfossils of the Early Archean Apex Chert.” 15. Schopf and Packer, “Early Archean (3.3-Billion- to 3.5-Billion-Year-Old) Microfossils from Warrawoona Group, Australia,” 70; Hoffmann et al., “Origin of 3.45 Ga Coniform Stromatolites in Warrawoona Group, Western Australia.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1020-1025). HarperCollins. Kindle Edition.]
* There are also several reasons to question the second version of this hypothesis—the idea that the presumed Cambrian ancestors were too soft to be preserved. First, some paleontologists have questioned whether soft-bodied ancestral forms of the hard-bodied Cambrian animals would have even been anatomically viable.16 They argue that many animals representing phyla such as brachiopods and arthropods could not have evolved their soft parts first and then added shells later, since their survival depends upon their ability to protect their soft parts from hostile environmental forces. Instead, they argue that soft and hard parts had to arise together.17 As paleontologist James Valentine, of the University of California, Berkeley, has noted in the case of brachiopods, “The brachiopod Bauplan [body plan] cannot function without a durable skeleton.”18 Or as J. Y. Chen and his colleague Gui-Qing Zhou observe: “Animals such as brachiopods . . . cannot exist without a mineralized skeleton. Arthropods bear jointed appendages and likewise require a hard, organic or mineralized outer covering.”19 [16. Jan Bergström states: “Animals such as arthropods and brachiopods cannot exist without hard parts. The absence of remains of skeletons and shells in the Precambrian therefore proves that the phyla came into being with the Cambrian, not before, even if the lineages leading to the phyla were separate before the Cambrian” (“Ideas on Early Animal Evolution,” 464). 17. Valentine and Erwin, “Interpreting Great Developmental Experiments.” 18. Valentine, “Fossil Record of the Origin of Bauplan and Its Implications,” especially 215. 19. Chen and Zhou, “Biology of the Chengjiang Fauna,” 21.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1036-1046). HarperCollins. Kindle Edition.]
* Because these animals typically require hard parts, Chen and Zhou assume that the ancestral forms of these animals should have been preserved somewhere in the Precambrian fossil record if in fact they were ever present. Thus, the absence of hard-bodied ancestors of these Cambrian animals in the Precambrian strata shows that these animals first arose in the Cambrian period. As they rather emphatically insist: “The observation that such fossils are absent in Precambrian strata proves that these phyla arose in the Cambrian.”20 [Chen and Zhou, “Biology of the Chengjiang Fauna,” 21. Or as Valentine explains, “the interpretation of the explosion as an artifact of the evolution of durable skeletons has got it backward: the skeletons are artifacts, more or less literally, of the evolutionary explosion.” Valentine, On the Origin of Phyla, 181.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1046-1050). HarperCollins. Kindle Edition.]
* It should be pointed out that this argument cannot be made for all Cambrian animal groups and, in my view, does not achieve the standing of a “proof” in any case. Many Cambrian phyla, including phyla characterized by mostly hard-shelled animals such as mollusks and echinoderms, do have soft-bodied representatives. The earliest known mollusk, Kimberella, for example, lacked a hard external shell (though it did have other hard parts).21 So, clearly, some mainly hard-shelled Cambrian groups could have had soft-bodied ancestors. [Ivantsov, “A New Reconstruction of Kimberella, a Problematic Metazoan,” 3.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1051-1055). HarperCollins. Kindle Edition.]
* Nevertheless, it seems unlikely on a Darwinian view of the history of life that all Cambrian arthropod or brachiopod ancestors, especially the relatively recent ancestors of these animals, would have lacked hard parts entirely. There are many types of arthropods that arise suddenly in the Cambrian—trilobites, Marrella, Fuxianhuia protensa, Waptia, Anomalocaris—and all of these animals had hard exoskeletons or body parts. Moreover, the only known extant group of arthropods without a hard exoskeleton (the pentastomids) have a parasitic relationship with arthropods that do.23 Thus, surely, it seems likely that some of the near ancestors of the many arthropod animals that arose in the Cambrian would have left at least some rudimentary remains of exoskeletons in the Precambrian fossil record—if, in fact, such ancestral arthropods existed in the Precambrian and if arthropods arose in a gradual Darwinian way. [Frederick Schram, The Crustacea.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1061-1068). HarperCollins. Kindle Edition.]
* In any case, advocates of the artifact hypothesis must at least explain a Cambrian explosion of hard body parts, if not whole Cambrian animals. As paleontologist George Gaylord Simpson noted in 1983, even if it’s true that Precambrian ancestors were not preserved simply because they lacked hard parts, “there is still a mystery to speculate about: Why and how did many animals begin to have hard parts—skeletons of sorts—with apparent suddenness around the beginning of the Cambrian?”24 [Simpson, Fossils and the History of Life, 73. Indeed, an exoskeleton is far more than a mere covering for the soft parts of, say, a chelicerate or crustacean, because it provides the sites for the attachment of the muscles and various other tissues. Further, the limbs (including the mouthparts and in some instances certain reproductive components) are encased in exoskeletal elements that can articulate, allowing the arthropod to move, feed, and mate. An exterior skeleton of any shrimp, for example, also has interior projections that comprise its endophragmal system, which provides support for the animal’s internal musculature and organs. At the same time, the skeleton of any arthropod is a product of, and in turn regulates, its metabolism and physiology. In order for the first members of Fuxianhuia or Marrella to have grown (and possibly metamorphosed during their development), they would have had to have successively secreted a new skeleton beneath the old one; to have shed the used exoskeletons; and to have hardened each new exoskeleton. This tight functional integration suggests the implausibility of evolutionary models that envision the Arthropod exoskeleton arising late as a kind of accretion to an already integrated system of soft parts.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1080-1084). HarperCollins. Kindle Edition.]
* As we saw earlier, Precambrian sedimentary rocks in several places around the world have preserved fossilized colonial blue-green algae, single-celled algae, and cells with a nucleus (eukaryotes).25 These microorganisms were not only small, but they also entirely lacked hard parts. Another class of late Precambrian organisms called the Vendian or Ediacaran biota included the fossilized remains of many soft-bodied organisms, including many that may well have been lichens, algae, or protists (microorganisms with cells containing nuclei). Cambrian-era strata themselves preserve many soft-bodied creatures and structures. [Brocks et al., “Archean Molecular Fossils and the Early Rise of Eukaryotes.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1087-1092). HarperCollins. Kindle Edition.]
* The Burgess Shale in particular preserved the soft parts of several types of hard-bodied Cambrian animals, such as Marrella splendens,26 Wiwaxia,27 and Anomalocaris. The Burgess Shale also documents entirely soft-bodied representatives28 of several phyla, including: Cnidaria (represented by an animal called Thaumaptilon, a feather-shaped colonial organism formed from smaller soft sea anemone–like animals)29 Annelida (represented by the polychaete worms Burgessochaeta and Canadia)30 Priapulida (represented by Ottoia, Louisella, Selkirkia—all worms with a distinctive proboscis)31 Ctenophora (represented by Ctenorhabdotus, a gelatinous animal with a translucent body similar to a modern comb jelly)32 Lobopodia (represented by Aysheaia and Hallucigenia, segmented soft-bodied animals with many legs)33 [26. Conway Morris, The Crucible of Creation, 47–48; Gould, “The Disparity of the Burgess Shale Arthropod Fauna and the Limits of Cladistic Analysis.” 27. Wiwaxia is considered soft-bodied, but it does have harder scales and spines. See Conway Morris, The Crucible of Creation, 97–98. 28. Valentine, “The Macroevolution of Phyla,” sec. 3.2, “Soft-Bodied Body Fossils,” 529–31. 29. Conway Morris, The Crucible of Creation, 82. 30. Conway Morris, The Crucible of Creation, 76, 99. 31. Conway Morris, The Crucible of Creation, 68, 73, 74; “Burgess Shale Faunas and the Cambrian Explosion.” 32. Conway Morris, The Crucible of Creation, 107. 33. Conway Morris, The Crucible of Creation, 92, 184.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1092-1106). HarperCollins. Kindle Edition.]
* The Burgess also preserves soft-bodied animals of unknown affinities, such as Amiskwia, a gelatinous air mattress–like animal;34 Eldonia, a jellyfish-like animal with a much more complex anatomy than a modern jellyfish;35 and the aforementioned, difficult to classify, Nectocaris.36 [34. Conway Morris, “Burgess Shale Faunas and the Cambrian Explosion.” 35. Conway Morris, The Crucible of Creation, 103; Conway Morris, “Burgess Shale Faunas and the Cambrian Explosion.” 36. A recent scientific paper reinterprets Nectocaris as a cephalopod mollusk, though it also acknowledges the problems long associated with the definitive classification of this animal. See Smith and Caron, “Primitive Soft-Bodied Cephalopods from the Cambrian.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1106-1110). HarperCollins. Kindle Edition.]
* As Simon Conway Morris notes, “The existing [Burgess] collections represent approximately 70,000 specimens. Of these, about 95 percent are either soft-bodied or have thin skeletons.”37 [Conway Morris, The Crucible of Creation, 140.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1110-1112). HarperCollins. Kindle Edition.]
* Any doubts about the ability of sedimentary rocks to preserve soft and small body parts were permanently laid to rest by a series of dramatic fossil finds in southern China beginning in the 1980s. In June 1984, paleontologist Xian-Guang Hou journeyed to Kunming, in southern China, to prospect for fossilized samples of a bivalved arthropod called a bradoriid.38 [Hou et al., The Cambrian Fossils of Chengjiang, China, 10.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1113-1116). HarperCollins. Kindle Edition.]
* In the summer of 1984 Hou traveled to the town of Chengjiang to look for bradoriids in another geological formation called the Heilinpu Formation. His efforts there yielded little success. As a result, he turned his attention to another outcrop, a sedimentary sequence now called the Maotianshan Shale. Hou’s team set farmworkers to digging out and scouring the mudstone blocks. His book, The Cambrian Fossils of Chengjiang, China, describes what happened next: At about three o’clock in the afternoon of Sunday July 1, a semicircular white film was discovered in a split slab, and was mistakenly thought to represent the valve of an unknown crustacean. With the realization that this . . . represented a previously unreported species, breaking of the rock in a search for additional fossils continued apace. With the find of another specimen, a 4–5 cm long animal with limbs preserved, it became apparent that here was nothing less than a soft-bodied biota.39 [Hou et al., The Cambrian Fossils of Chengjiang, China, 10, 12.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1119-1127). HarperCollins. Kindle Edition.]
* Hou remembers the Cambrian specimen vividly, for it appeared “as if it was alive on the wet surface of the mudstone.”40 Redoubling their efforts, the researchers quickly uncovered the fossilized remains of one extraordinary soft-bodied animal after another. Most of the fossils were preserved as flattened two-dimensional imprints of three-dimensional organisms, although, as Hou observes, “some retain a low three-dimensional relief.”41 Most important, he notes, “The remains of hard tissues, such as the shells of brachiopods or the carapaces of trilobites, are well represented in the Chengjiang fauna, but less robust tissues, which are usually lost through decomposition, are also beautifully preserved.”42 [40. Hou et al., The Cambrian Fossils of Chengjiang, China, 13. 41. Hou et al., The Cambrian Fossils of Chengjiang, China, 10, 12. 42. Hou et al., The Cambrian Fossils of Chengjiang, China, 23.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1127-1134). HarperCollins. Kindle Edition.]
* They found fossils preserving the anatomical details of numerous soft tissues and organs such as eyes, intestines, stomachs, digestive glands, sensory organs, epidermes, bristles, mouths, and nerves.45 They also discovered jellyfish-like organisms called Eldonia, which exhibit delicate, soft body parts such as radiating water canals and nerve rings. Other fossils even revealed the contents of the guts of several animals.46 [45. Chen et al., “Weng’an Biota”; Chien et al., “SEM Observation of Precambrian Sponge Embryos from Southern China.” 46. Chen et al., The Chengjiang Biota: A Unique Window of the Cambrian Explosion. This book is currently available only in the Chinese language. The translated English version is being completed by Paul K. Chien, of the University of San Francisco.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1142-1146). HarperCollins. Kindle Edition.]
* As J. Y. Chen began to examine the sedimentary rocks that enclosed his fossilized sponge, he decided to look at them in a so-called thin section under a light microscope. Chen wondered whether smaller embryonic forms of these Precambrian animals might also have been preserved in these phosphorite rocks. Sure enough, under magnification he found little round balls that he and Paul Chien identified as sponge embryos. In 1999, at a major international conference about the Cambrian explosion held near Chengjiang, J. Y. Chen, Paul Chien, and three other colleagues presented their findings.47 [Chen et al., “Weng’an Biota”; Chien et al., “SEM Observation of Precambrian Sponge Embryos from Southern China.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1164-1168). HarperCollins. Kindle Edition.]
* A number of Chinese paleontologists questioned them at first, suggesting that the little round balls were not sponge embryos at all, but instead the remains of brown and green algae.48 Here Paul Chien’s expertise came to the fore. Early in his career, Chien had perfected a technique for examining the embryos of living sponges under a scanning electron microscope. He now adapted his technique to examine these microscopic fossilized structures using a more powerful microscope. What he found startled him and amazed other scientists. [For other alternative interpretations, see Huldtgren et al., “Fossilized Nuclei and Germination Structures Identify Ediacaran ‘Animal Embryos’ as Encysting Protists,” 1696–99; Xiao et al., “Comment on ‘Fossilized Nuclei and Germination Structures Identify Ediacaran ‘Animal Embryos’ as Encysting Protists’,” 1169; Huldtgren et al., “Response to Comment on ‘Fossilized Nuclei and Germination Structures Identify Ediacaran ‘Animal Embryos’ as Encysting Protists’,” 1169.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1169-1173). HarperCollins. Kindle Edition.]
* Only sponges have spicules, and the fossilized cells he was examining preserved microscopic spicules in the early stages of their development.50 Clearly, these were not algal balls; they were sponge embryos. Even more surprising, Chien was able to observe the internal structure of these embryonic cells, allowing him to identify the nuclei of some of these cells within the fossilized remains of the larger outer cell membrane. [Chien et al., “SEM Observation of Precambrian Sponge Embryos from Southern China.” Sponges are assumed by most evolutionary biologists to represent a side branch, not a node on evolutionary tree of life leading to the Cambrian phyla. Thus, sponges are not regarded as plausible transitional intermediates between Precambrian and Cambrian forms (nor are they regarded as ancestral to other Cambrian animals).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1180-1183). HarperCollins. Kindle Edition.]
* J. Y. Chen found these sponge embryos beneath the Cambrian–Precambrian boundary in late Precambrian rock. Yet these Precambrian layers did not preserve remains of any clearly ancestral or intermediate forms leading to the other main groups of Cambrian animals. This raised an obvious question. If the Precambrian sedimentary strata beneath the Maotianshan Shale preserved the soft tissues of tiny, microscopic sponge embryos, why didn’t they also preserve the near ancestors of the whole animals that arose in the Cambrian, especially since some of those animals must have had at least some hard parts as a condition of their viability? If these strata could preserve embryos, then they should have preserved fully developed animals—at least, if such animals were present at the time. That well-developed, clearly ancestral animal forms were not preserved, when tiny sponge embryos51 were, strongly indicates that such forms were simply not present in the Precambrian layers. [Some have challenged the interpretation of these Precambrian microfossils as embryos, arguing that they are, instead, large micro-organisms. For example, Therese Huldtgren and colleagues have argued that these fossils “have features incompatible with multicellular metazoan embryos” and that “the developmental pattern is [more] comparable with nonmetazoan holozoans,” a group that includes one-celled protozoans. [Huldtgren et al., “Fossilized Nuclei and Germination Structures Identify Ediacaran ‘Animal Embryos’ as Encysting Protists,” 1696–99.] Critics of Huldtgren’s proposal instead think they may well be tiny metazoan embryos, though of unknown affiliation. [Xiao et al., “Comment on ‘Fossilized Nuclei and Germination Structures Identify Ediacaran ‘Animal Embryos’ as Encysting Protists’,” 1169. Huldtgren and colleagues have defended their interpretation here: Huldtgren et al., “Response to Comment on ‘Fossilized Nuclei and Germination Structures Identify Ediacaran “Animal Embryos” as Encysting Protists’,” 1169.] Another interpretation is that the fossils represent giant sulphur bacteria, since “sulphur bacteria of the genus Thiomargarita have sizes and morphologies similar to those of many Doushantuo microfossils, including symmetrical cell clusters that result from multiple stages of reductive division in three planes.” [Bailey et al., “Evidence of giant sulphur bacteria in Neoproterozoic phosphorites,” 198–201.] Critics of this hypothesis doubt that sulphur bacteria could be fossilized because they “collapse easily and have only patchy biofilms that are limited to the multi-layered envelope.” [Cunningham et al., “Experimental taphonomy of giant sulphur bacteria: implications for the interpretation of the embryo-like Ediacaran Doushantuo fossils,” 1857–64.] The debate over whether the Doushantuo microfossils should be interpreted as metazoan embryos, protozoans, or giant sulphur bacteria will doubtless continue. Whatever the outcome, however, the fact remains: small, fragile, and soft-bodied organisms of some kind have been found fossilized in this Precambrian strata, raising the question of why the same layers of rock were unable to preserve the immediate precursors to the numerous metazoan phyla that emerge so abruptly in the Cambrian layers above them.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1190-1197). HarperCollins. Kindle Edition.]
* In their 2013 book, The Cambrian Explosion, paleontologists James Valentine and Douglas Erwin go further. They note that many late Precambrian depositional environments actually provide more favorable settings for the preservation of fossils than those present in the Cambrian period. As they note, “a revolutionary change in the sedimentary environment—from microbially stabilized sediments during the Ediacaran [late Precambrian] to biologically churned sediments as larger, more active animals appeared—occurred during the early Cambrian. Thus, the quality of fossil preservation in some settings may have actually declined from the Ediacaran to the Cambrian, the opposite of what has sometimes been claimed, yet we find a rich and widespread explosion of [Cambrian] fauna.”54 [Erwin and Valentine, The Cambrian Explosion, 8.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1215-1221). HarperCollins. Kindle Edition.]
* First, in 1993, radiometric dating of zircon crystals from formations just above and below Cambrian strata in Siberia allowed for a precise redating of Cambrian strata. Radiometric analyses of these crystals fixed the start of the Cambrian period at 544 million years ago,58 and the beginning of the Cambrian explosion itself to about 530 million years ago (see Fig. 3.8). These studies also suggested that the explosion of the novel Cambrian animal forms occurred within a window of geologic time much shorter than previously believed, lasting no more than 10 million years, and the main “period of exponential increase of diversification” lasting only 5 to 6 million years.59 [58. Bowring et al., “Calibrating Rates of Early Cambrian Evolution.” 59. Bowring et al., “Calibrating Rates of Early Cambrian Evolution,” 1297.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1268-1273). HarperCollins. Kindle Edition.]
* Geologically speaking, 5 million years represents a mere 1/10 of 1 percent (0.11 percent, to be precise) of earth’s history. J. Y. Chen explains that “compared with the 3-plus-billion-year history of life on earth, the period [of the explosion] can be likened to one minute in 24 hours of one day.”60 [Lili, “Traditional Theory of Evolution Challenged,” 10.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1276-1278). HarperCollins. Kindle Edition.]
* In my response to Prothero, I noted that he was, of course, free to redefine the term “Cambrian explosion” any way he liked, but that by using the term to describe several separate explosions (of different kinds), he had done nothing to diminish the difficulty of explaining the origin of the first explosive appearance of the Cambrian animals with their unique body plans and complex anatomical features. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1289-1292). HarperCollins. Kindle Edition.]
* An analysis by MIT geochronologist Samuel Bowring has shown that the main pulse of Cambrian morphological innovation occurred in a sedimentary sequence spanning no more than 6 million years.62 Yet during this time representatives of at least sixteen completely novel phyla and about thirty classes first appeared in the rock record. In a more recent paper using a slightly different dating scheme, Douglas Erwin and colleagues similarly show that thirteen new phyla appear in a roughly 6-million-year window.63 [62. Bowring et al., “Calibrating Rates of Early Cambrian Evolution,” 1297. See also McMenamin, The Emergence of Animals. 63. Erwin et al., “The Cambrian Conundrum: Early Divergence and Later Ecological Success in the Early History of Animals,” 1091–97.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1297-1301). HarperCollins. Kindle Edition.]

**4 The Not Missing Fossils?**

* The Ediacaran fauna derive their name from their most notable discovery site, the Ediacaran Hills in the outback of southeastern Australia. These fauna date from late Precambrian time, a period that the International Union of Geological Sciences has recently renamed the “Ediacaran period.”1 Since geologists used to call the last period of Precambrian time the “Vendian period,” paleontologists also refer to the Ediacaran fauna as the Vendian fauna or biota. [Gradstein, Ogg, Schmitz, and Ogg, The Geological Time Scale 2012.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1391-1395). HarperCollins. Kindle Edition.]
* The fourth group is the fossils of what may be primitive mollusks, a possibility that received support from a recent discovery in the cliffs along the White Sea in northwestern Russia. There, Russian scientists have discovered thirty-five distinctive specimens of a possible mollusk called Kimberella, probably a simple animal form. These new White Sea specimens, dated to 550 million years ago, suggest that Kimberella “had a strong [though not hard], limpet-like shell, crept along the sea floor, and resembled a mollusk.”3 [Monastersky, “Ancient Animal Sheds False Identity.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1412-1416). HarperCollins. Kindle Edition.]
* Paleontologist Douglas Erwin, of the Smithsonian Institution, has commented: “It’s the first animal that you can convincingly demonstrate is more complicated than a flatworm.”4 Additionally, seafloor tracks from Precambrian sediments in both Canada and Australia have been attributed to mollusks, since the tracks resemble what might have been left by a row of small teeth on the tongue-like ribbon of some mollusks as they scraped food particles off the seafloor. In this case, Kimberella may well have been the track maker.5 The authors of the original descriptive paper in Nature, Mikhail Fedonkin, from the Russian Academy of Sciences, and Benjamin Waggoner, then at the University of California at Berkeley, conclude as much and suggest that such creatures “began to diversify before the beginning of the Cambrian.”6 Paleontologists, however, are still weighing the evidence.7 [4. Monastersky, “Ancient Animal Sheds False Identity.” 5. Monastersky, “Ancient Animal Sheds False Identity.” 6. Fedonkin and Waggoner, “The Late Precambrian Fossil Kimberella is a Mollusc-like Bilaterian Organism,” 868. 7. For example, Graham Budd, a Swedish paleontologist and Cambrian expert, has expressed skepticism about this classification. He acknowledges that “the strongest case for an Ediacaran bilaterian body fossil has been made by Fedonkin and Waggoner (1997) for Kimberella,” but nevertheless disputes the classification of Kimberella as a true mollusk. He argues that “Kimberella does not possess any unequivocal derived molluscan features, and its assignment to the Mollusca or even the Bilateria must be considered to be unproven” (Budd and Jensen, “A Critical Reappraisal of the Fossil Record of the Bilaterian Phyla,” 270).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1416-1425). HarperCollins. Kindle Edition.]
* Other leading paleontologists also doubt that the Cambrian animals descended from these Ediacaran forms. In a phylogenetic diagram showing the evolutionary relationship of Precambrian and Cambrian fossils, Oxford biologists Alan Cooper and Richard Fortey depict the Ediacaran fauna as lying on a line of descent separate from the Cambrian animals rather than being ancestral to them.23 In another paper, Fortey asserts that the beginning of the Cambrian “saw the sudden appearance in the fossil record of almost all the main types of animals (phyla) that still dominate the biota today.” He concedes that there are a variety of fossils in older strata, but insist that “they are either very small (such as bacteria and algae) or their relationships to the living fauna are highly contentious, as is the case with the famous soft-bodied fossils from the late Precambrian Pound Quartzite, Ediacara, South Australia.”24 [23. Cooper and Fortey, “Evolutionary Explosions and the Phylogenetic Fuse,” 151–56. 24. Fortey, “Cambrian Explosion Exploded,” 438.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1481-1489). HarperCollins. Kindle Edition.]
* Similarly, paleontologist Andrew Knoll and biologist Sean B. Carroll have argued: “It is genuinely difficult to map the characters of Ediacaran fossils onto the body plans of living invertebrates.”25 Although many paleontologists initially showed interest in the possibility that the Cambrian animal forms might have evolved from the Ediacaran organisms, paleontologist Peter Ward explains that “later study cast doubt on the affinity between these ancient remains preserved in sandstones [the Australian Ediacaran] and living creatures of today” (that is, animals representing phyla that first arose in the Cambrian).26 As Nature recently noted, if the Ediacaran fauna “were animals, they bore little or no resemblance to any other creatures, either fossil or extant.”27 [25. Knoll and Carroll, “Early Animal Evolution,” 2129. 26. Ward, On Methuselah’s Trail, 36. 27. “Life on Land,” 153–54. Recently, Gregory Retallack has published a controversial hypothesis about the Ediacaran fauna. Retallack has studied the depositional environments of key Ediacaran fossils such as Dickinsonia. He has concluded that these organisms should not be classified as marine animals, because they were deposited on land. According to Retallack, the rocks that bore these Ediacaran fossils “have a variety of features that are more like the biological soil crusts of desert and tundra than the parallel wrinkled, and undulose hydrated microbial mats of intertidal flats and shallow seas.” [Retallack, “Ediacaran Life on Land,” 89.] Retallack’s thesis has received a cool reception from other Ediacaran experts, however. They have not only questioned his analysis of ancient sediments but pointed out that the Ediacaran forms that he analyzed from Australia are also preserved in clearly marine sediments (from Newfoundland, for example) and that it is unlikely that the same organisms would live both on land and in the sea. [Callow, Brasier, Mcilroy, “Discussion: ‘Were the Ediacaran siliciclastics of South Australia coastal or deep marine?’’’ 1–3.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1489-1496). HarperCollins. Kindle Edition.]
* Graham Budd, a British paleontologist who works at Uppsala University in Sweden, and others, have disputed these associations. Budd and geologist colleague Sören Jensen argue that many alleged trace fossils actually show evidence of inorganic origin: “There are numerous reports of older trace fossils, but most can be immediately shown to represent either inorganic sedimentary structures or metaphytes [land plants], or alternatively they have been misdated.”31 Still others have suggested that surface tracks and trails could have been left by mobile single-celled organisms, including a known form of a giant deep-sea protist that leaves bilaterian-like impressions. As one paper explains, “Some such traces date back to 1.5 billion to 1.8 billion years ago, which outdates even the boldest claims of the time of origin of animal multi-cellularity and forces researchers to contemplate the possibility of an inorganic or bacterial origin.”32 [31. Budd and Jensen, “A Critical Reappraisal of the Fossil Record of the Bilaterian Phyla,” 270. 32. See Matz et al., “Giant Deep-Sea Protist Produces Bilaterian-like Traces.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1506-1513). HarperCollins. Kindle Edition.]
* Moreover, even assuming, as some evolutionary biologists do,34 that later Cambrian animals had a sponge-like Precambrian ancestor, the gap in complexity as measured by the number of cell types alone, to say nothing of the specific anatomical structures and distinct modes of body plan organization that are present in later animals but not in sponges, leaves a massive discontinuity in the fossil record that requires explanation (much like the morphological gap between Spriggina and actual arthropods). [34. Sperling, Pisani, and Peterson, “Poriferan paraphyly and Its Implications for Precambrian Palaeobiology”; Erwin and Valentine, The Cambrian Explosion, 80.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1525-1529). HarperCollins. Kindle Edition.]
* Thus, the Ediacaran biota attest to a separate sudden increase in biological complexity within a short window of geological time (about 15 million years), following roughly 3 billion years in which only single-celled organisms inhabited the earth.35 This leap in complexity, in a relatively short span of geological time, may well exceed the explanatory resources of natural selection working on random mutations. [Conway Morris, “Evolution: Bringing Molecules into the Fold,” 5.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1537-1540). HarperCollins. Kindle Edition.]
* The Ediacaran fossils therefore do not solve the problem of the sudden increase in biological form and complexity during the Cambrian. Instead, they represent an earlier, if less dramatic, manifestation of the same kind of problem. To biology’s “big bang,”36 the Ediacaran biota add a significant “pow.” As paleobiologist Kevin Peterson, of Dartmouth College, and his colleagues note, these fauna represent “an apparent quantum leap in ecological complexity as compared with the ‘boring billions’ [of years] that characterize Earth before the Ediacaran,” even if these organisms are “still relatively simple when compared with the Cambrian,” which they characterize as another “quantum leap in organismal and ecological complexity.”37 [36. McMenamin and McMenamin, The Emergence of Animals, 167–68. 37. Peterson et al., “The Ediacaran Emergence of Bilaterians.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1541-1547). HarperCollins. Kindle Edition.]
* Like classical Darwinism, the neo-Darwinian mechanism requires great stretches of time to produce novel biological form and structure. Yet, current studies in geochronology suggest that only 40 to 50 million years elapsed between the beginning of the Ediacaran radiation (570–565 million years ago) and the end of the Cambrian explosion (525–520 million years ago).40 To anyone unfamiliar with the equations of population genetics by which neo-Darwinian evolutionary biologists estimate how much morphological change is likely to occur in a given period of time, 40 to 50 million years may seem like an eternity. But empirically derived estimates of the rate at which mutations accumulate imply that 40 to 50 million years does not constitute anything like enough time to build the necessary anatomical novelties that arise in the Cambrian and Ediacaran periods. [Bowring et al., “Calibrating Rates of Early Cambrian Evolution,” 1293–98; Erwin et al., “The Cambrian Conundrum: Early Divergence and Later Ecological Success in the Early History of Animals,” 1091–97.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1555-1562). HarperCollins. Kindle Edition.]
* More recently, in 2012, Bengtson and three other colleagues published another paper sharply critical of the view that Vernanimalcula represents an ancestor of the bilaterian animals—or even an animal. They show that the “structures key to animal identity are effects of mineralization that do not represent biological tissues.” For this reason they conclude: “There is no evidential basis for interpreting Vernanimalcula as an animal, let alone a bilaterian.”50 [Bengtson et al., “A Merciful Death for the ‘Earliest Bilaterian,’ Vernanimalcula,” 421.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1627-1630). HarperCollins. Kindle Edition.]
* Though the paper was titled “A Merciful Death for the ‘Earliest Bilaterian,’ Vernanimalcula,” the authors were anything but merciful in wielding their arguments. Their article upbraided David J. Bottjer, the main paleontologist who has promoted the interpretation of Vernanimalcula as a bilaterian ancestor, for seeing what he wanted to see and disregarding the clear evidence of nonbiological mineralization. In a 2005 Scientific American article, Bottjer interpreted Vernanimalcula as the “oldest fossil animal with a bilaterian body plan yet discovered.” In that article, Bottjer claimed that Vernanimalcula confirmed the “suspicion that complex animals have a much deeper root in time” and “that the Cambrian was less of an explosion and more of a flowering of animal life.”51 [Bottjer, “The Early Evolution of Animals,” 47.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1631-1637). HarperCollins. Kindle Edition.]
* After unequivocally rejecting Bottjer’s interpretation on the basis of their geochemical analysis, Bengtson and his coauthors rebuked Bottjer in rather personal terms: It is likely that the fossils referred to [as] Vernanimalcula were interpreted as bilaterians because this was . . . the explicit quarry of its authors. If you know from the beginning not only what you are looking for, but what you are going to find, you will find it, whether or not it exists. As Richard Feynman (1974) famously remarked: “The first principle is that you must not fool yourself—and you are the easiest person to fool.” . . . Once you have fooled yourself you will fool other scientists.52 [Bengtson et al., “A Merciful Death for the ‘Earliest Bilaterian,’ Vernanimalcula,” 426.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1637-1643). HarperCollins. Kindle Edition.]
* Vernanimalcula—even if we take them as representing a common ancestor of many bilaterians—document little of the Darwinian story of the history of animal life. Hugely significant gaps in the fossil record would still remain, because the Precambrian fossil record simply does not document the gradual emergence of the crucial distinguishing characteristics of the Cambrian animals. The important anatomical novelties that define the individual Cambrian phyla as well as their first clear representatives arise as suddenly as ever. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1681-1684). HarperCollins. Kindle Edition.]
* This paradox is well known to paleontologists who work on the Cambrian radiation. Charles Marshall and James Valentine, for instance, describe the difficulty of attempting to characterize an “undiagnostic” group, by which they mean a possible ancestral “stem” group that lacks the specialized characteristics of its presumptive evolutionary progeny. They write: When trying to unravel the origins of the animal phyla . . . the hardest to examine is the phase between the actual cladogenic origin of a phylum and the time that it acquired its first phylum-specific characteristic(s). Even if we have fossils from this phase in a phylum’s history, we will not be able to prove their kinships at the level of phyla.54 [Marshall and Valentine, “The Importance of Preadapted Genomes in the Origin of the Animal Bodyplans and the Cambrian Explosion,” 1190, emphasis added.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1691-1697). HarperCollins. Kindle Edition.]
* As Graham Budd and Sören Jensen state, “The known [Precambrian/Cambrian] fossil record has not been misunderstood, and there are no convincing bilaterian candidates known from the fossil record until just before the beginning of the Cambrian (c. 543 Ma), even though there are plentiful sediments older than this that should reveal them.”55 Thus they conclude, “The expected Darwinian pattern of a deep fossil history of the bilaterians, potentially showing their gradual development, stretching hundreds of millions of years into the Precambrian, has singularly failed to materialize.”56 [55. Budd and Jensen, “The Limitations of the Fossil Record and the Dating of the Origin of the Bilateria,” 183. 56. Budd and Jensen, “The Limitations of the Fossil Record and the Dating of the Origin of the Bilateria,” 168.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1713-1718). HarperCollins. Kindle Edition.]
* One part of the account of what he saw while touring the museum’s own display about the Cambrian explosion is worth quoting at length: [The display] seemed factually accurate for the most part, emphasizing (among other things) that many of the Cambrian explosion fossils were soft-bodied—which puts the lie to the common explanation that their precursors are absent from the fossil record because they lacked hard parts. The exhibit also made it clear that the Ediacaran fossils went extinct at the end of the pre-Cambrian, so (with a few possible exceptions) they could not have been ancestral to the Cambrian phyla. One particular panel in the exhibit caught my attention. It showed over a dozen of the Cambrian phyla at the top of a branching tree with a single trunk, but none of the branch points corresponded to a real living thing. Instead, the branch points were artificial technical categories such as “Ecdysozoa,” “Lophotrochozoa,” “Deuterostomia,” and “Bilateria.” The artificiality of the branch points emphasized that the branching-tree pattern imposed on the fossil evidence was itself an artificial construct. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1726-1734). HarperCollins. Kindle Edition.]

**5 The Genes Tell the Story?**

* Many evolutionary biologists have commented on the forensic nature of their work. Here’s how Richard Dawkins puts it: “I have used the metaphor of a detective, coming on the scene of the crime after it is all over and reconstructing from the surviving clues what must have happened.”1 [Dawkins, The Greatest Show on Earth, 111.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1751-1753). HarperCollins. Kindle Edition.]
* In reconstructing the evolutionary history of life, most evolutionary biologists today emphasize the importance of homology. They assume that similarities in anatomy and in the sequences of information-bearing biomacromolecules such as DNA, RNA, and protein point strongly to a common ancestor.2 [According to Zvelebil and Baum, “The key assumption made when constructing a phylogenetic tree from a set of sequences is that they are all derived from a single ancestral sequence, i.e., they are homologous” (Understanding Bioinformatics, 239). Lecointre and Le Guyader note: “Cladistics can run into difficulties in its application because not all character states are necessarily homologous. Certain resemblances are convergent—that is, the result of independent evolution. We cannot always detect these convergences immediately, and their presence may contradict other similarities, ‘true homologies’ yet to be recognized. Thus, we are obliged to assume at first that, for each character, similar states are homologous, despite knowing that there may be convergence among them” (The Tree of Life, 16).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1770-1772). HarperCollins. Kindle Edition.]
* As evolutionary biologist Jerry Coyne, of the University of Chicago, notes, “Now we have a powerful, new, and independent way to establish ancestry: we can look directly at the genes themselves. By sequencing the DNA of various species and measuring how similar these sequences are, we can reconstruct their evolutionary relationships.”3 [Coyne, Why Evolution Is True, 10.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1778-1781). HarperCollins. Kindle Edition.]
* Genetic comparisons enable evolutionary biologists to estimate the number of mutational changes since divergence, and dating of the strata containing presumed fossil ancestors tells how long ago the divergence occurred. Assuming that different lineages evolve at the same rate,6 together the two pieces of information enable evolutionary biologists to calculate a baseline mutation rate. They can then use that rate to determine how long ago some other pair of animals diverged from each other on the evolutionary tree.7 [6. “The molecular clock . . . is the assumption that lineages have evolved at equal rates” (Felsenstein, Inferring Phylogenies, 118). 7. Smith and Peterson, “Dating the Time and Origin of Major Clades,” 72.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1819-1823). HarperCollins. Kindle Edition.]
* From an orthodox Darwinian point of view, the conclusions of these studies seem almost unavoidable since (1) the neo-Darwinian mechanism requires vast amounts of time to produce anatomical novelty and (2) such phylogenetic analyses assume that all the animal forms descended from a common ancestor. Many evolutionary biologists claim that clues long hidden in DNA now confirm these Darwinian axioms and, consequently, the existence of an extremely ancient, Precambrian ancestor of the Cambrian animals. As Andrew Knoll, a Harvard paleontologist, states, “The idea that animals should have originated much earlier than we see them in the fossil record is almost inescapable.”18 [Quoted in Hotz, “Finding Turns Back Clock for Earth’s First Animals,” A1, A14.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1853-1858). HarperCollins. Kindle Edition.]
* Nevertheless, there is now good reason to doubt this allegedly overwhelming genetic evidence. In the idiom of our forensic metaphor, other material witnesses (fossils) have already come forward to testify, the testimony of the genes (and other key indicators of biological history) is grossly inconsistent, and that genetic testimony has come to us through a translator, who is shaping the way the jury perceives the evidence. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1859-1862). HarperCollins. Kindle Edition.]
* A second crucial assumption behind the deep-divergence hypothesis is the idea of the common descent of all the animal forms—i.e., that all the Cambrian animals evolved from a common Precambrian ancestor. As the textbook Understanding Bioinformatics admits, “The key assumption made when constructing a phylogenetic tree from a set of sequences is that they are all derived from a single ancestral sequence, i.e., they are homologous.”41 Or as the Harvard University Press textbook The Tree of Life states, “We are obliged to assume at first that, for each character, similar states are homologous,” whereby “homologous” the text means characters are similar because they share a common ancestor.42 [41. Zvelebil and Baum, Understanding Bioinformatics, 239. 42. Lecointre and Le Guyader, The Tree of Life, 16.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1967-1973). HarperCollins. Kindle Edition.]
* Instead, these studies assume the existence of such ancestors, and then merely attempt, given that assumption, to determine how long ago such ancestors might have lived. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 1981-1982). HarperCollins. Kindle Edition.]

**6 The Animal Tree of Life**

* For many biologists, the iconic image of Darwin’s tree of life represents perhaps the single best distillation of what the science of evolutionary biology has to teach, namely the “fact of evolution,”3 apart from which “nothing in biology makes sense.”4 [3. Ruse, Darwinism Defended, 58. 4. Dobzhansky, “Nothing in Biology Makes Sense Except in the Light of Evolution,” 125.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2038-2041). HarperCollins. Kindle Edition.]
* As Richard Dawkins asserts, “when we look comparatively at . . . genetic sequences in all these different creatures—we find the same kind of hierarchical tree of resemblance. We find the same family tree—albeit much more thoroughly and convincingly laid out—as we did with . . . the whole pattern of anatomical resemblances throughout all the living kingdoms.”5 [Dawkins, The Greatest Show on Earth, 315.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2049-2052). HarperCollins. Kindle Edition.]
* Likewise, Jerry Coyne argues that gene sequences independently confirm the same set of evolutionary relationships—the same basic tree—established from the analysis of anatomy.6 Oxford University chemist Peter Atkins is even more emphatic: “There is not a single instance of the molecular traces of change being inconsistent with our observations of whole organisms.”7 [6. As Coyne has asserted, “both the visible traits of organisms and their DNA sequences usually give the same information about evolutionary relationships” (Why Evolution Is True, 10). 7. Atkins, Galileo’s Finger, 16.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2052-2056). HarperCollins. Kindle Edition.]
* As Coyne explains, “It stands to reason that if the history of life forms a tree, with all species originating from a single trunk, then one can find a common origin for every pair of twigs (existing species) by tracing each twig back through its branches until they intersect at the branch they have in common. This node, as we’ve seen, is their common ancestor.”8 [Coyne, Why Evolution Is True, 7.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2067-2070). HarperCollins. Kindle Edition.]
* Investigators employ these methods even in the absence of corroborating fossil evidence. In his textbook on fossils and evolution, following a full-page depiction of the discontinuous appearance of the Cambrian animals in the fossil record, Occidental College geologist Donald Prothero explains, “If the fossil record is poor in one particular group, we look to other sources of data.” He concludes that two such sources of data, anatomical and molecular data, now “converge on a common answer”—one “that is almost certainly ‘the truth’ (as much as we can use that term in science).”10 [Prothero, Evolution, 140.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2085-2089). HarperCollins. Kindle Edition.]
* History happened once. And if Richard Dawkins is correct that “there is, after all, one true tree of life, the unique pattern of evolutionary branchings that actually happened,”11 [Dawkins, A Devil’s Chaplain: Reflections on Hope, Lies, Science, and Love, 112.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2094-2095). HarperCollins. Kindle Edition.]
* A widely used textbook on phylogenetic methods explains this: “The fact that there is only one true tree . . . provides the basis for testing alternative hypotheses. If two hypotheses are generated for the same group of species, then we can conclude that at least one of these hypotheses is false. Of course, it is possible that both are false and some other tree is true.”12 [Wiley and Lieberman, Phylogenetics, 6.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2098-2101). HarperCollins. Kindle Edition.]
* A 2009 paper in Trends in Ecology and Evolution notes that “evolutionary trees from different genes often have conflicting branching patterns.”13 Likewise, a 2012 paper in Biological Reviews acknowledges that “phylogenetic conflict is common, and frequently the norm rather than the exception.”14 [13. Degnan and Rosenberg, “Gene Tree Discordance, Phylogenetic Inference and the Multispecies Coalescent,” 332. 14. Dávalos et al., “Understanding Phylogenetic Incongruence: Lessons from Phyllostomid Bats,” 993.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2133-2136). HarperCollins. Kindle Edition.]
* The New Scientist article cited a study by Michael Syvanen, a biologist at the University of California at Davis, who studied the relationships among several phyla that first arose in the Cambrian.15 Syvanen’s study compared two thousand genes in six animals spanning phyla as diverse as chordates, echinoderms, arthropods, and nematodes. His analysis yielded no consistent tree-like pattern. As the New Scientist reported, “In theory, he should have been able to use the gene sequences to construct an evolutionary tree showing the relationships between the six animals. He failed. The problem was that different genes told contradictory evolutionary stories.” Syvanen himself summarized the results in the bluntest of terms: “We’ve just annihilated the tree of life. It’s not a tree anymore, it’s a different topology [pattern of history] entirely. What would Darwin have made of that?”16 [Quoted in Lawton, “Why Darwin Was Wrong About the Tree of Life,” 39.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2140-2147). HarperCollins. Kindle Edition.]
* Vanderbilt University molecular systematist Antonis Rokas is a leader among biologists using molecular data to study animal phylogenetic relationships. Nevertheless, he concedes that a century and a half after The Origin of Species, “a complete and accurate tree of life remains an elusive goal.”17 [Rokas, “Spotlight: Drawing the Tree of Life.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2148-2151). HarperCollins. Kindle Edition.]
* In 2005, during the course of an authoritative study he eventually copublished in Science, Rokas was confronted with this stark reality. The study had sought to determine the evolutionary history of the animal phyla by analyzing fifty genes across seventeen taxa. He hoped that a single dominant phylogenetic tree would emerge. Rokas and his team reported that “a 50-gene data matrix does not resolve relationships among most metazoan phyla” because it generated numerous conflicting phylogenies and historical signals. Their conclusion was candid: “Despite the amount of data and breadth of taxa analyzed, relationships among most metazoan phyla remained unresolved.”18 [Rokas, Krüger, and Carroll. “Animal Evolution and the Molecular Signature of Radiations Compressed in Time,” 1933–34.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2151-2156). HarperCollins. Kindle Edition.]
* In a paper published the following year, Rokas and University of Wisconsin at Madison biologist Sean B. Carroll went so far as to assert that “certain critical parts of the TOL [tree of life] may be difficult to resolve, regardless of the quantity of conventional data available.”19 This problem applies specifically to the relationships of the animal phyla, where “[m]any recent studies have reported support for many alternative conflicting phylogenies.”20 Investigators studying the animal tree found that “a large fraction of single genes produce phylogenies of poor quality” such that in one case, a study “omitted 35% of single genes from their data matrix, because those genes produced phylogenies at odds with conventional wisdom.”21 [19. Rokas and Carroll, “Bushes in the Tree of Life,” 1899–1904. 20. Rokas and Carroll, “Bushes in the Tree of Life,” 1899–1904 (internal citations omitted). 21. Rokas and Carroll, “Bushes in the Tree of Life,” 1899–1904 (internal citations omitted).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2157-2164). HarperCollins. Kindle Edition.]
* Their article brings the discussion of the Cambrian explosion full circle from an attempt to use genes to compensate for the absence of fossil evidence to the acknowledgment that genes do not convey any clear signal about the evolutionary relationships of the phyla first preserved by fossils in the Cambrian. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2170-2172). HarperCollins. Kindle Edition.]
* Rokas and Carroll conclude from specifically genetic evidence that the phyla must have diverged rapidly. As they put it in another paper, “Inferences from these two independent lines of evidence (molecules and fossils) support a view of the origin of Metazoa as a radiation compressed in time.”23 Thus, the inability to reconstruct the evolutionary history of the animal phyla from the molecular data not only fails to establish a Precambrian pattern of descent; it ironically also reaffirms the extreme rapidity of the origin of the Cambrian animal forms. [Rokas, Krüger, and Carroll, “Animal Evolution and the Molecular Signature of Radiations Compressed in Time,” 1935.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2174-2179). HarperCollins. Kindle Edition.]
* In 1965, chemist Linus Pauling and biologist Emile Zuckerkandl, often hailed as the fathers of the molecular-clock concept, proposed a rigorous way to confirm evolutionary phylogenies. They suggested that if studies of comparative anatomy and DNA sequences generated similar phylogenetic trees, then “the best available single proof of the reality of macroevolution would be furnished.”24 As they went on to explain, “only the theory of evolution . . . could reasonably account for such a congruence between lines of evidence obtained independently.”25 [24. Zuckerkandl and Pauling, “Evolutionary Divergence and Convergence in Proteins,” 101. 25. Zuckerkandl and Pauling, “Evolutionary Divergence and Convergence in Proteins,” 101.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2180-2184). HarperCollins. Kindle Edition.]
* The Nature paper explained how unexpected this grouping of arthropods and nematodes was: “Considering the greatly differing morphologies, embryological features, and life histories of the molting animals, it was initially surprising that the ribosomal RNA tree should group them together.”32 [Aguinaldo et al., “Evidence for a Clade of Nematodes, Arthropods and Other Moulting Animals,” 492.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2210-2213). HarperCollins. Kindle Edition.]
* As a major review article in Nature in 2000 observes, “Evolutionary trees constructed by studying biological molecules often don’t resemble those drawn up from morphology.”43 And the problem isn’t getting better over time. A 2012 paper admits that larger datasets are not solving this problem: “Incongruence between phylogenies derived from morphological versus molecular analyses and between trees based on different subsets of molecular sequences has become pervasive as datasets have expanded rapidly in both characters and species.”44 [43. Gura, “Bones, Molecules . . . or Both?” 230. A 2004 paper in the Annual Review of Ecology and Systematics puts it this way: “Molecular tools have profoundly rearranged our understanding of metazoan phylogeny.” (Halanych, “The New View of Animal Phylogeny,” 229.) 44. Dávalos et al., “Understanding Phylogenetic Incongruence: Lessons from Phyllostomid Bats,” 993.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2250-2255). HarperCollins. Kindle Edition.]
* As Jeffrey H. Schwartz and Bruno Maresca put it in the journal Biological Theory: “This assumption derives from interpreting molecular similarity (or dissimilarity) between taxa in the context of a Darwinian model of continual and gradual change. Review of the history of molecular systematics and its claims in the context of molecular biology reveals that there is no basis for the ‘molecular assumption.’ ”46 [Schwartz and Maresca, “Do Molecular Clocks Run at All?” 357.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2258-2261). HarperCollins. Kindle Edition.]
* After completing a survey of many such difficulties, University of St. Andrews zoologist Pat Willmer and Oxford University zoologist Peter Holland, experts on invertebrate anatomy, draw this conclusion: “Taken together, modern re-evaluations of traditional evidence support different and mutually exclusive subsets of [phylogenetic] relations.”54 They go on to observe that “patterns of symmetry, the number of germ layers in the body, the nature of the body cavity, and the presence or type of serial repetition [segmentation] have all been used to infer common ancestry.” But, they explain, the phylogenetic story these characteristics tell is “now either unacceptable or at least controversial” because the data are, at best, inconsistent.55 [54. Willmer and Holland, “Modern Approaches to Metazoan Relationships,” 691, emphasis in original. 55. Willmer and Holland, “Modern Approaches to Metazoan Relationships,” 690.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2332-2339). HarperCollins. Kindle Edition.]
* The historical record of ongoing uncertainty about the animal tree of life since 1859 confirms, as one respected textbook on invertebrate animals explains, that “phylogenetic analysis at the level of the phyla is highly problematical.”56 As a result, “the study of higher level animal phylogeny has yielded an expansive literature but relatively little detailed consensus. . . . In point of fact, there exists no such thing as ‘the traditional textbook phylogeny.’ A diversity of different schemes can be found.”57 [56. Brusca and Brusca, Invertebrates, 120; 2nd ed., 115. 57. Jenner, “Evolution of Animal Body Plans,” 209.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2339-2344). HarperCollins. Kindle Edition.]

**7 Punk Eek!**

* One day while standing in a Michigan Laundromat, following months of collecting trilobite fossils for his Ph.D. research, Eldredge happened to reach into his pocket. He removed one of the fossils he had been collecting, a specimen of a trilobite species called Phacops rana. Initially, as he examined the specimen, he felt “depressed.” The fossil closely resembled many others that he had found across layers of strata during his fieldwork in the Midwest. His trilobites showed no evidence of gradual change, as classical neo-Darwinism had taught him to expect.1 [Lecture Notes, Paul Nelson, University of Pittsburgh, 9-28-83.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2410-2415). HarperCollins. Kindle Edition.]
* As Eldredge explained in a lecture at the University of Pittsburgh in 1983, he then experienced a kind of scientific epiphany. He realized that the “absence of change itself” was “a very interesting pattern.” Or as he later put it, “Stasis is data.”2 [Gould and Eldredge, “Punctuated Equilibrium: The Tempo and Mode of Evolution Reconsidered,” 147.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2415-2417). HarperCollins. Kindle Edition.]
* “Stasis” is the term that Eldredge and his scientific collaborator, Stephen Jay Gould, later gave to the pattern in which most species, “during their geological history, either do not change in any appreciable way or else they fluctuate mildly in morphology, with no apparent direction.”3 [Gould and Eldredge, “Punctuated Equilibrium: The Tempo and Mode of Evolution Reconsidered,” 115.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2418-2420). HarperCollins. Kindle Edition.]
* As Eldredge examined that solitary trilobite, he realized that he had been observing evidence of stasis for some time—however much he might have wanted it otherwise. As he explained, “Stasis . . . was by far the most important pattern to emerge from all my staring at Phacops specimens.” He continued, “Traditionally seen as an artifact of a poor record, as the inability of paleontologists to find what evolutionary biologists going back to Darwin had told them must be there, stasis was, as Stephen Jay Gould put it, ‘paleontology’s trade secret’—an embarrassing one at that.”4 [Eldredge, The Pattern of Evolution, 21.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2420-2425). HarperCollins. Kindle Edition.]
* As historian of science David Sepkoski explains, “Gould and Eldredge proposed a radical revision of this standard [neo-Darwinian] narrative. They argued that the pattern of evolutionary history really was composed of fits and starts, consisting of long periods of evolutionary stasis (or ‘equilibrium’) ‘punctuated’ by shorter periods of rapid speciation.”8 [Sepkoski, “ ‘Radical’ or ‘Conservative’?” 304.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2448-2451). HarperCollins. Kindle Edition.]
* In Gould and Eldredge’s view, allopatric speciation helped to explain how evolution could occur in larger, more discrete jumps than Darwinian gradualism predicts (see Fig. 7.2). As allopatric speciation occurs, it can generate what Gould and Eldredge conceived as sibling or offspring species. They thought that the processes that drive these speciation events occur relatively quickly in smaller populations, thus helping to explain the sudden jumps in the fossil record. As they put it: “Small numbers and rapid evolution virtually preclude the preservation of speciation events in the fossil record.”14 As they envisioned the evolutionary process working, the branches on the tree of life would split off so abruptly that they would appear as virtually “horizontal” lines, producing sudden discontinuities in the fossil record and therefore fewer fossilized intermediates. Eldredge and Gould explained it this way: “The theory of allopatric (or geographic) speciation suggests a different interpretation of paleontological data. If new species arise very rapidly in small, peripherally isolated populations, then the expectation of insensibly graded fossils is a chimera. A new species does not evolve in the area of its ancestors; it does not arise from the slow transformation of all its forbears.” Thus, they concluded, “Many breaks in the fossil record are real.”15 [14. Gould and Eldredge, “Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered,” 117. 15. Eldredge and Gould, “Punctuated Equilibria: An Alternative to Phyletic Gradualism,” 84.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2489-2500). HarperCollins. Kindle Edition.]
* As Gould himself explained: “I propose, as the central proposition of macroevolution, that species play the same role of fundamental individual that organisms assume in microevolution. Species represent the basic units in theories and mechanisms of macroevolutionary change.”17 Since natural selection then would act upon large differences in overall biological form—differences between whole species as opposed to individuals within species—evolutionary change would take place in bigger, more discrete jumps.18 [17. Gould, The Structure of Evolutionary Theory, 703. As Gould and Eldredge also emphasized elsewhere: “The main insight for revision [of evolutionary theory] holds that all substantial evolutionary change must be reconceived as higher-level sorting based on differential success of certain kinds of stable species, rather than as progressive transformation within lineages [i.e., species]” (“Punctuated Equilibrium Comes of Age,” 224). 18. If natural selection acts upon a larger unit of selection, the species rather than the individual, it followed logically that evolution would occur in larger more discrete jumps. Nevertheless, Gould and Eldredge rarely emphasized this implication of their conception of species selection explicitly, instead highlighting allopatric speciation as the main reason for fossil discontinuity. Stanley did, however, often draw a connection between the activity of species selection as a mechanism of evolutionary change and fossil discontinuity. As he noted, “The validity of the species as the fundamental unit of large-scale evolution depends upon the presence of discontinuities between many species in the tree of life” (Macroevolution, 3).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2509-2513). HarperCollins. Kindle Edition.]
* Many critics of punctuated equilibrium have noted this problem. As Richard Dawkins wrote in 1986: “What I mainly want a theory of evolution to do is explain complex, well-designed mechanisms like hearts, hands, eyes and echolocation. Nobody, not even the most ardent species selectionist, thinks that species selection can do this.”31 Or as paleontologist Jeffrey Levinton argued in 1988, “It is inconceivable how selection among species can produce the evolution of detailed morphological structures. . . . Species selection did not form an eye.”32 [31. Dawkins, The Blind Watchmaker, 265. 32. Levinton, Genetics, Paleontology, and Macroevolution, 208.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2632-2637). HarperCollins. Kindle Edition.]
* Gould resorted to the alleged power of the neo-Darwinian mechanism. As he wrote in his magisterial tome The Structure of Evolutionary Theory, published in 2002, the year of his death: “I do not deny either the wonder, or the powerful importance, of organized adaptive complexity.” He went on to concede, “I recognize that we know no mechanism for the origin of such organismal features other than conventional natural selection at the organismic level.”33 [Gould, The Structure of Evolutionary Theory, 710.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2638-2641). HarperCollins. Kindle Edition.]
* As the evolutionary biologists Brian Charlesworth, Russell Lande, and Montgomery Slatkin have concluded, “genetic mechanisms that have been proposed [by proponents of punctuated equilibrium] to explain the abrupt appearance and prolonged stasis of many species are conspicuously lacking in empirical support.”34 [Charlesworth, Lande, and Slatkin, “A Neo-Darwinian Commentary on Macroevolution,” 493. As David Jablonski concluded in 2008, “The extent and efficacy of the specific processes [of species selection] remain poorly known” (“Species Selection,” 501).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2643-2646). HarperCollins. Kindle Edition.]
* From 1972 to 1980, Eldredge and Gould presented a series of provocative scientific papers that portrayed punctuated equilibrium as a bold, and even revolutionary, alternative theory of macroevolution. Indeed, Gould himself referred to it explicitly as “a speciational theory of macroevolution.”36 [Gould, The Structure of Evolutionary Theory, 55.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2655-2658). HarperCollins. Kindle Edition.]
* In their second main paper, published in 1977, Gould and Eldredge made explicit their intention to position their theory as a “radical”37 challenge to neo-Darwinian gradualism and to replace it with a completely different understanding of the mode and mechanism of evolutionary change. Sepkoski notes that in this 1977 article “the authors were more explicit about the exact nature of the conceptual reconfiguration their theory brought to macroevolution.”38 In particular, he argues that Gould and Eldredge “extended their model to propose a new and ‘general philosophy of change’ in the natural world.”39 Gould was no less radical in a widely cited 1980 paper in the journal Paleobiology in which he offered punctuated equilibrium as “a new and general theory” of evolution. There he also famously declared the synthetic theory of neo-Darwinism “effectively dead, despite its persistence as textbook orthodoxy.”40 [37. Gould and Eldredge, “Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered,” 134. 38. Sepkoski, “ ‘Radical’ or ‘Conservative’?” 307. 39. Sepkoski, “ ‘Radical’ or ‘Conservative’?” 7. 40. Gould, “Is a New and General Theory of Evolution Emerging?” 120. Because his colleagues understood Gould to be offering a theory of macroevolution, many of Gould’s scientific colleagues at the time thought of him, as Sepkoski notes, as an “ardent proponent of a radical (and perhaps misguided) view of evolutionary change” (“ ‘Radical’ or ‘Conservative’?” 302).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2658-2667). HarperCollins. Kindle Edition.]
* No wonder, then, that leading Cambrian paleontologists such as James Valentine and Douglas Erwin concluded in 1987, that “neither of the contending theories of evolutionary change at the species level, phyletic gradualism or punctuated equilibrium, seem applicable to [explaining] the origin of new body plans.”42 [Valentine and Erwin, “Interpreting Great Developmental Experiments,” 96.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2682-2685). HarperCollins. Kindle Edition.]

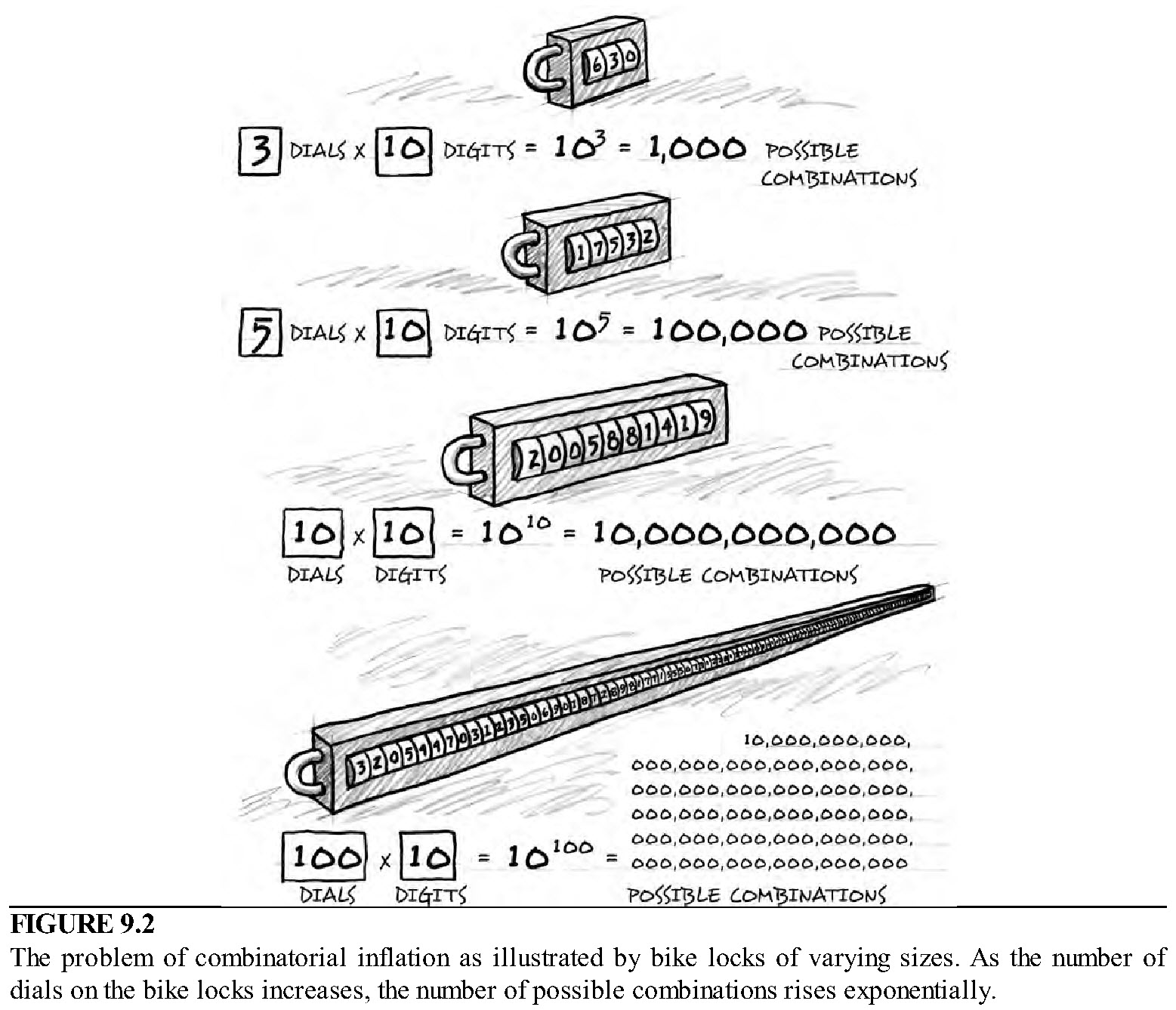
**Part Two: How to Build an Animal**

**8 The Cambrian Information Explosion**

* When I was a college professor, I used to ask my students a question: “If you want your computer to acquire a new function or capability, what do you have to give it?” Typically, I would hear a smattering of similar answers from the class: “code,” “instructions,” “software,” “information.” Of course, all these are correct. And thanks to discoveries in modern biology, we now know that something similar is true of life: to build a new form of life from a simpler preexisting form requires new information. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2706-2709). HarperCollins. Kindle Edition.]
* As Darwin envisioned the process, natural selection can accomplish nothing without a steady supply of variation as a source of new biological traits, forms, and structures. Only after useful new variations arise can natural selection sift them from the chaff of unhelpful variations. If, however, the amount of variation available to natural selection is limited, then natural selection will encounter limits on how much new biological form and structure it can build. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2716-2719). HarperCollins. Kindle Edition.]
* In fact, between 1870 and 1920 classical Darwinism entered a period of eclipse, because many scientists thought that it could not explain the origin and transmission of new heritable variation.1 [Bowler, Theories of Human Evolution, 44–50.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2721-2723). HarperCollins. Kindle Edition.]
* At the celebration, Julian Huxley, the grandson of T. H. Huxley, summarized this optimism in a grand proclamation: Future historians will perhaps take this Centennial Week as epitomizing an important critical period in the history of this earth of ours—the period when the process of evolution, in the person of inquiring man, began to truly be conscious of itself. . . . This is one of the first public occasions on which it has been frankly faced that all aspects of reality are subject to evolution, from atoms and stars to fish and flowers, from fish and flowers to human societies and values—indeed, that all reality is a single process of evolution . . .7 [Huxley, “The Evolutionary Vision,” 249, 253.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2773-2779). HarperCollins. Kindle Edition.]
* In a television broadcast leading up to the Centennial celebration, Huxley captured the optimistic mood more succinctly: “Darwinism has come of age, so to speak. We are no longer having to bother about establishing the fact of evolution.”8 [Huxley, quoted in “ ‘At Random’: A Television Preview,” 45.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2779-2781). HarperCollins. Kindle Edition.]
* James Valentine has noted that one useful way of comparing degrees of complexity is to assess the number of cell types in different organisms.11 [Valentine, “Late Precambrian Bilaterians.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2815-2816). HarperCollins. Kindle Edition.]
* These new cell types, in turn, require many new and specialized proteins. An epithelial cell lining a gut or intestine, for example, secretes a specific digestive enzyme. This enzyme requires structural proteins to modify its shape and regulatory enzymes to control the secretion of the digestive enzyme itself. Thus, building novel cell types typically requires building novel proteins, which requires assembly instructions for building proteins—that is, genetic information. Thus, an increase in the number of cell types implies an increase in the amount of genetic information. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2820-2823). HarperCollins. Kindle Edition.]
* For over 3 billion years, the living world included little more than one-celled organisms such as bacteria and algae.12 Then, beginning in the late Ediacaran period (about 555–570 million years ago), the first complex multicellular organisms appeared in the rock strata, including sponges and the peculiar Ediacaran biota discussed in Chapter 4.13 This represented a large increase in complexity. Studies of modern animals suggest that the sponges that appeared in the late Precambrian, for example, probably required about ten cell types.14 [12. Brocks et al., “Archean Molecular Fossils and the Early Rise of Eukaryotes.” 13. Grotzinger et al., “Biostratigraphic and Geochronologic Constraints on Early Animal Evolution.” 14. Ruppert et al, Invertebrate Zoology, 82.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2827-2832). HarperCollins. Kindle Edition.]
* Then 40 million years later, the Cambrian explosion occurred.15 Suddenly the oceans swarmed with animals such as trilobites and anomalocaridids that probably required fifty or more cell types—an even greater jump in complexity. Moreover, as Valentine notes, measuring complexity differences by measuring differences in the number of cell types probably “greatly underestimate[s] the complexity differentials between bodyplans.”16 [15. Bowring et al., “Calibrating Rates of Early Cambrian Evolution.” 16. Valentine, Origin of the Phyla, 73.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2832-2836). HarperCollins. Kindle Edition.]
* One way to estimate the amount of new genetic information that appeared with the Cambrian animals is to measure the size of the genomes of modern representatives of the Cambrian groups and compare that to the amount of information in simpler forms of life. Molecular biologists have estimated that a minimally complex single-celled organism would require between 318,000 and 562,000 base pairs of DNA to produce the proteins necessary to maintain life.17 More complex single cells might require upwards of a million base pairs of DNA. Yet to assemble the proteins necessary to sustain a complex arthropod such as a trilobite would need orders of magnitude more protein-coding instructions. By way of comparison, the genome size of a modern arthropod, the fruit fly Drosophila melanogaster, is approximately 140 million base pairs.18 Thus, transitions from a single cell to colonies of cells to complex animals represent significant—and in principle measurable—increases in genetic information. [17. Koonin, “How Many Genes Can Make a Cell?” 18. Gerhart and Kirschner, Cells, Embryos, and Evolution, 121; Adams et al., “The Genome Sequence of Drosophila melanogaster”; see also www.ncbi.nlm.nih.gov/genome/?term=drosophila%20melanogaster (accessed November 1, 2012).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2837-2845). HarperCollins. Kindle Edition.]
* During the Cambrian period a veritable carnival of novel biological forms arose. But because new biological form requires new cell types, proteins, and genetic information, the Cambrian explosion of animal life also generated an explosion of genetic information unparalleled in the previous history of life.19 [Moreover, in addition to requiring a vast amount of new genetic information, building a new animal from a single-celled organism also requires a way of arranging gene products—proteins—into higher levels of organization, including cell types, organs, and body plans. Later, in Chapter 14, I will discuss the importance of these higher-level arrangements and why they also constitute a kind of information—one that, although not stored in genes alone, nevertheless has to be explained as well.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2845-2848). HarperCollins. Kindle Edition.]
* Information scientists measure such informational increases through a unit they call a bit. A bit represents the minimum amount of information that can be conveyed (or uncertainty reduced) by a single digit in a two-character alphabet.21 [To determine how much Shannon information is present in any sequence of characters, information scientists use a formula that converts probability measures into informational measures using a negative logarithmic function. A simple form of that equation can be expressed as I = –log2 p, where the negative sign indicates the inverse relationship between probability and information.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2892-2894). HarperCollins. Kindle Edition.]
* As Warren Weaver, one of Shannon’s close collaborators, made clear in 1949, “The word ‘information’ in this theory is used in a special mathematical sense that must not be confused with its ordinary usage.”23 [Shannon and Weaver, The Mathematical Theory of Communication, 8.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2912-2914). HarperCollins. Kindle Edition.]
* Strands of DNA contain information-carrying capacity—something Shannon’s theory can measure.24 But DNA, like natural languages and computer codes, also contains functional information.25 [24. Schneider, “Information Content of Individual Genetic Sequences”; Yockey, Information Theory and Molecular Biology, 58–177. 25. DNA clearly does not convey meaningful information in the sense of “knowledge” conveyed to, and comprehended by, a conscious agent, although the precise sequences of bases could be said to be meaningful in the sense that they are ‘significant’ to the function DNA performs. Clearly, however, the cellular machinery that uses and “reads” the information in DNA to build proteins is not conscious. Nevertheless, semantically meaningful information—a message, the meaning of which is understood by a conscious agent—represents only a special kind of functional information. And all sequences of characters containing functional information can be distinguished from mere Shannon information in that the precise arrangement of characters or symbols in such sequences matters to the function that they perform.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2924-2926). HarperCollins. Kindle Edition.]
* And DNA contains specified information, not just Shannon information or information-carrying capacity. As Crick himself put it in 1958, “By information I mean the specification of the amino acid sequence in protein. . . . Information means here the precise determination of sequence, either of bases in the nucleic acid or on amino acid residues of the protein.”26 [Crick, “On Protein Synthesis,” 144, 153. See also Sarkar, “Biological Information,” 191.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2933-2936). HarperCollins. Kindle Edition.]

**9 Combinatorial Inflation**

* During the early 1960s, Eden began discussing the plausibility of the neo-Darwinian theory of evolution with several MIT colleagues in math, physics, and computer science. As the discussion grew to include mathematicians and scientists from other institutions, the idea of a conference was born. In 1966, a distinguished group of mathematicians, engineers, and scientists convened a conference at the Wistar Institute in Philadelphia called “Mathematical Challenges to the Neo-Darwinian Interpretation of Evolution.” Prominent among the attendees were Marcel-Paul Schützenberger, a mathematician and physician at the University of Paris; Stanislaw Ulam, the codesigner of the hydrogen bomb; and Eden himself. The conference also included a number of prominent biologists, including Ernst Mayr, an architect of modern neo-Darwinism, and Richard Lewontin, at the time a professor of genetics and evolutionary biology at the University of Chicago. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2965-2971). HarperCollins. Kindle Edition.]
* Sir Peter Medawar, a Nobel laureate and the director of the North London Medical Research Council’s laboratories, chaired the meeting. In his opening remarks, he said, “The immediate cause of this conference is a pretty widespread sense of dissatisfaction about what has come to be thought of as the accepted evolutionary theory in the English-speaking world, the so-called neo-Darwinian theory.”2 [The quotation and the historical material about the Geneva gathering are drawn from G. R. Taylor, Great Evolution Mystery, 4.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2973-2976). HarperCollins. Kindle Edition.]
* At the conference the French mathematician Marcel Schützenberger agreed with Eden’s concerns about the effect of random alterations. He noted that if someone makes even a few random changes in the arrangement of the digital characters in a computer program, “we find that we have no chance (i.e., less than 1/101000) even to see what the modified program would compute: it just jams.”4 [Schützenberger, “Algorithms and the Neo-Darwinian Theory of Evolution,” 74–75.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2988-2991). HarperCollins. Kindle Edition.]
* Eden argued that much the same problem applied to DNA—that insofar as specific arrangements of bases in DNA function like digital code, random changes to these arrangements would likely efface their function, while attempts to generate completely new sections of genetic text by random means were likely doomed to failure.5 [Commenting on the symposium thirty years later in a now infamous article in Commentary magazine, mathematician David Berlinski amplified Eden’s argument. As he explains, “However it may operate in life, randomness in language is the enemy of order, a way of annihilating meaning. And not only in language, but in any language-like system” (“The Deniable Darwin”).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 2992-2994). HarperCollins. Kindle Edition.]
* As evolutionary biologists Jack King and Thomas Jukes put it in 1969, “Natural selection is the editor, rather than the composer, of the genetic message.”6 [King and Jukes, “Non-Darwinian Evolution,” 788.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3014-3015). HarperCollins. Kindle Edition.]



* Eden and others questioned whether mutations provided an adequate explanation for the origin of the genetic information necessary to build new proteins, let alone whole new forms of life. As physicist Stanislaw Ulam explained at the conference, the evolutionary process “seems to require many thousands, perhaps millions, of successive mutations to produce even the easiest complexities we see in life now. It appears, naïvely at least, that no matter how large the probability of a single mutation is, should it be even as great as one-half, you would get this probability raised to a millionth power, which is so very close to zero that the chances of such a chain seem to be practically non-existent.”9 [Ulam, “How to Formulate Mathematically Problems of Rate of Evolution,” 21.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3090-3095). HarperCollins. Kindle Edition.]
* When Denton compared linguistic and genetic text to explain the potential severity of the combinatorial inflation facing the neo-Darwinian mechanism, he noted that biologists still didn’t know enough “to calculate with any degree of certainty the actual rarity of functional proteins.” He concluded, however, that since future experiments surely would continue to deepen molecular biology’s fund of knowledge, “it may be that before long quite rigorous estimates may be possible.”13 [Denton, Evolution, 324.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3130-3134). HarperCollins. Kindle Edition.]
* In the same way, Sauer established that though many different combinations of amino acids will produce roughly the same protein structure and function, the sequences capable of producing these functional outcomes are still extremely rare. He showed that for every functional 92-amino-acid sequence there are roughly another 1063 nonfunctional sequences of the same length. To put that ratio in perspective, the probability of attaining a correct sequence by random search would roughly equal the probability of a blind spaceman finding a single marked atom by chance among all the atoms in the Milky Way galaxy—on its face clearly not a likely outcome.17 [Behe, “Experimental Support for Regarding Functional Classes of Proteins,” 66.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3186-3192). HarperCollins. Kindle Edition.]

**10 The Origin of Genes and Proteins**

* Axe made the assumption that each new organism received one new sequence of bases (one potential gene) capable of generating one of the possible amino-acid sequences in sequence space per generation. This was an extremely generous assumption. Since mutations have to be quite rare for life to survive, most bacterial cells inherit an exact copy of their parent’s DNA. Furthermore, the ones that differ from their parents are likely to carry a mutation that has already occurred many times in other cells. For these reasons, the actual number of new sequences sampled in the history of life is much lower than the total number of bacterial cells that have existed. Nevertheless, Axe assumed that one new gene per organism has been transmitted to the next generation. Thus, he used 1040 gene sequences as a liberal estimate of the total number of gene sequences (evolutionary trials) that have been generated to search sequence space in the history of life. Even so, 1040 represents only a tiny fraction—1 ten trillion, trillion, trillionth—of 1077. Thus, the conditional probability of generating a gene sequence capable of producing a novel protein fold and function is still only 1 in 1037. This means that if every organism from the dawn of time had generated, by random mutation, one new base sequence in the sequence space of interest, that would amount to only one 10 trillion, trillion, trillionth of the sequences in that space—the space that needs to be searched. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3522-3534). HarperCollins. Kindle Edition.]

**11 Assume a Gene**

* The same year, I published a peer-reviewed scientific article about the Cambrian explosion and the problem of the origin of the biological information needed to explain it.1 [Stephen C. Meyer, “The Origin of Biological Information and the Higher Taxonomic Categories.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3619-3621). HarperCollins. Kindle Edition.]
* Museum scientists and evolutionary biologists from around the country were furious with the journal and its editor, Richard Sternberg, for allowing the article to be peer-reviewed and then published. Recriminations followed. Museum officials took away Sternberg’s keys, his office, and his access to scientific samples. He was transferred from a friendly to a hostile supervisor. A congressional subcommittee staff later investigated and found that museum officials initiated an intentional disinformation campaign against Sternberg in an attempt to get him to resign. His detractors circulated false rumors: “Sternberg has no degrees in biology” (actually he has two Ph.D.’s, one in evolutionary biology and one in systems biology); “He is a priest, not a scientist” (Sternberg is not a priest, but a research scientist); “He is a Republican operative working for the Bush campaign” (he was far too busy doing scientific research to be involved in political campaigns, Republican or otherwise); “He’s taken money to publish the article” (not true); and so on. Eventually, despite the demonstrable falsehood of the charges, he was demoted.2 [For detailed discussions of facts of the Sternberg case, see “Smithsonian Controversy,” www.richardsternberg.com/smithsonian.php; U.S. Office of Special Counsel Letter (2005) at www.discovery.org/f/1488; United States House of Representatives Committee on Government Reform, Subcommittee Staff Report, “Intolerance and the Politicization of Science at the Smithsonian” (December 2006), at www.discovery.org/f/1489; Appendix, United States House of Representatives Committee on Government Reform, Subcommittee Staff Report (December 2006) at [www.discovery.org/f/1490](http://www.discovery.org/f/1490).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3626-3634). HarperCollins. Kindle Edition.]
* Major news stories about the controversy appeared in Science, Nature, The Scientist, and the Chronicle of Higher Education.3 Then articles appeared in the mainstream press, including the Washington Post and the Wall Street Journal.4 A major story aired on National Public Radio.5 Sternberg himself even appeared on The O’Reilly Factor. [3. See Holden, “Defying Darwin”; Giles, “Peer-Reviewed Paper Defends Theory of Intelligent Design,” 114; Agres, “Smithsonian ‘Discriminated ’Against Scientist”; Stokes, “ . . . And Smithsonian Has ID Troubles”; Monastersky, “Society Disowns Paper Attacking Darwinism.” 4. Powell, “Controversial Editor Backed”; Klinghoffer, “The Branding of a Heretic.” 5. Hagerty, “Intelligent Design and Academic Freedom.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3634-3639). HarperCollins. Kindle Edition.]
* The oft-cited Long paper points to a variety of studies that purport to explain the evolution of various genes. These studies typically begin by taking a gene and then seeking to find other genes that are similar (or homologous) to it. They then seek to trace the history of slightly different homologous genes back to a hypothetical common ancestor gene (or genes). [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3665-3667). HarperCollins. Kindle Edition.]
* The Long essay highlights seven main mutational mechanisms at work in the sculpting of new genes: (1) exon shuffling, (2) gene duplication, (3) retropositioning of messenger RNA transcripts, (4) lateral gene transfer, (5) transfer of mobile genetic units or elements, (6) gene fission or fusion, and (7) de novo origination (see Fig. 11.1). Yet each of these mechanisms, with the exception of de novo generation, begins with preexisting genes or extensive sections of genetic text. This preexisting functionally specified information is in some cases enough to code for the construction of an entire protein or a distinct protein fold. Moreover, these scenarios not only assume unexplained preexisting sources of biological information, they do so without explaining or even attempting to explain how any of the mechanisms they envision could have solved the combinatorial search problem. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3754-3760). HarperCollins. Kindle Edition.]
* Long does cite at least one type of mutation that does not presuppose existing genetic information, the de novo origination of new genes. For example, one paper he discusses sought to explain the origin of a promoter region for a gene (the part of the gene that helps initiate the transcription of the gene’s instructions) and found that “this unusual regulatory region did not really ‘evolve.’ ” Instead, it somehow snapped into being: “It was aboriginal, created de novo by the fortuitous juxtaposition of suitable sequences.”21 [Nurminsky et al., “Selective Sweep of a Newly Evolved Sperm-Specific Gene in Drosophila,” 574.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 3795-3799). HarperCollins. Kindle Edition.]

**12 Complex Adaptations and the Neo-Darwinian Math**

* Could this complex system of bones, joints, tissues, and ligaments have evolved gradually? “A movable joint dividing the maxilla into two segments,” observed Frazzetta, “seems to have either a presence or absence, with no intermediate to connect the two conditions.”2 That is, either the maxilla occurs as one bone (as it does in every other vertebrate) or as two segments with all the accompanying joints, bones, ligaments, and tissues necessary to make it work, as it does in the bolyerine snakes. No intermediate condition—a broken maxilla with two pieces of bone lacking the necessary joints, tissues, and ligaments, for example—appears viable. [Frazzetta, “From Hopeful Monsters to Bolyerine Snakes?” 63.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4012-4017). HarperCollins. Kindle Edition.]
* As Stephen Jay Gould asked of the same system, “How can a jawbone be half broken?”3 Or as Frazzetta himself observed, “I thus find it difficult to envision a smooth transition from a single maxilla to the divided condition seen in bolyerines.”4 Yet because the intermediate forms would not be viable, building a bolyerine jaw would require all the necessary parts—the jointed maxilla, the adjoining ligaments, and the necessary muscles and tissues—arising together. [3. Gould, “Return of the Hopeful Monsters,” 28. 4. Frazzetta, “From Hopeful Monsters to Bolyerine Snakes?” 63.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4017-4021). HarperCollins. Kindle Edition.]
* Yet the problem for neo-Darwinian theory, Frazzetta realized, extended well beyond the anatomical peculiarities of rare snakes. As a young evolutionary biology professor, he had studied complex features in a wide variety of species. He knew that almost any biological structure of interest—the inner ear, the amniotic egg, eyes, olfactory organs, gills, lungs, feathers, the reproductive, circulatory, and respiratory systems—possesses multiple necessary components. To change such systems requires altering each of the many independent parts upon which their functions are based. This cannot be done willy-nilly. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4022-4026). HarperCollins. Kindle Edition.]
* In 1975, Frazzetta wrote a minor classic entitled Complex Adaptations in Evolving Populations explaining this concern. He wrote: When modifying the design of a machine, an engineer is not bound by the need to maintain a real continuity between the first machine and the modification. . . . But in evolution, transitions from one type to the next presumably involve a greater continuity by means of a vast number of intermediate types. Not only must the end product—the final machine—be feasible, but so must be all the intermediates. The evolutionary problem is, in a real sense, the gradual improvement of a machine while it is running!5 [Frazzetta, Complex Adaptations in Evolving Populations, 20.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4037-4042). HarperCollins. Kindle Edition.]
* As Frazzetta explained, “Phenotypic alteration of integrated systems requires an improbable coincidence of genetic (and hence, heritable phenotypic) modifications of a tightly specified kind.”8 Yet the extreme specificity of the fit of the components and the functional dependence of the whole system on this fit imply limits to allowable genetic change. [Frazzetta, “Modeling Complex Morphological Change in Evolution,” 129.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4057-4060). HarperCollins. Kindle Edition.]
* For this reason, as Frazzetta concluded, “We are still left with the unabating need to explain evolutionary changes in systems that have the operational integration characteristic of things we recognize as ‘machines.’ ”9 At the time, the doubts he expressed gained little traction in the evolutionary biology community, because neo-Darwinian evolutionary biologists assumed that mutation and selection had nearly unlimited creative power, enough to generate even complex systems of the kind described in Frazzetta’s book. [Frazzetta, “Modeling Complex Morphological Change in Evolution,” 130.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4061-4066). HarperCollins. Kindle Edition.]
* Confidence in these mathematical models (and their underlying assumptions) led many neo-Darwinists to disregard the need to give detailed accounts of the specific evolutionary pathways by which complex systems might have arisen. For example, in an evolutionary biology text widely used about the time Frazzetta first posed this challenge, evolutionary biologists Paul Ehrlich and Richard Holm advised: One need not go into the details of the evolution of the bird’s wing, the giraffe’s neck, the vertebrate eye, the nest building of some fish, etc., as the selective origins of these and other structures and of behavioral patterns may be assumed to be basically the same in outline as those, such as industrial melanism, which have already been discussed. Even a slight advantage or disadvantage in a particular genetic change provides a sufficient differential for the operation of natural selection.10 [Ehrlich and Holm, The Process of Evolution, 157.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4075-4082). HarperCollins. Kindle Edition.]
* Classically, Darwinian biologists have assumed that small, separate step-by-step changes could produce all biological structures and features, provided each change confers some survival or reproductive advantage. In his chapter in the 1909 anthology Darwin and Modern Science, the British geneticist William Bateson wryly described how this widespread assumption prevented evolutionary biologists from confronting the real difficulty of explaining the origin of complex adaptations: By suggesting that the steps through which an adaptive mechanism arises are indefinite and insensible, all further trouble is spared. While it could be said that species arise by an insensible and imperceptible process of variation, there was clearly no use in tiring ourselves by trying to perceive that process. This labour-saving counsel found great favor.12 [Bateson, “Heredity and Variation in Modern Lights,” 83–84.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4133-4140). HarperCollins. Kindle Edition.]
* According to Salisbury’s calculations, “The mutational mechanism as presently imagined could fall short by hundreds of orders of magnitude of producing, in a mere four billion years, even a single required gene.”14 [Salisbury, “Natural Selection and the Complexity of the Gene,” 342–43.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4148-4150). HarperCollins. Kindle Edition.]
* Maynard Smith compared protein-to-protein evolution to changing one letter in an English word in order to generate a different word (while at each step generating a different meaningful word). He used this example to convey how he thought protein evolution might work: WORD → WORE → GORE → GONE → GENE, He explained: The words [in this analogy] represent proteins; the letters represent amino acids; the alteration of a single letter corresponds to the simplest evolutionary step, the substitution of one amino acid for another; and the requirement of meaning corresponds to the requirement that each unit step in evolution should be from one functional protein to another.15 [Maynard Smith, “Natural Selection and the Concept of a Protein Space,” 564.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4153-4159). HarperCollins. Kindle Edition.]
* As a self-professed “convinced Darwinist,” Maynard Smith realized that natural selection and random mutation could only build new biological structures from preexisting structures if each intermediate structure along the way conferred some adaptive advantage. He thought that this requirement applied as much to the evolution of new genes and proteins as it did to the evolution of new phenotypic traits or larger-scale anatomical structures.16 [As Maynard Smith writes in Nature: “If evolution by natural selection is to occur, functional proteins must form a continuous network which can be traversed by unit mutational steps without passing through nonfunctional intermediates” (“Natural Selection and the Concept of a Protein Space,” 564).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4160-4163). HarperCollins. Kindle Edition.]
* Here’s how he described the potential problem: Suppose that a protein ABCD . . . exists, and that a protein abCD . . . would be favoured by selection if it arose. Suppose further that the intermediates aBCD . . . and AbCD . . . are nonfunctional. These forms would arise by mutation, but would usually be eliminated by selection before a second mutation could occur. The double step from abCD . . . to ABCD would thus be very unlikely to occur.17 [Maynard Smith, “Natural Selection and the Concept of a Protein Space,” 564.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4168-4172). HarperCollins. Kindle Edition.]
* In Maynard Smith’s view, the improbability associated with “double-step” or multiple-step coordinated mutations presented a significant potential problem for molecular evolution. In the end, however, he concluded that such mutations were so improbable that they must not have played a significant role in the evolution of novel structures. As he explained, “Such double steps . . . may occasionally occur, but are probably too rare to be important in evolution.”18 [Maynard Smith, “Natural Selection and the Concept of a Protein Space,” 564.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4173-4176). HarperCollins. Kindle Edition.]
* Their calculation suggested that it would take not several hundred million years, but “only” 216 million years to generate and fix two coordinated mutations in the hominid line—more than thirty times the amount of time available to produce humans and chimps and all their distinctive complex adaptations and differences from their inferred common ancestor. In seeking to refute Behe, Durrett and Schmidt inadvertently confirmed his main contention. As they acknowledged, their calculation implies that generating two or more coordinated mutations is “very unlikely to occur on a reasonable timescale.”32 In sum, calculations performed by both critics and defenders of neo-Darwinian evolution now reinforce the same conclusion: if coordinated mutations are necessary to generate new genes and proteins, then the neo-Darwinian math itself, as expressed in the principles of population genetics, establishes the implausibility of the neo-Darwinian mechanism. [Durrett and Schmidt, “Waiting for Two Mutations,” 1507.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4347-4354). HarperCollins. Kindle Edition.]
* There is a concluding irony in all this. The researchers calculating waiting times for the appearance of complex adaptations have in each case done so using models based on the core principles of population genetics, the mathematical expression of neo-Darwinian theory. In a real sense, therefore, the neo-Darwinian math is itself showing that the neo-Darwinian mechanism cannot build complex adaptations—including the new information-rich genes and proteins that would have been necessary to build the Cambrian animals. To adapt a metaphor that Tom Frazzetta might appreciate, the snake has eaten its own tail. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4442-4446). HarperCollins. Kindle Edition.]

**13 The Origin of Body Plans**

* The thoroughness and novelty of the “Heidelberg screens” (as the experiments came to be known) and their importance for revealing the mechanisms of regulatory control during animal embryogenesis won the attention of the Nobel committee. In 1995, the committee awarded the Nobel Prize in Medicine or Physiology to Nüsslein-Volhard and Wieschaus. “This work was revolutionary,” University of Cambridge geneticist Daniel St. Johnston explained, “because it was the first mutagenesis in any multicellular organism that attempted to find most or all of the mutations that affect . . . the essential patterning genes that are used throughout development.”2 [St. Johnston, “The Art and Design of Genetic Screens,” 177.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4462-4467). HarperCollins. Kindle Edition.]
* Another questioner then asked Wieschaus about the implications of his findings for evolutionary theory. Here Wieschaus responded more soberly, wondering aloud about whether his collection of mutants offered any insights into how the evolutionary process could have constructed novel body plans. “The problem is, we think we’ve hit all the genes required to specify the body plan of Drosophila,” he said, “and yet these results are obviously not promising as raw materials for macroevolution. The next question then, I guess, is what are—or what would be—the right mutations for major evolutionary change? And we don’t know the answer to that.”4 [Quotes recorded in contemporaneous notes taken by philosopher of biology Paul Nelson, who was in attendance at this lecture.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4476-4480). HarperCollins. Kindle Edition.]
* Mutations that are expressed early in development, however, may affect many cells and could conceivably produce significant changes in the form or body plan, especially if these changes occur in key regulatory genes.7 Thus, mutations that are expressed early in the development of animals have probably the only realistic chance of producing large-scale macroevolutionary change.8 As evolutionary geneticists Bernard John and George Miklos explain, “macroevolutionary change” requires changes in “very early embryogenesis.”9 Former Yale University evolutionary biologist Keith Thomson concurs: only mutations expressed early in the development of organisms can produce large-scale macroevolutionary change.10 [7. Van Valen, “How Do Major Evolutionary Changes Occur?” 173. 8. Thomson, “Macroevolution,” 111. 9. John and Miklos, The Eukaryote Genome in Development and Evolution, 309. 10. Thomson, “Macroevolution.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4525-4532). HarperCollins. Kindle Edition.]
* Yet from the first experiments by geneticist T. H. Morgan systematically mutating fruit flies early in the twentieth century until today, as many model species have been subjected to mutagenesis, developmental biology has shown that mutations affecting body-plan formation expressed early in development inevitably damage the organism.11 (See Fig. 13.2, for examples.) As one of the founders of neo-Darwinism geneticist R. A. Fisher noted, such mutations are “either definitely pathological (most often lethal) in their effects,” or they result in an organism that cannot survive “in the wild state.”12 [11. See, e.g., the special issue of Development (December 1996) dedicated to the large-scale mutagenesis of the model vertebrate Danio rerio (the zebrafish), especially Haffter et al., “The Identification of Genes with Unique and Essential Functions in the Development of the Zebrafish, Danio rerio”; or the many fruit-fly mutagenesis experiments summarized in Bate and Arias, eds., The Development of Drosophila melanogaster. Summarizing the evidence from a wide range of animal systems, Wallace Arthur writes, “Those genes that control key early developmental processes are involved in the establishment of the basic body plan. Mutations in these genes will usually be extremely disadvantageous, and it is conceivable that they are always so” (The Origin of Animal Body Plans, 14, emphasis in original). Arthur goes on to speculate that because developmental regulatory genes often differ between phyla, perhaps “mutations of these genes are sometimes advantageous” (15). He offers no evidence for such mutations, however, other than as a deduction from his prior assumption of common descent. 12. Fisher, The Genetical Theory of Natural Selection, 44.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4533-4538). HarperCollins. Kindle Edition.]
* Geneticist Bruce Wallace explains why early-acting mutations are thus overwhelmingly likely to disrupt animal development. “The extreme difficulty encountered,” he observes, “when attempting to transform one organism into another . . . still functional one lies in the difficulty in resetting a number of the many controlling switches in a manner that still allows for the individual’s orderly (somatic) development.”13 [Wallace, “Adaptation, Neo-Darwinian Tautology, and Population Fitness,” 70.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4542-4545). HarperCollins. Kindle Edition.]
* My Discovery Institute colleague Paul Nelson (see Fig. 13.3), a philosopher of biology who specializes in evolutionary theory and developmental biology, summarizes the challenge to neo-Darwinism posed by animal development as three premises: 1. Animal body plans are built in each generation by a stepwise process, from the fertilized egg to the many cells of the adult. The earliest stages in this process determine what follows. 2. Thus, to evolve any body plan, mutations expressed early in development must occur, must be viable, and must be stably transmitted to offspring. 3. Such early-acting mutations of global effect on animal development, however, are those least likely to be tolerated by the embryo and, in fact, never have been tolerated in any animals that developmental biologists have studied. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4577-4584). HarperCollins. Kindle Edition.]
* Nelson argues, however, that those premises strongly imply that the neo-Darwinian mechanism does not—and indeed cannot—provide an adequate mechanism for producing new animal body plans. As he has told me: “If the only kind of mutations that can conceivably produce enough morphological change to alter whole body plans never causes beneficial and heritable changes, then it is difficult to see how mutation and selection could ever produce new body plans in the first place.”19 Thus, he concludes: Research on animal development and macroevolution over the last thirty years—research done from within the neo-Darwinian framework—has shown that the neo-Darwinian explanation for the origin of new body plans is overwhelmingly likely to be false—and for reasons that Darwin himself would have understood. [Nelson notes that there is one noteworthy exception to this generalization: the loss of structures. A wide range of well-documented cases—including cave animals, island birds and insects, and marine and freshwater fishes—show that many animals will tolerate, or actually thrive, after losing traits to mutation—as long as those traits are not essential for survival in some specialized environment. For example, macromutations resulting in loss of vision have had no deleterious effects on some species of now blind cave fish that no longer have a need to see. Similarly, macromutations that disrupt wing formation in an insect—ordinarily devastating in an environment where functional wings are essential equipment—might well be tolerated in an island setting where that species faces no need to fly. The processes that generate these exceptions, however, do not help to explain the origin of form such as occurs in the Cambrian explosion. Clearly, processes that result in a loss of form and structure cannot be credibly invoked to explain the origin of form and structure in the first place.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4595-4602). HarperCollins. Kindle Edition.]
* Indeed, Darwin himself insisted that “nothing can be effected” by natural selection, “unless favorable variations occur.”20 Or as Swedish evolutionary biologist Søren Løvtrup succinctly explains: “Without variation, no selection; without selection, no evolution. This assertion is based on logic of the simplest kind. . . . Selection pressure as an evolutionary agent becomes void of sense unless the availability of the proper mutations is assumed.”21 Yet the “proper” kind of mutations—the mutations that produce favorable changes to early-acting, body-plan–shaping, regulatory genes—do not occur. [20. Darwin, On the Origin of Species, 108. 21. Løvtrup, “Semantics, Logic and Vulgate Neo-Darwinism,” 162.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4602-4608). HarperCollins. Kindle Edition.]
* When they proposed their theory in 1969, Britten and Davidson acknowledged that “little is known . . . of the molecular mechanisms by which gene expression is controlled in differentiated cells.”24 Nevertheless, they deduced that such a system must be at work. Given: (1) that tens or hundreds of specialized cell types arise during the development of animals, and (2) that each cell contains the same genome, they reasoned (3) that some control system must determine which genes are expressed in different cells at different times to ensure the differentiation of different cell types from each other—some system-wide regulatory logic must oversee and coordinate the expression of the genome.25 [24. Britten and Davidson, “Gene Regulation for Higher Cells,” 57. 25. Britten and Davidson, “Gene Regulation for Higher Cells,” 353.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4630-4636). HarperCollins. Kindle Edition.]
* As Davidson emphasizes, mutations affecting the dGRNs that regulate body-plan development lead to “catastrophic loss of the body part or loss of viability altogether.”30 He explains in more detail: There is always an observable consequence if a dGRN subcircuit is interrupted. Since these consequences are always catastrophically bad, flexibility is minimal, and since the subcircuits are all interconnected, the whole network partakes of the quality that there is only one way for things to work. And indeed the embryos of each species develop in only one way.31 [30. Davidson, “Evolutionary Bioscience as Regulatory Systems Biology,” 38. 31. Davidson, “Evolutionary Bioscience as Regulatory Systems Biology,” 40, emphasis added.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4677-4682). HarperCollins. Kindle Edition.]
* Davidson makes clear that no one really knows: “contrary to classical evolution theory, the processes that drive the small changes observed as species diverge cannot be taken as models for the evolution of the body plans of animals.”33 He elaborates: Neo-Darwinian evolution . . . assumes that all process works the same way, so that evolution of enzymes or flower colors can be used as current proxies for study of evolution of the body plan. It erroneously assumes that change in protein-coding sequence is the basic cause of change in developmental program; and it erroneously assumes that evolutionary change in body-plan morphology occurs by a continuous process. All of these assumptions are basically counterfactual. This cannot be surprising, since the neo-Darwinian synthesis from which these ideas stem was a premolecular biology concoction focused on population genetics and . . . natural history, neither of which have any direct mechanistic import for the genomic regulatory systems that drive embryonic development of the body plan.34 [33. Davidson, The Regulatory Genome, 195. 34. Davidson, “Evolutionary Bioscience as Regulatory Systems Biology,” 35–36.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4695-4703). HarperCollins. Kindle Edition.]
* ***Darwin's Doubt*** about the Cambrian explosion centered on the problem of missing fossil intermediates. Not only have those forms not been found, but the Cambrian explosion itself illustrates a profound engineering problem that fossil evidence does not address—the problem of building a new form of animal life by gradually transforming one tightly integrated system of genetic components and their products into another. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4710-4713). HarperCollins. Kindle Edition.]

**14 The Epigenetic Revolution**

* Instead, many of the scientists in their volume reported that so-called epigenetic information—information stored in cell structures, but not in DNA sequences—plays a crucial role. The Greek prefix epi means “above” or “beyond,” so epigenetics refers to a source of information that lies beyond the genes. As Müller and Newman explain in their introduction, “Detailed information at the level of the gene does not serve to explain form.”5 Instead, as Newman explains, “epigenetic” or “contextual information” plays a crucial role in the formation of animal “body assemblies” during embryological development.6 [5. Müller and Newman, “Origination of Organismal Form,” 8. 6. Müller and Newman, “Origination of Organismal Form,” 8.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4736-4742). HarperCollins. Kindle Edition.]
* In the introductory essay to their volume, Müller and Newman list a number of “open questions” in evolutionary biology, including the question of the origin of Cambrian-era animal body plans and the origin of organismal form generally, the latter being the central topic of their book. They note that though “the neo-Darwinian paradigm still represents the central explanatory framework of evolution,” it has “no theory of the generative.”7 In their view, neo-Darwinism “completely avoids [the question of] the origination of phenotypic traits and of organismal form.”8 As they and others in their volume maintain, neo-Darwinism lacks an explanation for the origin of organismal form precisely because it cannot explain the origin of epigenetic information. [7. Müller and Newman, “Origination of Organismal Form,” 7. 8. Müller and Newman, “Origination of Organismal Form,” 7. Or as Müller also explains, the question of how “individualized constructional elements” are organized during “the evolution of organismal form” is “not satisfactorily answered by current evolutionary theories”; Müller, “Homology,” 57–58.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4746-4752). HarperCollins. Kindle Edition.]
* Many biologists no longer believe that DNA directs virtually everything happening within the cell. Developmental biologists, in particular, are now discovering more and more ways that crucial information for building body plans is imparted by the form and structure of embryonic cells, including information from both the unfertilized and fertilized egg. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4792-4794). HarperCollins. Kindle Edition.]
* Jonathan Wells explains it this way: “What matters in [embryological] development is the shape and location of microtubule arrays, and the shape and location of a microtubule array is not determined by its units.”14 For this reason, as University of Colorado cell biologist Franklin Harold notes, it is impossible to predict the structure of the cytoskeleton of the cell from the characteristics of the protein constituents that form that structure.15 [14. Wells, “Making Sense of Biology,” 121. 15. Harold, The Way of the Cell, 125.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4831-4835). HarperCollins. Kindle Edition.]
* As biologist Ronald Schnaar explains, “Each [sugar] building block can assume several different positions. It is as if an A could serve as four different letters, depending on whether it was standing upright, turned upside down, or laid on either of its sides. In fact, seven simple sugars can be rearranged to form hundreds of thousands of unique words, most of which have no more than five letters.”24 [Schnaar, “The Membrane Is the Message,” 34–40.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4884-4887). HarperCollins. Kindle Edition.]
* These sequence-specific information-rich structures influence the arrangement of different cell types during embryological development. Thus, some cell biologists now refer to the arrangements of sugar molecules as the “sugar code” and compare these sequences to the digitally encoded information stored in DNA.25 As biochemist Hans-Joachim Gabius notes, sugars provide a system with “high-density coding” that is “essential to allow cells to communicate efficiently and swiftly through complex surface interactions.”26 According to Gabius, “These [sugar] molecules surpass amino acids and nucleotides by far in information-storing capacity.”27 So the precisely arranged sugar molecules on the surface of cells clearly represent another source of information independent of that stored in DNA base sequences. [25. Schnaar, “The Membrane Is the Message,” 34–40; Gabius et al., “Chemical Biology of the Sugar Code,” 740-764; Gabius, “Biological Information Transfer Beyond the Genetic Code: The Sugar Code,” 108–121. 26. Gabius et al., “Chemical Biology of the Sugar Code,” 741. See also Gabius, “Biological Information Transfer Beyond the Genetic Code: The Sugar Code,” 108–21. 27. Gabius, “Biological Information Transfer Beyond the Genetic Code,” 109; Gabius et al., “Chemical Biology of the Sugar Code,” 741.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4887-4895). HarperCollins. Kindle Edition.]
* Contemporary critics of neo-Darwinism acknowledge, of course, that preexisting forms of life can diversify under the twin influences of natural selection and genetic mutation. Known microevolutionary processes can account for small changes in the coloring of peppered moths, the acquisition of antibiotic resistance in different strains of bacteria, and cyclical variations in the size of Galápagos finch beaks. Nevertheless, many biologists now argue that neo-Darwinian theory does not provide an adequate explanation for the origin of new body plans or events such as the Cambrian explosion. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4993-4997). HarperCollins. Kindle Edition.]
* For example, evolutionary biologist Keith Stewart Thomson, formerly of Yale University, has expressed doubt that large-scale morphological changes could accumulate by minor changes at the genetic level.38 Geneticist George Miklos, of the Australian National University, has argued that neo-Darwinism fails to provide a mechanism that can produce large-scale innovations in form and structure.39 [38. Thomson, “Macroevolution,” 107. 39. Miklos, “Emergence of Organizational Complexities During Metazoan Evolution.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 4997-5001). HarperCollins. Kindle Edition.]
* Biologists Scott Gilbert, John Opitz, and Rudolf Raff have attempted to develop a new theory of evolution to supplement classical neo-Darwinism, which, they argue, cannot adequately explain large-scale macroevolutionary change. As they note: Starting in the 1970s, many biologists began questioning its [neo-Darwinism’s] adequacy in explaining evolution. Genetics might be adequate for explaining microevolution, but microevolutionary changes in gene frequency were not seen as able to turn a reptile into a mammal or to convert a fish into an amphibian. Microevolution looks at adaptations that concern the survival of the fittest, not the arrival of the fittest. As Goodwin (1995) points out, “the origin of species—Darwin’s problem—remains unsolved.”40 [Gilbert, Opitz, and Raff, “Resynthesizing Evolutionary and Developmental Biology,” 361. The Brian Goodwin quotation is from How the Leopard Changed Its Spots.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5001-5007). HarperCollins. Kindle Edition.]
* Gilbert and his colleagues have tried to solve the problem of the origin of form by invoking mutations in genes called Hox genes, which regulate the expression of other genes involved in animal development—an approach that I will examine in Chapter 16.41 [Gilbert, Opitz, and Raff, “Resynthesizing Evolutionary and Developmental Biology.” Specifically, they argue that changes in morphogenetic fields might produce large-scale changes in the developmental programs and, ultimately, in the body plans of organisms. However, they offer no evidence that such fields—if indeed they exist—can be altered to produce advantageous variations in body plan, though such a condition is necessary to any successful causal theory of macroevolution.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5008-5010). HarperCollins. Kindle Edition.]
* Notwithstanding, many leading biologists and paleontologists—Gerry Webster and Brian Goodwin, Günter Theissen, Marc Kirschner, and John Gerhart, Jeffrey Schwartz, Douglas Erwin, Eric Davidson, Eugene Koonin, Simon Conway Morris, Robert Carroll, Gunter Wagner, Heinz-Albert Becker and Wolf-Eckhart Lönnig, Stuart Newman and Gerd Müller, Stuart Kauffman, Peter Stadler, Heinz Saedler, James Valentine, Giuseppe Sermonti, James Shapiro and Michael Lynch, to name several—have raised questions about the adequacy of the standard neo-Darwinian mechanism, and/or the problem of evolutionary novelty in particular.42 For this reason, the Cambrian explosion now looks less like the minor anomaly that Darwin perceived it to be, and more like a profound enigma, one that exemplifies a fundamental and as yet unsolved problem—the origination of animal form. [Webster, How the Leopard Changed Its Spots, 33; Webster and Goodwin, Form and Transformation, x; Gunter Theißen, “The Proper Place of Hopeful Monsters in Evolutionary Biology,” 351; Marc Kirschner and John Gerhart, The Plausibility of Life, 13; Schwartz, Sudden Origins, 3, 299–300; Erwin, “Macroevolution Is More Than Repeated Rounds of Microevolution”; Davidson, “Evolutionary Bioscience as Regulatory Systems Biology,” 35; Koonin, “The Origin at 150,” 473–5; Conway Morris, “Walcott, the Burgess Shale, and Rumours of a Post-Darwinian World,” R928–R930; Carroll, “Towards a New Evolutionary Synthesis,” 27; Wagner, “What Is the Promise of Developmental Evolution?”; Wagner and Stadler, “Quasi-independence, Homology and the Unity-of Type”; Becker and Lönnig, “Transposons: Eukaryotic,” 529–39; Lönnig and Saedler, “Chromosomal Rearrangements and Transposable Elements,” 402; Müller and Newman, “Origination of Organismal Form,” 7; Kauffman, At Home in the Universe, 8; Valentine and Erwin, “Interpreting Great Developmental Experiments,” 96; Sermonti, Why Is a Fly Not a Horse?; Lynch, The Origins of Genome Architecture, 369; Shapiro, Evolution, 89, 128. The perspective of Eugene Koonin, a biologist at the National Center for Biotechnology Information at the National Institutes of Health, provides just one good example of this skepticism. He argues: “The edifice of the modern synthesis has crumbled, apparently, beyond repair . . . The summary of the state of affairs on the 150th anniversary of the Origin is somewhat shocking. In the postgenomic era, all major tenets of the modern synthesis have been, if not outright overturned, replaced by a new and incomparably more complex vision of the key aspects of evolution. So, not to mince words, the modern synthesis is gone. What comes next? The answer suggested by the Darwinian discourse of 2009 is a postmodern state, not so far a postmodern synthesis. Above all, such a state is characterized by the pluralism of processes and patterns in evolution that defies any straightforward generalization.” Koonin, “The Origin at 150,” 473–75. David J. Depew and Bruce H. Weber, writing in the journal Biological Theory, are even more frank: “Darwinism in its current scientific incarnation has pretty much reached the end of its rope” (89–102).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5011-5017). HarperCollins. Kindle Edition.]

**Part Three: After Darwin, What?**

**15 The Post-Darwinian World and Self-Organization**

* The year 2009 marked the 150th anniversary of the publication of The Origin of Species. In that year, the renowned Cambrian paleontologist Simon Conway Morris published an essay in the journal Current Biology titled “Walcott, the Burgess Shale and rumours of a post-Darwinian world,” assessing the current state of evolutionary biology. “Everywhere elsewhere in the Origin the arguments slide one by one skillfully into place, the towering edifice rises, and the creationists are left permanently in its shadow,” he wrote. “But not when it comes to the seemingly abrupt appearance of animal fossils.”1 Instead, unresolved problems exposed by the Cambrian explosion have, in Conway Morris’s view, “opened the way to a post-Darwinian world.”2 [1. Conway Morris, “Walcott, the Burgess Shale and Rumours of a Post-Darwinian World,” R928. 2. Conway Morris, “Walcott, the Burgess Shale and Rumours of a Post-Darwinian World,” R930.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5022-5029). HarperCollins. Kindle Edition.]
* As paleontologist Graham Budd, who was in attendance, explained, “When the public thinks about evolution, they think about [things like] the origin of wings. . . . But these are things that evolutionary theory has told us little about.”4 [Budd, quoted in Whitfield, “Biological Theory,” 282.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5037-5039). HarperCollins. Kindle Edition.]
* I quoted Cambrian paleontologists James Valentine and Douglas Erwin, who concluded exactly that. They argued that neither punctuated equilibrium nor neo-Darwinism has accounted for the origin of new body plans and that, consequently, biology needs a new theory to explain “the evolution of novelty.”5 [Valentine and Erwin, “Interpreting Great Developmental Experiments,” 97.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5041-5043). HarperCollins. Kindle Edition.]
* The neo-Darwinian mechanism rests on three core claims: first, that evolutionary change occurs as the result of random, minute variations (or mutations); second, that the process of natural selection sifts among those variations and mutations, such that some organisms leave more offspring than others (differential reproduction) based on the presence or absence of certain variations; and third, favored variations must be inherited faithfully in subsequent generations of organisms, thus causing the population in which they reside to change or evolve over time.6 Biologists Marc Kirschner and John Gerhart call these three elements—variation, natural selection, and heritability—the “three pillars” of neo-Darwinian evolution.7 [6. Endler, Natural Selection in the Wild, 46, 248; Lewontin, “Adaptation,” 212–30. 7. Gerhart and Kirschner, The Plausibility of Life: Resolving Darwin’s Dilemma, 10.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5047-5053). HarperCollins. Kindle Edition.]
* As he explained in 1977: “Attempts to relate the idea of order . . . with biological organization or specificity must be regarded as a play on words that cannot stand careful scrutiny. Informational macromolecules can code genetic messages and therefore can carry information because the sequence of bases or residues is affected very little, if at all, by [self-organizing] physicochemical factors.”43 [Yockey, “A Calculation of the Probability of Spontaneous Biogenesis by Information Theory,” 380.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5341-5344). HarperCollins. Kindle Edition.]
* Near the end of the meeting one advocate of self-organization privately acknowledged to me the validity of these critiques, admitting that, for now, “self-organization is really more of a slogan than a theory.” Stuart Kauffman, perhaps attempting to make a virtue of the necessity of accepting this explanatory deficit, has recently celebrated the self-organizational perspective for embracing what he calls “natural magic.” In a lecture at MIT, he concluded: “Life bubbles forth in a natural magic beyond the confines of entailing law, beyond mathematization.”45 He went on to explain that one benefit of the self-organizational perspective is that it allows us to be “reenchanted” with nature and to “find a way beyond modernity.”46 [45. Kauffman, “The End of a Physics Worldview: Heraclitus and the Watershed of Life.” 46. Kauffman, “The End of a Physics Worldview: Heraclitus and the Watershed of Life.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5360-5367). HarperCollins. Kindle Edition.]

**16 Other Post-Neo-Darwinian Models**

* When Stephen Jay Gould was first wrestling with the question of how new forms of animal life could have arisen so quickly in the fossil record, he considered many possible mechanisms of change. In the famed 1980 paper in which he declared neo-Darwinism “effectively dead,”1 he didn’t just propose allopatric speciation and species selections as new evolutionary mechanisms. He also granted a rehearing to a long discredited idea. Specifically, he argued that large-scale “macromutations” might generate significant innovations in form relatively quickly.2 [1. See Gould, “Is a New and General Theory of Evolution Emerging?” 120. 2. Gould does not use the term “macromutation” anywhere in his famous 1980 article (“Is a New and General Theory of Evolution Emerging?”). He does, however, use the term “micromutation” (see 120) and challenges the sufficiency of accumulated micromutations to explain “macroevolution” (a term used throughout the article).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5383-5388). HarperCollins. Kindle Edition.]
* In the 1930s and 1940s, this idea had been associated with University of California at Berkeley geneticist Richard Goldschmidt. Aware of the many discontinuities in the fossil record, Goldschmidt envisioned radical transformations in the form of animals arising in even one generation as the result of such large-scale mutations. He endorsed, for instance, the view of the German paleontologist Otto Schindewolf (1896–1971) that “the first bird hatched from a reptilian egg” and, thus, in Goldschmidt’s words, “that the many missing links in the paleontological record are sought for in vain because they have never existed.”3 If a bird hatched directly from a reptilian egg as the result of heritable, large-scale mutations, then such a sudden leap or “saltation” would obviously leave no fossil intermediates behind. [Goldschmidt, The Material Basis of Evolution, 395.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5389-5395). HarperCollins. Kindle Edition.]
* Neo-Darwinists rejected this idea as biologically implausible in the extreme. They argued that changing so many functionally integrated anatomical and physiological systems so quickly would inevitably result in deformed mutants, not different integrated systems of organs constituting a whole new animal.4 Goldschmidt’s macromutations, they contended, would produce not what Goldschmidt called “hopeful monsters,” but “hopeless monsters”—that is, nonviable organisms.5 [4. The rejection of large-scale mutations affecting morphology and function as adaptive nonstarters emerged early and persisted as one of the defining aspects of the neo-Darwinian synthesis. Neo-Darwinian paleontologist and macroevolution theorist Jeffrey Levinton, for instance, gives expression to the widely held skepticism about the evolutionary plausibility of such mutants in his major textbook dealing with macroevolution: As a general rule, major developmental mutants give a picture of hopeless monsters, rather than hopeful change. Epigenetic and genetic pleiotropy [i.e., side effects] both impart great burden to any major developmental perturbation. Thus it is unlikely that mutants affecting any fundamental prepattern in development are likely to produce a functional organism. Genes that activate switches in prepatterns are not sufficiently isolated in effect on other parts of the phenotype to expect major saltations. The cyclops mutant of the [brine shrimp] Artermia is lethal. The homeotic mutants of Drosophila melanogaster suffer similar fates. . . . Disruptions, i.e., mutants, have drastic effects on other parts of the phenotype. . . . Thus, the accumulated evidence suggests that major developmental mutants are of minor significance in evolution. The side effects are drastic. (Genetics, Paleontology, and Macroevolution, 252–54) 5. The central difficulty with relying on developmental macro-mutations to generate innovations in form, many neo-Darwinians noted, arises from the consequence of rapidly changing a system of genetic and developmental switches directed toward producing one “target” (stable adult form) to another system of such switches directed toward producing another form. Geneticist Bruce Wallace, trained by Theodosius Dobzhansky at Columbia University, explains: “The Bauplan [body plan] of an organism . . . can be thought of as the arrangement of genetic switches that control the course of the embryonic and subsequent development of the individual; such control must operate properly both in time generally and sequentially in the separately differentiated tissues. Selection, both natural and artificial, that leads to morphological change and other developmental modification does so by altering the settings and triggerings of these switches. . . . The extreme difficulty encountered when attempting to transform one organism into another but still functioning one lies in the difficulty in resetting a number of the many controlling switches in a manner that still allows for the individual’s orderly (somatic) development” (“Adaptation, Neo-Darwinian Tautology, and Population Fitness,” 70). Our discussion in Chapter 13 suggests that the need to alter these functionally integrated switches also presents an obstacle to the efficacy of the neo-Darwinian mechanism.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5395-5399). HarperCollins. Kindle Edition.]
* Gould explained: “I do not refer to the saltational origin of entire new designs, complete in all their complex and integrated features. . . . Instead, I envisage a potential saltational origin for the essential features of key adaptations.”6 [Gould, “Is a New and General Theory of Evolution Emerging?” 127.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5405-5407). HarperCollins. Kindle Edition.]
* One approach falls under the rubric of “evo-devo” and conceives of mutations producing modifications in larger increments. Another, the neutral theory of evolution, sees mutations acting absent selection. Another, neo-Lamarckian “epigenetic inheritance,” envisions heritable alterations in epigenetic information influencing the future course of evolution. Still another, called “natural genetic engineering,” affirms that nonrandom genetic rearrangements drive evolutionary innovation.7 [Of course, the range of post-neo-Darwinian theories is not exhausted by this chapter’s survey of four prominent contenders. In a recent review paper, evolutionary biologist Armin Moczek, of Indiana University, examined three additional ideas attempting to move beyond what Moczek calls the “unrealistic and unproductive” assumptions of gene-centered neo-Darwinian theory. Those ideas are, respectively: (1) the theory of “facilitated variation” (Gerhart and Kirschner, “The Theory of Facilitated Variation”), the theory of “genetic accommodation” and “niche construction theory.” See Moczek, “The Nature of Nurture and the Future of Evodevo.” Short explanations and critiques of these models are posted on the website for this book, [www.darwinsdoubt.com](http://www.darwinsdoubt.com).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5418-5422). HarperCollins. Kindle Edition.]
* The neo-Darwinian synthesis has long emphasized that large-scale macroevolutionary change occurs as the inevitable by-product of the accumulation of small-scale “microevolutionary” changes within populations. The consensus in support of this idea began to fray in evolutionary biology during the early 1970s, when young paleontologists such as Gould, Niles Eldredge, and Steven Stanley realized that the fossil record did not show a pattern of gradual “micro-to-macro” change. In 1980, at a now famous symposium on macroevolution at the Field Museum in Chicago, the rebellion burst into full view, exposing what developmental biologist Scott Gilbert called “an underground current in evolutionary theory” among theorists who had concluded that “macroevolution could not be derived from microevolution.”9 [Gilbert, Opitz, and Raff, “Resynthesizing Evolutionary and Developmental Biology,” 362.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5429-5435). HarperCollins. Kindle Edition.]
* In 2007, I coauthored a textbook with several colleagues titled Explore Evolution. In it, we explained this “either/or” (“major-not-viable, viable-not-major”) dilemma and suggested that it posed a challenge to theories that rely on the mutation and selection mechanism to explain the origin of major morphological changes.14 [Meyer et al., Explore Evolution, 108.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5460-5462). HarperCollins. Kindle Edition.]
* For example, Jeffrey Schwartz, at the University of Pittsburgh, invokes mutations in Hox genes to explain the sudden appearance of animal forms in the fossil record. In his book Sudden Origins, Schwartz acknowledges the discontinuities in the fossil record. As he notes, “We are still in the dark about the origin of most major groups of organisms. They appear in the fossil record as Athena did from the head of Zeus—full-blown and raring to go, in contradiction to Darwin’s depiction of evolution as resulting from the gradual accumulation of countless infinitesimally minute variations.”22 [Schwartz, Sudden Origins, 3.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5500-5504). HarperCollins. Kindle Edition.]
* For instance, in arthropods the Hox gene Distal-less is required for the normal development of jointed arthropod legs. But in vertebrates a homologous gene (e.g., the Dlx gene in mice) builds a different kind of (nonhomologous) leg. Another homologue of the Distal-less gene in echinoderms regulates the development of tube feet and spines—anatomical features classically thought not to be homologous to arthropod limbs, nor to limbs of tetrapods.34 In each case, the Distal-less homologues play different roles determined by the higher-level organismal context. And since mutations in Hox genes do not alter higher-level epigenetic contexts,35 they cannot explain the origin of the novel epigenetic information and structure that establishes the context and that is necessary to building a new animal body plan.36 [34. Panganiban et al., “The Origin and Evolution of Animal Appendages.” 35. Instead, epigenetic information and structures actually determine the function of many Hox genes. This can be seen dramatically when the same Hox gene (as determined by nucleotide sequence homology) regulates the development of the strikingly different (i.e., classically nonhomologous) anatomical features found in different phyla. For instance, in arthropods, the Hox gene Distal-less is required for the normal development of limbs, but homologous genes are found in vertebrates (e.g., the Dlx gene in mice), where the gene also plays a key role in limb development—albeit a vertebrate (internal skeleton), not arthropod (external skeleton) limb. Distal-less homologues in yet other phyla, such as echinoderms, regulate the development of tube feet and spines—again, anatomical features classically not homologous to arthropod or vertebrates limbs. In each case, the roles of the Hox genes are governed “top-down” by the higher-level organismal contexts in which they occur. Panganiban et al., “The Origin and Evolution of Animal Appendages.” 36. Despite all this, some evolutionary theorists have argued that the emergence of Hox genes in Precambrian organisms may have triggered the Cambrian explosion by providing the raw materials for the diversification of body plans (Carroll, Patterns and Processes of Vertebrate Evolution). Yet, in addition to those difficulties already noted, recent studies have highlighted another problem with attributing the origin of body plans to Hox genes. Hox genes first emerged long before the diversification of the various bilaterian phyla, suggesting—because of the length of the time lag—that something else must have responsible for the Cambrian explosion. As a paper in the journal Science explains, “The temporal lag between the initial construction of these networks and the eventual appearance of bilaterian fossils suggests that the solution to the dilemma of the Cambrian explosion lies not solely with this genomic and developmental potential, but instead must also be found in the ecology of the Cambrian radiation itself” (Erwin et al., “The Cambrian Conundrum,” 1095). See also de Rosa et al., “Hox Genes in Brachiopods and Priapulids and Protostome Evolution.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5557-5565). HarperCollins. Kindle Edition.]
* As Lynch summarizes, “Three factors (low population sizes, low recombination rates and high mutation rates) conspire to reduce the efficiency of natural selection with increasing organism size.”37 Consequently, nonprotein-coding elements are not removed from the genome, but instead tend to accumulate, causing the genomes of organisms living in small populations to grow—even though these sequences may be neutral or even deleterious. Moreover, in small populations, “neutral” processes such as random mutation, genetic recombination, and genetic drift predominate in their effects over natural selection. [Lynch, “The Origins of Eukaryotic Gene Structure,” 454.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5579-5583). HarperCollins. Kindle Edition.]
* Extant eukaryotic organisms depend on a sophisticated molecular machine called a spliceosome—a machine that excises introns and fuses together exons (the portions of the genome that code for proteins) before gene expression takes place. “This large complex,” observes cell biologist Melissa Jurica, is “composed of over 150 individual proteins” and several structural RNAs, and thus “may indeed deserve the moniker ‘the most complicated macromolecular machine in the cell.’ ”39 [Jurica, “Detailed Closeups and the Big Picture of Spliceosomes,” 315. See also Butcher, “The Spliceosome as Ribozyme Hypothesis Takes a Second Step,” 12211–12; Nilsen, “The Spliceosome: The Most Complex Macromolecular Machine in the Cell?” 1147–49.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5610-5614). HarperCollins. Kindle Edition.]
* As he explains, “The continued insistence on the random nature of genetic change by evolutionists should be surprising for one simple reason: empirical studies of the mutational process have inevitably discovered patterns, environmental influences, and specific biological activities at the roots of novel genetic structures and altered DNA sequences.”55 The depth of Shapiro’s challenge to orthodox neo-Darwinism is profound. He rejects the randomness of novel variation that Darwin himself emphasized and that neo-Darwinian theorists throughout the twentieth century have reaffirmed.56 Instead, he favors a view of the evolutionary process that emphasizes preprogrammed adaptive capacity or “engineered” change, where organisms respond in a “cognitive” way to environmental influences, rearranging or mutating their genetic information in regulated ways to maintain viability. [55. Shapiro, Evolution, 2. 56. Shapiro contends that the neo-Darwinian insistence on fundamental randomness arose for philosophical, not empirical (or observational) reasons, having to do with the exclusion of “supernatural intervention” in the origin of organisms.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5779-5787). HarperCollins. Kindle Edition.]
* As an example, Shapiro notes that—contrary to the neo-Darwinian assumption that “DNA alterations are accidental”57—all organisms possess sophisticated cellular systems for proofreading and repairing their DNA during its replication. He notes that these systems are “equivalent to a quality-control system in human manufacturing,” where the “surveillance and correction” functions represent “cognitive processes, rather than mechanical precision.”58 [57. Shapiro, Evolution, 12. 58. Shapiro, Evolution, 14.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5787-5791). HarperCollins. Kindle Edition.]
* Shapiro argues that these and other kinds of directed, rather than random, genetic changes and responses to stimuli occur under “algorithmic control.” He describes the cell as “a powerful real-time distributed computing system”64 implementing various “if-then” subroutines. This emphatically challenges one of the three key elements of the neo-Darwinian triad: the claim that mutations and variations occur in a strictly random way. [Shapiro, “Darwin’s Black Box: The Biochemical Challenge to Evolution-Book Reviews.”] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5817-5821). HarperCollins. Kindle Edition.]

**17 The Possibility of Intelligent Design**

* Clearly, standard evolutionary theory has reached an impasse. Neither neo-Darwinism nor a host of more recent proposals (punctuated equilibrium, self-organization, evolutionary developmental biology, neutral evolution, epigenetic inheritance, natural genetic engineering) have succeeded in explaining the origin of the novel animal forms that arose in the Cambrian period. Yet all these evolutionary theories have two things in common: they rely on strictly material processes, and they also have failed to identify a cause capable of generating the information necessary to produce new forms of life. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5849-5853). HarperCollins. Kindle Edition.]
* This raises a question. Is it possible that a different or unexpected kind of cause might provide a more adequate explanation for the origin of the new form and information—as well as the other distinctive features—present in the Cambrian explosion? In particular, is it possible that intelligent design—the purposeful action of a conscious and rational agent—might have played a role in the Cambrian explosion? [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5854-5856). HarperCollins. Kindle Edition.]
* As the late Harvard evolutionary biologist Ernst Mayr explains: “The real core of Darwinism . . . is the theory of natural selection. This theory is so important for the Darwinian because it permits the explanation of adaptation, the ‘design’ of the natural theologian, by natural means.”2 Or as another prominent evolutionary biologist, Francisco Ayala, has put it succinctly, natural selection explains “design without a designer.”3 [2. Mayr, Foreword, in Ruse, ed., Darwinism Defended, xi–xii. 3. Ayala, “Darwin’s Greatest Discovery,” 8572.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5880-5885). HarperCollins. Kindle Edition.]
* Other contemporary neo-Darwinian biologists including Richard Dawkins, Francis Crick, and Richard Lewontin have also emphasized that biological organisms only appear to have been designed.4 They recognize that many biological structures—whether the chambered nautilus, the compound eye of a trilobite, the electrical system of the mammalian heart, or numerous molecular machines—attract our attention because the sophisticated organization of such systems is reminiscent of our own designs. Dawkins has noted, for example, that the digital information in DNA bears an uncanny resemblance to computer software or machine code.5 He explains that many aspects of livings systems “give the appearance of having been designed for a purpose.”6 [4. As Dawkins notes: “Biology is the study of complicated things that give the appearance of having been designed for a purpose” (The Blind Watchmaker, 1). Crick likewise explains: “Organisms appear as if they had been designed to perform in an astonishingly efficient way, and the human mind therefore finds it hard to accept that there need be no Designer to achieve this” (What Mad Pursuit, 30). Lewontin also observes that living organisms “appear to have been carefully and artfully designed” (“Adaptation”). 5. Dawkins, River Out of Eden, 17. 6. Dawkins, The Blind Watchmaker, 1.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5885-5892). HarperCollins. Kindle Edition.]
* But it was in the book’s epilogue that the three scientists proposed a radical alternative. There they suggested that the information-bearing properties of DNA might point to the activity of a designing intelligence—to the work of a mind, or an “intelligent cause” as they put it.8 Drawing on the analysis of the British-Hungarian physical chemist Michael Polanyi, they argued that chemistry and physics alone could not produce the information in DNA any more than ink and paper alone could produce the information in a book. Instead, they argued that our uniform experience suggests a cause-and-effect relationship between intelligent activity and the production of information.9 [8. Thaxton, Bradley, and Olsen, The Mystery of Life’s Origin, 211. 9. We have observational evidence in the present that intelligent investigators can (and do) build contrivances to channel energy down nonrandom chemical pathways to bring about some complex chemical synthesis, even gene building. May not the principle of uniformity then be used in a broader frame of consideration to suggest that DNA had an intelligent cause at the beginning? (Thaxton, Bradley, and Olsen, The Mystery of Life’s Origin, 211).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5927-5932). HarperCollins. Kindle Edition.]
* In my research, I discovered that historical scientists often do make inferences with a distinctive logical form. This type of inference is known technically as an abductive inference.10 [Peirce, Collected Papers, 2:372–88; Meyer, “Of Clues and Causes,” 25. See also Whewell, “Lyell’s Principles of Geology”; The Philosophy of the Inductive Sciences.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 5956-5958). HarperCollins. Kindle Edition.]

**18 Signs of Design in the Cambrian Explosion**

* In saying this, Erwin emphasizes the uniqueness of the innovations that occurred in the Cambrian explosion. He explains: “Unlike later events, the most significant developmental events of the Cambrian radiation involved the proliferation of cell types, developmental hierarchies and epigenetic cascades.”4 Consequently, he concludes, “The crucial difference between the developmental events of the Cambrian and subsequent events is that the former involved the establishment of these developmental patterns, not their modification.”5 For this reason, Erwin denies that the central event of the Cambrian explosion—the origin of novel body plans—has any parallel to currently observed biological processes. Rather, he insists that the events of the past were fundamentally different—that profound asymmetries exist between evolution then, and evolution now.6 Thus, he amplifies his denial of the sufficiency of current evolutionary theory by adding one additional attribute, albeit a negative one, to his portrait of “the suspect”: the cause responsible for generating the new animal forms, whatever it was, must have been unlike any observed biological process operating in actual living populations today. [4. Erwin, “Early Introduction of Major Morphological Innovations,” 288. 5. Erwin, “Early Introduction of Major Morphological Innovations,” 288, emphasis added. 6. As Erwin puts it: “There is every indication that the range of morphological innovation possible in the Cambrian is simply not possible today” (“The Origin of Body Plans,” 626, emphasis added).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6187-6197). HarperCollins. Kindle Edition.]
* As Richard Dawkins observes, for example, “The machine code of the genes is uncannily computer-like.”10 [Dawkins, River Out of Eden, 17.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6237-6238). HarperCollins. Kindle Edition.]
* Richard Dawkins, Bernd-Olaf Küppers, and others have developed computer programs that putatively simulate the production of genetic information by mutation and natural selection.15 Yet these programs succeed only by the illicit expedient of providing the computer with a “target sequence” and then treating proximity to future function (i.e., the target sequence), not actual present function, as a selection criterion. As mathematician David Berlinski shows, genetic algorithms need something akin to a “forward-looking memory” in order to succeed.16 Yet such foresighted selection has no analogue in nature. In biology, where differential survival depends upon maintaining function, natural selection cannot occur before new functional sequences arise. Natural selection lacks foresight; the process, as evolutionary theorists Rodin and Szathmáry note, works strictly “ ‘in the present moment,’ right here and right now . . . lacking the foresight of potential future advantages.”17 [15. Dawkins, The Blind Watchmaker, 47–49; Küppers, “On the Prior Probability of the Existence of Life”; Scheider, “The Evolution of Biological Information”; Lenski, “The Evolutionary Origin of Complex Features.” For a critique of these genetic algorithms and claims that they simulate the ability of natural selection and random mutation to generate new biological information apart from intelligent activity, see Meyer, Signature in the Cell, 281–95. 16. Berlinski, “On Assessing Genetic Algorithms.” 17. Rodin, Szathmáry, and Rodin, “On the Origin of the Genetic Code and tRNA Before Translation,” 2.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6293-6301). HarperCollins. Kindle Edition.]
* As Nelson and Jonathan Wells note, “An intelligent cause may reuse or redeploy the same module in different systems, without there necessarily being any material or physical connection between those systems.”27 They also observe that intelligent agents “can generate identical patterns independently” and put them to different uses in different systems of parts: If we suppose that an intelligent designer constructed organisms using a common set of polyfunctional genetic modules—just as human designers, for instance, may employ the same transistor or capacitor in a car radio or a computer, . . . then we can explain why we find the “same” genes expressed in the development of what are very different organisms. . . . A particular gene, employed for its DNA-binding properties, finds its functional role in a higher-level system whose ultimate origin was intelligently caused.28 [27. Nelson and Wells, “Homology in Biology,” 316. 28. Nelson and Wells, “Homology in Biology,” 316.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6432-6440). HarperCollins. Kindle Edition.]
* As biologist Michael Denton expresses it, “What is true of sentences and watches is also true of computer programs, airplane engines, and in fact of all known complex systems. Almost invariably, function is restricted to unique and fantastically improbable combinations of subsystems, tiny islands of meaning lost in an infinite sea of incoherence.”32 In fact, such structural disparity or morphological isolation constitutes a diagnostic of designed systems—that is, a feature of systems for which only one kind of cause—an intelligent cause—is known. [Denton, Evolution, 313.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6550-6555). HarperCollins. Kindle Edition.]

**19 The Rules of Science**

* In 1997, in an article in the New York Review of Books, Harvard geneticist Richard Lewontin made explicit a similar commitment to a strictly materialistic explanation—whatever the evidence might seem to indicate. As he explained in a now often quoted passage: We take the side of science in spite of the patent absurdity of some of its constructs, in spite of its failure to fulfill many of its extravagant promises of health and life, in spite of the tolerance of the scientific community for unsubstantiated just-so stories, because we have a prior commitment, a commitment to materialism. It is not that the methods and institutions of science somehow compel us to accept a material explanation of the phenomenal world, but, on the contrary, that we are forced by our a priori adherence to material causes to create an apparatus of investigation and a set of concepts that produce material explanations, no matter how counter-intuitive, no matter how mystifying to the uninitiated. Moreover, that materialism is absolute, for we cannot allow a Divine Foot in the door.12 [Lewontin, “Billions and Billions of Demons,” 28. The role of methodological materialism in artificially buttressing Darwin’s theory began with Darwin himself. According to historian of science Neal Gillespie: “The uneasy reservations about natural selection among Darwin’s contemporaries and the widespread rejection of it from the 1890s to the 1930s suggest that . . . it was more Darwin’s insistence on totally natural explanations than on natural selection that won their adherence. . . . The primary change had not been in speciation theory but in beliefs about the nature of science.” In short, Darwin’s new definition of science excluded “both direct and indirect design” in living things and thereby protected it from competition (Charles Darwin and the Problem of Creation, 123, 147, 152).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6668-6676). HarperCollins. Kindle Edition.]
* Advocates of methodological naturalism have argued that the theory of intelligent design is inherently unscientific for some, or all, of the following reasons: (a) is not testable,21 (b) is not falsifiable,22 (c) does not make predictions,23 (d) does not describe repeatable phenomena, (e) does not explain by reference to natural law,24 (f) does not cite a mechanism,25 (g) does not make tentative claims,26 and (h) has no problem-solving capability.27 They have also claimed that it is not science because it (i) refers to an unobservable entity.28 These critics also assume, imply, or assert that materialistic evolutionary theories do meet such criteria of proper scientific method. [21. Gould, “Creationism”; Ruse, “Witness Testimony Sheet”; Ebert et al., Science and Creationism, 8–10. 22. Kline, “Theories, Facts and Gods,” 42; Gould, “Evolution as Fact and Theory,” 120; Root-Bernstein, “On Defining a Scientific Theory,” 72. 23. Root-Bernstein, “On Defining a Scientific Theory,” 73; Ruse, “A Philosopher’s Day in Court,” 28; Ebert et al., Science and Creationism, 8–10. 24. Ruse, “Witness Testimony Sheet,” 301; “A Philosopher’s Day in Court,” 26; “Darwinism: Philosophical Preference, Scientific Inference, and a Good Research Strategy,” 1–6. 25. Ruse, Darwinism Defended, 59; “Witness Testimony Sheet,” 305; Gould, “Evolution as Fact and Theory,” 121; Root-Bernstein, “On Defining a Scientific Theory,” 74. 26. Kehoe, “Modern Anti-Evolutionism”; Ruse, “Witness Testimony Sheet,” 305; “A Philosopher’s Day in Court,” 28; Ebert et al., Science and Creationism, 8. 27. Kitcher, Abusing Science, 126–27, 176–77. 28. Skoog, “A View from the Past”; Root-Bernstein, “On Defining a Scientific Theory,” 74; Scott, “Keep Science Free from Creationism,” 30.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6737-6746). HarperCollins. Kindle Edition.]
* As William Dembski, a leading design proponent, predicted in 1998, “On an evolutionary view we expect a lot of useless DNA. If, on the other hand, organisms are designed, we expect DNA, as much as possible, to exhibit function.”43 [Dembski, “Science and Design,” 26.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 6953-6955). HarperCollins. Kindle Edition.]

**20 What’s at Stake**

* In particular, two popular ideas about how Darwinism informs worldview have come to different conclusions about the worldview it affirms—or allows. The first view, the “New Atheism,” has been articulated by spokesmen such as Richard Dawkins in his book The God Delusion and the late Christopher Hitchens in God Is Not Great.1 It purports to refute the existence of God as “a failed hypothesis,”2 as another New Atheist book puts it. Why? Because, according to Dawkins and others, there is no evidence of design in nature. [1. Dawkins, The God Delusion; Hitchens, God Is Not Great; Stenger, God: The Failed Hypothesis. 2. Stenger, God: The Failed Hypothesis.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7079-7084). HarperCollins. Kindle Edition.]
* The New Atheists took the publishing world by storm in 2006 when The God Delusion first appeared. But nothing about the “New” Atheism was actually “new.” Instead, it represents a popularization of a science-based philosophy, called scientific materialism, that came into currency among scientists and philosophers during the late nineteenth century in the wake of the Darwinian revolution. For many scientists and scholars at the time, a scientifically informed worldview was a materialistic worldview in which entities such as God, free will, mind, soul, and purpose played no role. Scientific materialism, following classical Darwinism, denied evidence of any design in nature and, therefore, any ultimate purpose to human existence. As British philosopher and mathematician Bertrand Russell put it early in the twentieth century, “Man is the product of causes which had no prevision of the end they were achieving” and which predestine him “to extinction in the vast death of the solar system.”4 [Russell, quoted in Conant, Modern Science and Modern Man, 139–40.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7089-7096). HarperCollins. Kindle Edition.]
* An alternative and increasingly popular view is known as theistic evolution. Popularized by Christian geneticist Francis Collins in his book The Language of God (also published in 2006),5 this perspective affirms the existence of God and the Darwinian account of biological origins. Yet it provides few details about how God might or might not influence the evolutionary process, or how to reconcile seemingly contradictory claims in the Darwinian and Judeo-Christian accounts of origins. [Collins, The Language of God. See also Giberson, Saving Darwin; Miller, Finding Darwin’s God.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7097-7101). HarperCollins. Kindle Edition.]
* For example, Collins has declined to say whether he thinks God in any way directed or guided the evolutionary process, though he affirms neo-Darwinism, which specifically denies that natural selection is guided in any way. Darwinism and neo-Darwinism insist that the appearance of design in living organisms is an illusion because the mechanism that produces that appearance is unguided and undirected. Does God, in Collins’s view, guide the unguided process of natural selection? He, and many other theistic evolutionists, don’t say. This ambiguity has made an uneasy reconciliation of science and faith possible, but it has also left many questions unanswered. In fairness, many theistic evolutionists would argue that not all such questions can be answered, because science and faith occupy separate, non-overlapping realms of inquiry, knowledge, and experience. But that answer itself underscores the limits of the harmonization of science and faith that Collins and others holding his view has achieved. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7101-7107). HarperCollins. Kindle Edition.]
* This book has presented four separate scientific critiques demonstrating the inadequacy of the neo-Darwinian mechanism, the mechanism that Dawkins assumes can produce the appearance of design without intelligent guidance. It has shown that the neo-Darwinian mechanism fails to account for the origin of genetic information because: (1) it has no means of efficiently searching combinatorial sequence space for functional genes and proteins and, consequently, (2) it requires unrealistically long waiting times to generate even a single new gene or protein. It has also shown that the mechanism cannot produce new body plans because: (3) early acting mutations, the only kind capable of generating large-scale changes, are also invariably deleterious, and (4) genetic mutations cannot, in any case, generate the epigenetic information necessary to build a body plan. Thus, despite the commercial success of The God Delusion and its wide cultural currency, the New Atheist philosophy lacks credibility because it has based its understanding of the metaphysical implications of modern science on a scientific theory that itself lacks credibility—as even many leading evolutionary biologists now acknowledge.6 [For prominent critics of the neo-Darwinian consensus, see Chapter 14, n. 42.] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7112-7120). HarperCollins. Kindle Edition.]
* The perspective of this book offers a potentially more coherent and satisfying way of addressing the big questions, of synthesizing science and metaphysics (or faith), than either of the currently popular views on offer. The Cambrian explosion, like evolutionary theory itself, raises larger worldview questions precisely because it raises questions of origins and of design, and with them, the question that all worldviews must address: What is the thing or the entity from which everything comes? But unlike strict Darwinian materialism and the New Atheism built atop it, the theory of intelligent design affirms the reality of a designer—a mind or personal intelligence behind life. This case for design restores to Western thought the possibility that human life in particular may have a purpose or significance beyond temporary material utility. It suggests the possibility that life may have been designed by an intelligent person, indeed, one that many would identify as God. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7131-7137). HarperCollins. Kindle Edition.]
* It occurred to me only much later how closely his experience parallels our own as human beings trying to make sense of the world around us. To gain a true picture of the world and our place in it we need facts—empirical data. But we also need perspective, sometimes called wisdom, the reference points that a coherent view of the world provides. Historically, that wisdom was provided for many men and women by the traditions of Western monotheism—by our belief in God. The theory of intelligent design generates both excitement and loathing because, in addition to providing a compelling explanation of the scientific facts, it holds out the promise of help in integrating two things of supreme importance—science and faith—that have long been seen as at odds.8 [As Alfred North Whitehead said, “When we consider what religion is for mankind and what science is, it is no exaggeration to say that the future course of history depends upon the decision of this generation as to the relations between them” (Science and the Modern World, 260).] [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7152-7158). HarperCollins. Kindle Edition.]
* The theory of intelligent design is not based upon religious belief, nor does it provide a proof for the existence of God. But it does have faith-affirming implications precisely because it suggests the design we observe in the natural world is real, just as a traditional theistic view of the world would lead us to expect. Of course, that by itself is not a reason to accept the theory. But having accepted it for other reasons, it may be a reason to find it important. [Stephen C. Meyer: ***Darwin's Doubt*** (Kindle Locations 7158-7162). HarperCollins. Kindle Edition.]

الحمد لله الذي بنعمته تتمّ الصَّالِحات