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THE PARADOX OF THE PARADIGM
Punctuated Equilibrium and the Nature of Revolutionary Science

> Down went the owners—greedy men whom hope of gain allured:
> Oh, dry the starting tear, for they were heavily insured.
> —W. S. Gilbert, *The 'Bab' Ballads*, "Etiquette"

STEPHEN JAY GOULD CAN FIND meaning and metaphor in the most unusual of literary places, so perhaps we can consider this consoling advice of his favorite operatic authors in the light of ambitious proprietors of scientific ideas who have apparently been rejected, as later exonerated by the insurance of the truth. But how can we know today who will be villified or venerated tomorrow? As paranormalists are fond of saying (after citing such notable blunders as Lord Kelvin's paper "proving" that heavier-than-air craft could not fly), "they laughed at the Wright Brothers." The standard rejoinder, made by skeptics for both levity and effect, is: "They also laughed at the Marx Brothers."

The point is that specific historical references to wrongly rejected theories is not a general principle that applies to all cases of intellectual rebuff. Every instance of dismissal has its peculiar set of historical contingencies that led to that outcome. Historical abnegation does not automatically equal future vindication. For every Columbus, Copernicus, and Galileo who turned out to be right, there are a thousand Velikovskys (*Worlds in Collision*), von Danikens (ancient astronauts), and Newmans (perpetual motion machines) who turned out to be wrong.

This is why scientists and skeptics bristle when they hear descriptions such

as "revolutionary," "earth-shattering," and "paradigm shift" freely thrown about by any and all would-be (and wanna-be) revolutionaries. To reverse the analysis, however, just because some quacks and flimflam artists (and genuinely honest thinkers) making claims of a new paradigm are wrong, does not mean that *all* challenging new ideas will go the way of colliding planets, ancient astronauts, and perpetual motion machines. We must examine each claim on its own.

In 1992 *Skeptic* magazine marked the 150th anniversary of Charles Darwin's first essay on natural selection, and the 20th anniversary of Niles Eldredge's and Stephen Jay Gould's first paper on punctuated equilibrium, by considering their status as paradigms. Few would challenge the idea that Darwin's theory of evolution by natural selection triggered a paradigm shift, but many are skeptical that punctuated equilibrium deserves equal status as a new paradigm. Since Darwinism is alive and well as we begin the twenty-first century it seems paradoxical to even consider the question. Darwinism displaced creationism, but itself has not been displaced, so no other paradigm shift can have occurred.

This is what I call the *paradox of the paradigm*. It is a false dichotomy created, in part, by our assumption that only one paradigm may rule a scientific field at any one time, and that paradigms can only "shift" from one to another, instead of building upon one another (and cohabitating within the same field). What I wish to argue is that there exists simultaneously an overarching Darwinian paradigm and a subsidiary punctuated equilibrium paradigm, both constituting paradigm shifts (with the former significantly broader in scope and the latter more narrowly focused), and that they presently and peacefully coexist and share overlapping methods and models. The paradigm paradox disappears when we define with semantic precision science, paradigm, and paradigm shift, and eschew the either-or fallacy of a false alternative choice by seeing punctuated equilibrium as a paradigm set within a larger Darwinian paradigm.

THE SCIENCE OF PARADIGMS

Science is a specific way of thinking and acting common to most members of a scientific group, as a tool to understand information about the past or present. More formally, I define science as *a set of cognitive and behavioral methods to describe and interpret observed or inferred phenomenon, past or present, aimed at building a testable body of knowledge open to rejection or confirmation.* Cognitive methods include hunches, guesses, ideas, hypotheses, theories, and paradigms; behavioral methods include background research, data collection and organi-

zation, colleague collaboration and communication, experiments, correlation of findings, statistical analyses, manuscript preparation, conference presentations, and paper and book publications.

There are two major methodologies in the sciences—experimental and historical. Experimental scientists (e.g., physicists, geneticists, experimental psychologists) constitute what most people think of when they think of scientists in the laboratory with their particle accelerators, fruit flies, and rats. But historical scientists (e.g., cosmologists, paleontologists, archaeologists) are no less rigorous in their cognitive and behavioral methods to describe and interpret past phenomena, and they share the same goal as experimental scientists of building a testable body of knowledge open to rejection or confirmation. Unfortunately a hierarchical order exists in the academy, as well as in the general public, in two orthogonal directions: (1) experimental sciences higher than historical sciences, (2) physical sciences higher than biological sciences higher than social sciences. Within both of these there exists a corresponding ranking from hard science to soft (with experimental physicists on top and social scientists and historians on the bottom), further discoloring our perceptions of how science is done. The sooner we can overcome what is known colloquially as "physics envy," the deeper will be our understanding of the nature of the scientific enterprise.

One common element within both the experimental and historical sciences, as well as within the physical, biological, and social sciences, is that they all operate within defined paradigms, as originally described by Thomas Kuhn in 1962 as a way of thinking that defines the "normal science" of an age, founded on "past scientific achievements . . . that some particular scientific community acknowledges for a time as supplying the foundation for its further practice."[1] Kuhn's concept of the paradigm has achieved nearly cult status in both elite and populist circles (even motivation speakers—as populist as they come—speak of shifting paradigms). But he has been challenged time and again for his multiple usages of the term without semantic clarification.[2] His 1977 expanded meaning of "all shared group commitments, all components of what I now wish to call the disciplinary matrix," still fails to give the reader a sense of just what Kuhn means by paradigm.[3]

Because of this lack of clarity, and based on the definition of science above, I define a paradigm as *framework(s) shared by most members of a scientific community, to describe and interpret observed or inferred phenomena, past or present, aimed at building a testable body of knowledge open to rejection or confirmation.* The singular/plural option and the modifier "shared by most" is included to allow

for competing paradigms to coexist, compete with, and sometimes displace old paradigms, and to show that a paradigm(s) may exist even if all scientists working in the field do not accept it/them. Philosopher Michael Ruse, in fact, identified four usages of "paradigm" in his attempt to answer the question "Is the theory of punctuated equilibria a new paradigm?"[4] These include:

(1) *Sociological*, focusing on "a group of people who come together, feeling themselves as having a shared outlook (whether they do really, or not), and to an extent separating themselves off from other scientists."

(2) *Psychological*, where individuals within the paradigm literally and figuratively see the world differently from those outside the paradigm. An analogy can be made to people viewing the reversible figures in perceptual experiments, for example, the old woman/young woman shifting figure where the perception of one precludes the perception of the other.

(3) *Epistemological*, where "one's ways of doing science are bound up with the paradigm" because the research techniques, problems, and solutions are determined by the hypotheses, models, theories, and laws.

(4) *Ontological*, where in the deepest sense "what there is depends crucially on what paradigm you hold. For Priestley, there literally was no such thing as oxygen. . . . In the case of Lavoisier, he not only believed in oxygen: oxygen existed."

In my definition of paradigm the shared cognitive framework for interpreting observed or inferred phenomena can be used in the sociological, psychological, and epistemological sense. To make it wholly ontological, however, risks drawing the conclusion that one paradigm is as good as any other paradigm because there is no outside source for corroboration. Tea-leaf reading and economic forecasting, sheep's livers and meteorological maps, astrology and astronomy, all equally determine reality if one fully accepts the ontological construct of a paradigm. But paradigms are not equal in their ability to understand, predict, or control nature. As difficult as it is for economists and meteorologists to understand, predict, and control the actions of the economy and the weather, they are still better at it than tea-leaf readers and sheep's liver diviners.

The other component of science that makes it different from all other paradigms and allows us to resolve the paradigm paradox is that it has a self-correcting feature that operates, after a fashion, like natural selection functions in nature. Science, like nature, preserves the gains and eradicates the mistakes. When paradigms shift (e.g., during scientific revolutions) scientists do not necessarily abandon the entire paradigm any more than a new species is begun from scratch. Rather, what remains useful in the paradigm is retained, as new features

are added and new interpretations given, just as in homologous features of organisms the basic structures remain the same while new changes are constructed around it. Thus, I define a *paradigm shift as a new cognitive framework, shared by a minority in the early stages and a majority in the later, that significantly changes the description and interpretation of observed or inferred phenomena, past or present, aimed at improving the testable body of knowledge open to rejection or confirmation.*

As Einstein observed about his own new paradigm of relativity (which added to Newtonian physics but did not displace it):

> Creating a new theory is not like destroying an old barn and erecting a skyscraper in its place. It is rather like climbing a mountain, gaining new and wider views, discovering unexpected connections between our starting point and its rich environment. But the point from which we started out still exists and can be seen, although it appears smaller and forms a tiny part of our broad view gained by the mastery of the obstacles on our adventurous way up.[5]

The shift from one paradigm to another may be a mark of improvement in the understanding of causality, the prediction of future events, or the alteration of the environment. It is, in fact, the attempt to refine and improve the paradigm that may ultimately lead to either its demise or to the sharing of the field with another paradigm, as anomalous data unaccounted for by the old paradigm (as well as old data accounted for but capable of reinterpretation) fit into the new paradigm in a more complete way.

Science allows for both cumulative growth and paradigmatic change. This is *scientific progress,* which I define as *the cumulative growth of a system of knowledge over time, in which useful features are retained and non-useful features are abandoned, based on the rejection or confirmation of testable knowledge.*

THE PUNCTUATED EQUILIBRIUM PARADIGM

A deeper question to ask about paradigms is what causes them to shift and who is most likely to be involved in the shift? Kuhn answers the question this way: "Almost always the men who achieve these fundamental inventions of a new paradigm have either been very young or very new to the field whose paradigm they change."[6] Kuhn was reflecting Max Planck's famous quip: "An important scientific innovation rarely makes its way by gradually winning over and con-

verting its opponents. What does happen is that its opponents gradually die out and that the growing generation is familiarized with the idea from the beginning."[7] In his 1996 book, *Born to Rebel*, social scientist Frank Sulloway presented experimental and historical evidence for the relationship between age and receptivity to radical ideas, with openness related to youthfulness (see chapter 6 for a complete discussion).[8]

It was in 1972 that two young newcomers to the field of paleontology and evolutionary biology, Niles Eldredge and Stephen Jay Gould, presented the theory of punctuated equilibrium. What Eldredge and Gould proposed is a model of nonlinear change—long periods of equilibrium punctuated by, in geological terms, "sudden" change. This appears to contrast sharply with the Darwinian gradualistic model of linear change—slow and steady (and so minute it cannot be observed) transformation that given enough time can produce significant change. Thus its challenge to the Darwinian paradigm might be considered by some to be a paradigm shift. Michael Ruse called punctuated equilibria a paradigm "as far as the sociological aspect is concerned," but he expressly denies it paradigm status at the psychological, epistemological, and ontological levels.[9] We shall see.

The development of the theory of punctuated equilibrium was stimulated by Tom Schopf, who in 1971 organized a symposium integrating evolutionary biology with paleontology. The goal was to apply theories of modern biological change to the history of life. Eldredge had already done this with a 1971 paper in the prestigious journal *Evolution*, under the title "The Allopatric Model and Phylogeny in Paleozoic Invertebrates."[10] Schopf then directed Gould and Eldredge to collaborate on a paper applying theories of speciation to the fossil record, and this resulted in a paper published in 1972 in the volume *Models in Paleobiology* (with Schopf as the editor). This paper was entitled "Punctuated Equilibria: An Alternative to Phyletic Gradualism."[11] Gould explained that he coined the term but "the ideas came mostly from Niles, with yours truly acting as a sounding board and eventual scribe."[12] In brief, they argued that Darwin's linear model of change could not account for the apparent lack of transitional species in the fossil record. Darwin himself was acutely aware of this and stated so up front in the *Origin of Species*: "Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic chain; and this, perhaps, is the gravest objection which can be urged against my theory."[13]

Ever since the *Origin* the missing transitional forms have vexed paleontologists and evolutionary biologists. Collectively both groups have tended to ignore

the problem, usually dismissing it as an artifact of a spotty fossil record. (This is actually a reasonable argument considering the exceptionally low probability of any dead animal escaping the jaws and stomachs of scavengers and detritus feeders, reaching the stage of fossilization, and then somehow finding its way back to the surface through geological forces and contingent events to be discovered millions of years later. It's a wonder we have as many fossils as we do.) Eldredge and Gould, however, see the gaps in the fossil record not as missing evidence of gradualism but as extant evidence of punctuation. Stability of species is so enduring that they leave plenty of fossils (comparatively speaking) in the strata while in their stable state. The change from one species to another, however, happens relatively quickly (on a geological time scale) in "a small subpopulation of the ancestral form," and occurs "in an isolated area at the periphery of the range," thus leaving behind few fossils. Therefore, the authors conclude, "breaks in the fossil record are real; they express the way in which evolution occurs, not the fragments of an imperfect record."[14]

Punctuated equilibrium is primarily the application of Ernst Mayr's theory of allopatric speciation to the history of life. Mayr's theory states that living species most commonly give rise to a new species when a small group breaks away (the "founder" population) and becomes geographically (and thus reproductively) isolated from the ancestral group. This new founder group (the "peripheral isolate"), as long as it remains small and detached, may experience relatively rapid change (large populations tend to sustain genetic homogeneity). The speciational change happens so rapidly that few fossils are left to record it. But once changed into a new species they will retain their phenotype for a considerable time, living in relatively large populations and leaving behind many well preserved fossils. (See FIGURE 13.) Millions of years later this process results in a fossil record that records mostly the equilibrium. The punctuation is there in the blanks.

Eldredge and Gould claim in this first paper that "the idea of punctuated equilibria is just as much a preconceived picture as that of phyletic gradualism," and that their "interpretations are as colored by our preconceptions as are the claims of the champions of phyletic gradualism." There is, however, a sense of paradigmatic progress when they note that "the picture of punctuated equilibria is more in accord with the process of speciation as understood by modern evolutionists."[15] It is not just that the gaps in the fossil record can now be ignored, but that they are real data. Thus, the gradualistic "tree of life" depicted by Darwin in the *Origin*, appears to be in conflict with the punctuated model of Eldredge and Gould. If punctuated equilibrium is a paradigm, this would appear

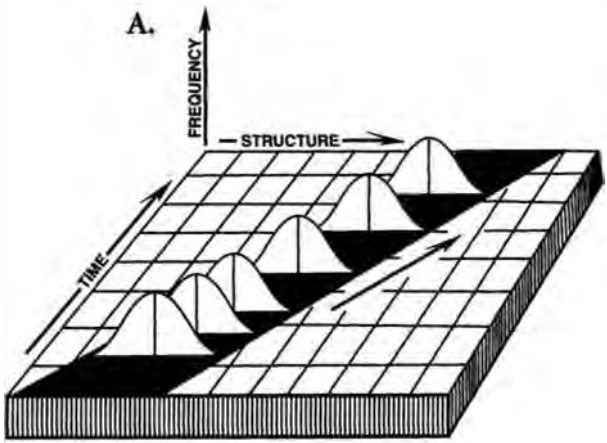
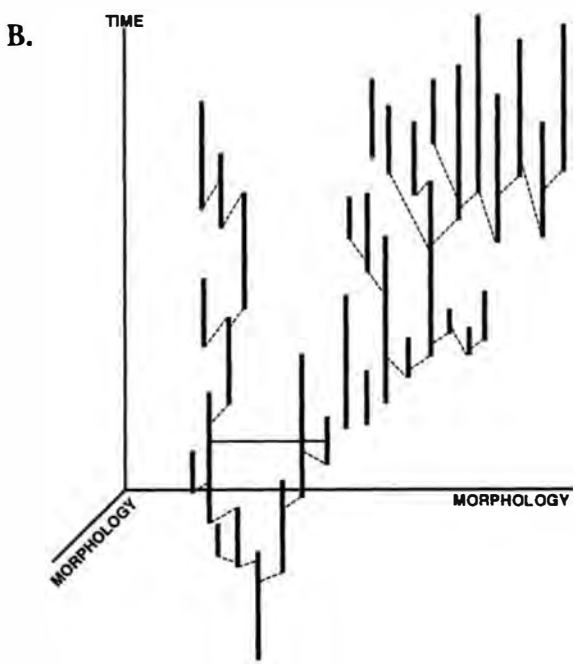


Figure 13. Competing or complementary paradigms? A. Above, the gradualistic model of shifting means of species characteristics through time (from Moore, et al., 1952). B. The punctuated equilibrium model, below, with static species abruptly giving rise to new species through geological time (from Eldredge and Gould, 1972).



to be a paradigm shift, and thus we would be forced to accept the problem of the paradigm paradox and choose between the two competing models of evolutionary change.

The reaction to the theory, in Gould's words, "provoked a major brouhaha, still continuing, but now in much more productive directions."[16] Initially, says Gould, paleontologists missed the connection with allopatric speciation because "they had not studied evolutionary theory . . . or had not considered its translation to geological time." Evolutionary biologists "also failed to grasp the implication, primarily because they did not think at geological scales."[17] Though more in acceptance now, the theory at first received a thorough round of bashing for both good and bad reasons, the latter of which, Gould observes, include the "misunderstanding of basic content"; association with creationists who misrepresented the theory as spelling the demise of Darwin and all evolutionary theory; and, "this is harder to say but cannot be ignored, a few colleagues allowed personal jealousy to cloud their judgment."[18] Of course, the critical pounding could also be because Eldredge and Gould are wrong. But I think something else is going on here. The veracity of punctuated equilibrium aside, the paradigm paradox has forced observers to judge punctuated equilibrium as either completely right or totally wrong, when it can clearly be judged in fuzzy shades of correctness or wrongness, depending on the specific cases under question. In fact, Ruse notes that Eldredge and Gould "have polarized evolutionists in such a way that punctuated equilibria theory has defining paradigm properties at the social level."[19] Why must paradigms polarize? Because of this unresolved paradox.

Of course, we cannot judge a book by its author. As Gould confesses, "the worst possible person to ask about the genesis of a theory is the generator himself."[20] The ideal person to ask is a second generation student of the first generators, which I found in Occidental College world-class paleontologist Donald Prothero, who was a college freshman in 1973 when his paleontology class was assigned the new Raup and Stanley textbook, *Principles of Paleontology,* focusing on theoretical issues of fossil interpretation. Is punctuated equilibrium a paradigm, and was there a paradigm shift? Applying my definition of each, we can restate the question in several parts.

1. *Was punctuated equilibrium a new cognitive framework?* Yes and no. Yes, says Don Prothero, who writes that before punctuated equilibrium, "Virtually all the paleontology textbooks of the time were simply compendia of fossils. The meetings of the Paleontological Society at the Geological Society of America convention were dominated by descriptive papers." After the introduction

of the theory, new theoretical journals sprang up, old journals changed their emphasis from description to theory, and paleontological conferences were "packed with mind-boggling theoretical papers."[21]

No says Ernst Mayr, who makes it clear that *he* "was the first author to develop a detailed model of the connection between speciation, evolutionary rates, and macroevolution" and thus he finds it curious "that the theory was completely ignored by paleontologists until brought to light by Eldredge and Gould."[22] Mayr recalls that "In 1954 I was already fully aware of the macroevolutionary consequences of my theory," quoting himself as saying that "rapidly evolving peripherally isolated populations may be the place of origin of many evolutionary novelties. Their isolation and comparatively small size may explain phenomena of rapid evolution and lack of documentation in the fossil record, hitherto puzzling to the palaeontologist."[23] In a 1999 interview with Mayr (still going strong at the remarkable age of 95), he clarified for me the proper priority for the paradigm of punctuated equilibrium:

> I published that theory in a 1954 paper and I clearly related it to paleontology. Darwin argued that the fossil record is very incomplete because some species fossilize better than others. But what I derived from my research in the South Sea islands is that you get these isolated little populations for which it is much easier to make a genetic restructuring because it is small so it takes rather few steps to become a new species. Being a small local population that changes very rapidly I noted that you are never going to find them in the fossil record. My essential point was that gradual populational shifts in founder populations appear in the fossil record as gaps.[24]

I then pointed out to Mayr that Eldredge and Gould did credit him, citing his 1963 book *Animal Species and Evolution* several times. To this Mayr responded: "Gould was for three years my course assistant at Harvard where I presented this theory again and again, so he thoroughly knew it, so did Eldredge. In fact, Eldredge in his 1971 paper credited me with it. But that was lost over time."[25]

Was it lost over time? All professionals I have spoken to about punctuated equilibrium recognize this fact, as they do Niles Eldredge's solo paper published in *Evolution* in 1971. As Prothero concludes, however, it was the joint Eldredge and Gould paper published in 1972 that "has been the focus of all the controversy." Even Mayr admits: "Whether one accepts this theory, rejects, it, or greatly modifies it, there can be no doubt that it had a major impact on paleontology and evolutionary biology."[26]

What this historical development provides is further evidence for the social and psychological nature of paradigms. There are many reasons for the eighteen-year delay between Mayr's 1954 paper and Eldredge's and Gould's 1972 paper, having to do with the recent completion of the modern synthesis in evolutionary biology and, along sociological lines, who was proferring the theory. In a pure and unsullied scientific enterprise it should not matter who makes the discovery, when, and how it is presented. But science is not the objective process we would like it to be, and these factors do make a difference.

2. *Was punctuated equilibrium shared by a minority in the early stages and by a majority in the later?* Again, we must answer yes and no. Yes, says Prothero, and the "young Turks" who cut their paleontological teeth on the theory "are now middle-aged" and their influence "dominates the profession."[27] No, say Daniel Dennett, Richard Dawkins, and Michael Ruse, philosopher, zoologist, and philosopher respectively.[28] Dennett calls Gould "the boy who cried wolf," a "failed revolutionary," and "Refuter of Orthodox Darwinism."[29] Dawkins calls punctuated equilibrium a "tempest in a teapot," "bad poetic science," and says that Gould unfairly downplays the differences between rapid gradualism and macromutational saltation that "depend upon totally different mechanisms and they have radically different implications for Darwinian controversies."[30]

Dawkins is right on this last count, but as I read the original Eldredge and Gould 1972 paper, they are not arguing for punctuated equilibrium as anything more than a description of rapid gradualism reflected in the fossil record as gaps. A quarter century later, of course, much more has been made for punctuated equilibrium, occasionally by the authors but more often by the public. (My favorite example comes from an *X-Files* episode where the skeptical scientist Scully attempts to explain to her believing partner Mulder that the rational explanation for a suddenly mutated cancer-eating man is none other than punctuated equilibrium!) Michael Ruse believes that one reason for the confusion on this point is that punctuated equilibrium has gone through three phases, from a modest new description of the fossil record in the 1970s, to a radical new theory about evolutionary change in the 1980s, back to a more reserved tier of a multitiered hierarchical model of evolutionary change that incorporates both gradualism and punctuation.[31] (I should also point out that none of the most vocal critics of the theory—Dennett, Dawkins, and Ruse—are paleontologists. If the theory has limited application we should not be surprised if it is not openly utilized by those outside its boundaries.)

Ruse attempted a quantitative analysis of Gould's writings through the *Science Citation Index*, concluding that "virtually nobody (including evolutionists) out-

side of the paleontological community builds on Gould's theory of punctuated equilibria."[32] Ruse's critical interpretation, however, does not follow from the data. He begins by tallying up the number of citations of Gould's major works on punctuated equilibrium, including the original 1972 paper, the 1977 paper, "Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered," the 1980 paper, "Is a New and General Theory of Evolution Emerging?" and the 1982 paper, "The Meaning of Punctuated Equilibrium and Its Role in Validating a Hierarchical Approach to Macroevolution" (the first two coauthored with Eldredge). The grand total number of citations between 1972 and 1994 is 1,311, which Ruse admits is "respectable." But respectable (or not) compared to what? Ruse compares these four papers to the citation figures of four books by Edward O. Wilson: *The Theory of Island Biogeography, The Insect Societies, Sociobiology*, and *On Human Nature*. From this comparison Ruse concludes that "punctuated equilibria theory seems not to be in the same category as MacArthur and Wilson's island biography or Wilson's sociobiology." Ruse then totals the citations to everything Gould has written in two key scientific journals: *Paleobiology* and *Evolution*. In *Paleobiology* between 1975 and 1994 "35 percent refer to something by Gould, but only 13 percent refer to punctuated equilibria and a mere 4 percent respond favorably." In *Evolution* in the same time frame "9.8 percent refer to something by Gould, but only 2.1 percent to punctuated equilibria and a mere 0.4 percent respond favorably." Ruse then concludes: "The average working evolutionist is no better off with Gould than without him."[33]

What can we make of this analysis in our consideration of punctuated equilibrium as a paradigm? First, I applaud Ruse for his attempt to quantify a subjective evaluation, something almost unheard of in the historical profession. But has he made a fair comparison? Has he controlled for intervening variables that could account for the differences? No. Has he established a baseline from which to compare punctuated equilibrium to other revolutions in science? No. Comparing citation rates of scientific papers with scientific books is unsound because, with few exceptions, books are almost always of greater influence and impact than papers. And to compare a narrowly restricted theory like punctuated equilibrium to the much broader biogeography, and especially to the maximally encompassing sociobiology, is untenable. Punctuated equilibrium applies only to the fossil record and is mainly of interest to paleontologists. Biogeography applies to not only the fossil record, but to modern species and speciational processes, and is of interest to zoologists, botanists, ecologists, environmentalists, and field biologists. And sociobiology applies to all social animals from ants

to humans and is of interest to anyone concerned with animal or human behavior, which is to say, almost everyone working in both the biological and social sciences, not to mention the general public's fascination with all things genetic. Also, according to Prothero, the journal *Evolution* is hardly read by paleontologists at all since its editorial slant is heavily weighted toward molecular biology, genetics and population genetics, and other biological subjects that have little or nothing to do with either punctuated equilibrium or the general working subjects of professional paleontologists. Finally, what does a citation rate of 13 percent (in *Paleobiology*) and 2.1 percent (in *Evolution*) mean? Compared to what? Perhaps other theories in *Paleobiology* merit only 6 percent, or maybe 25 percent. Without a comparison there is no way to know if Gould's figures are robust or weak. And shouldn't Eldredge's citation figures be included in this analysis since he was, after all, the first author of the original paper? Why is Eldredge largely left out of this discussion? Could it be that Gould's name is bigger, and bigger targets are easier to hit, especially from a distance?

3. *Did punctuated equilibrium significantly change the description and interpretation of observed or inferred phenomena?* This is the most important component of the sociological definition of a paradigm, but at this point in its history the answer could only be a provisional one. Prothero certainly thinks so, and most of his paleontological colleagues would agree. To me, Ruse's tally of 13 percent of all papers in *Paleobiology* referencing punctuated equilibrium sounds more than respectable; it seems quite high, considering the number of papers one sees in that journal that would have no reason to discuss punctuated equilibrium at all. But, again, without a formal survey of working paleontologists, and a quantitative comparison to other paradigms or revolutions, a comparison baseline, and preset operational definitions of judging criteria, there is no way to know if 13 percent is high or low.

4. *As a new paradigm, did punctuated equilibrium improve the testable body of knowledge that was open to rejection or confirmation?* That is, setting aside its cognitive components, historical acceptance or rejection, and changed perceptions, is it a superior model of nature? Again we are forced to offer a maximally equivocating "it depends." Prothero's extensive search through the empirical literature leads him to conclude that "among microscopic protistans, gradualism does seem to prevail," but "among more complex organisms . . . the opposite consensus had developed."[34] In hundreds of studies, including his own examination of "all the mammals with a reasonably complete record from the Eocene-Oligocene beds of the Big Badlands of South Dakota and related areas in Wy-

oming and Nebraska," Prothero concludes that "all of the Badlands mammals were static through millions of years, or speciated abruptly."[35] (See FIGURE 14). My own informal survey of paleontologists and evolutionary biologists at numerous conferences leads me to conclude that punctuated equilibrium applies to some fossil lineages, but not others. It is an accurate description of some specific evolutionary processes, but it is not universal.

It must be said again that most of the attacks on the punctuated equilibrium model have come from outside paleontological circles. Communities of knowledge share a set of common interests and methods that are most applicable to them and what they do, and less so to other communities. These other knowl-

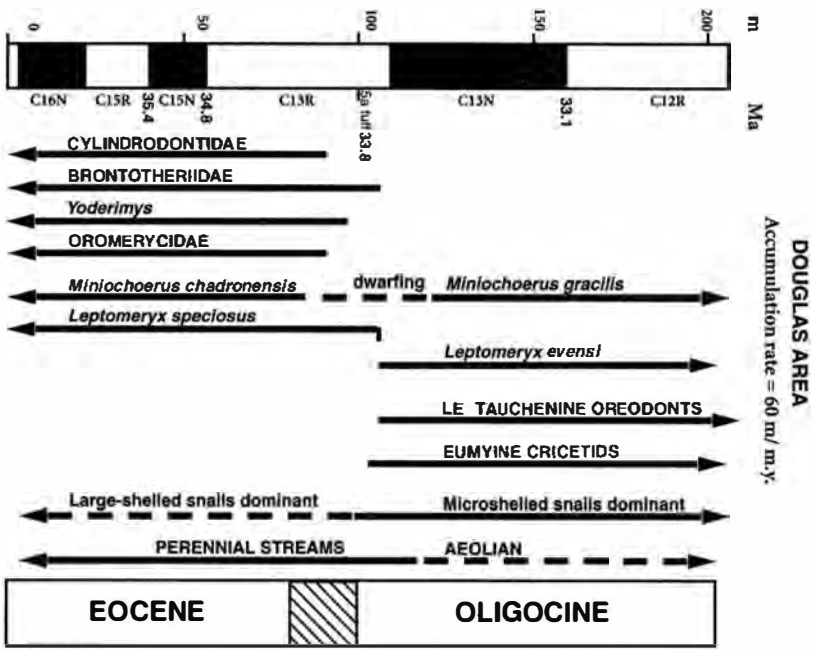


Figure 14. Evolutionary patterns at the Eocene-Oligocene transition (33–34 million years ago) recorded in strata near Douglas, Wyoming. On the top is the magnetic polarity time scale. In the middle are the ranges of species and families through the climatic shift. Most show prolonged stasis, followed by rapid speciation or extinction. All other mammals (not shown) exhibit no change through the interval. On the bottom are the climatic indicators that independently show that a major cooling event occurred at this time, even though most mammals did not track this climatic change.

edge explorers, of course, can, and do, borrow from other fields, but the models they swipe for temporary adoption will likely not have the universal appeal they may have to their originators. Thus it is that we see punctuated equilibrium—a model that describes the fossil record—most useful to those who specialize in studying the fossil record.

Still, it is useful to listen to critics outside the field for they may bring fresh insight to a problem. A case in point is Brown University cell biologist Kenneth Miller who, in his splendid book *Finding Darwin's God*, wonders if all of the brouhaha isn't over a fuzzy and fluid definition of the time scale under question.[36] Perhaps, he suggests, punctuated equilibrium and gradualism are the same models operating at different time scales. Let's return to the original source of the metaphor of the tree of life with its many branches of speciation—Charles Darwin's *Origin of Species* (FIGURE 15). What did Darwin say about the gradual versus punctuated nature of the tree of life? Miller calls out this quote from *The Origin of Species:* "But I must here remark that I do not suppose that the process ever goes on so regularly as is represented in the diagram, though in itself made somewhat irregular, nor that it goes on continuously; it is far more probable that each form remains for long periods unaltered, and then again undergoes modification."[37] It sounds like Darwin is saying that species remain stable over long periods of time, then undergo rapid speciational change. That's what Miller concludes: "A visitor to the land of evolution-speak might be forgiven for coming to the conclusion that the controversy over gradualism versus punctuated equilibrium was a wee bit contrived. And so it was."[38]

Was it? Not so fast. Miller pulls this quote out of the 6th edition of the *Origin*. In the first edition the sentence ends at "though in itself made somewhat irregular." The rest of the sentence, including the all important "each form remains for long periods unaltered, and then again undergoes modification," was added later. Why? Because, although he had discovered the mode of evolution—natural selection—he had not yet determined the tempo. And *that* is the difference between Darwin's tree of life and the iconography of punctuated equilibrium. Darwin does not tell us how rapid this modification process is, or, more importantly *what* the process is. He couldn't have, because in his time it was still unclear how populations shifted morphologically and behaviorally into new species (regardless of whether they did it rapidly or slowly), from one large population to another large population (peripatrically), or from a large population to a small population (allopatrically through the founder effect) that then develops back into a large population as a new species. In fact, this remains a point of great interest not only to paleontologists but to zoologists, botanists,

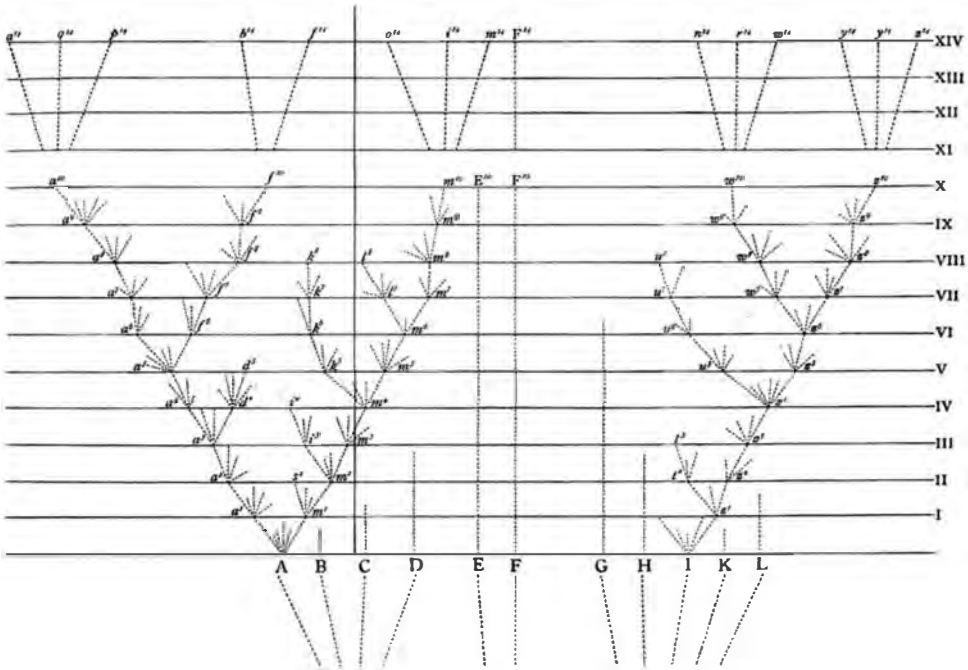


Figure 15. Darwin's tree of life from the *Origin of Species*.

biogeographers, and ecologists. What Darwin did identify in the first edition of the *Origin* was that there is a great range of evolutionary tempo:

> Species of different genera and classes have not changed at the same rate, or in the same degree. . . . The productions of the land seem to change at a quicker rate than those of the sea. . . . I believe in no fixed law of development, causing all the inhabitants of a country to change abruptly, or simultaneously, or to an equal degree. The process of modification must be extremely slow. The variability of each species is quite independent of that of all others.[39]

Darwin never explained why such variation in the speed of evolutionary change should exist. What Mayr, Eldredge, and Gould presented as something new and beyond what Darwin had said in the *Origin* was a mechanism—allopatric speciation—applied to the fossil record. That is what makes punctuated equilibrium a new paradigm—building on but not displacing Darwin and Darwinian gradualism.

To the extent that punctuated equilibrium constitutes a new paradigm (at least in paleontological circles), why has it received so much attention? Kenneth Miller frets about it because he doesn't want to give creationists any more targets to shoot at, and punctuated equilibrium has been a favorite theory of creationists looking for any angle they can find to tear down the Darwinian citadel. The creationists aside, however, it seems reasonable to ask why Ernst Mayr's 1954 paper didn't trigger a paradigm shift? The short answer is that he was the wrong triggerman. As a fifty-year-old biologist Ernst was not the "young Turk" needed to lead a paleontological revolution. The longer answer is found in the man who did champion punctuated equilibrium—Stephen Jay Gould—arguably the most prominent expositor of evolution of the past thirty years (and dubbed America's "Evolutionist Laureate"). Whether it was Mayr's idea or Eldredge's, it was, by his own admission, not Gould's idea, and yet it is his name most noticeably attached to it. As much as we may harbor a distaste for the social nature of science, the fact is *who* is doing the saying sometimes matters as much as what is being said. Even his critics admit that no one says it more often and with greater eloquence than Gould. Though he frequently calls himself a tradesman, and denies the polymathic modifier, one suspects that the gentleman doth protest too much. His monthly essays in *Natural History* range across the intellectual spectrum, and while they do indeed usually link up at some thematic middle, it is at the edges that Gould's reputation has grown well beyond the boundaries of his science, leading to a simultaneous overabundance of both credit and critique.

Carl Sagan certainly experienced this Janus-faced problem, and in chapter 10 I compare his accomplishments to those of other eminent scientists, one of whom is Gould. Gould matches Sagan in every category, including a National Magazine Award for his column "This View of Life," a National Book Award for *The Panda's Thumb,* a National Book Critics Circle Award for *The Mismeasure of Man,* the Phi Beta Kappa Book Award for *Hen's Teeth and Horse's Toes,* and a Pulitzer Prize Finalist for *Wonderful Life,* for which Gould characteristically commented "close but, as they say, no cigar."[40] At the time of this writing he has pulled down no less than forty-four honorary doctorates, published 593 scientific articles (including forty-five in *Science* and *Nature*), and written twenty books (only three of which were coauthored). Sixty-six major fellowships, medals, and awards bear witness to the depth and scope of his accomplishments in both the sciences and humanities: Fellow of AAAS, MacArthur Foundation "genius" Fellowship, Scientist of the Year from *Discover* magazine, Humanist Laureate from the Academy of Humanism, the Silver Medal from the Zoolog-

ical Society of London, the "Skeptic of the Year" award from the Skeptics Society, the Edinburgh Medal from the City of Edinburgh, and the Britannica Award and Gold Medal for dissemination of public knowledge, among others. With such awards come enough invitations to fill a calendar and earn prodigious frequent flyer miles. For those he cannot accommodate, a form letter is sent, written in vintage Gouldian style—cerebral but to the point:

> I can only beg your indulgence and ask you to understand an asymmetry that operates cruelly (since it produces tension and incomprehension) but that leads to an ineluctable (however regrettable) result. The asymmetry: you want an hour or two, perhaps a day, of my time—not much compared to what you think I might provide (exaggerated, I suspect, but I won't struggle to disillusion you). From that point of view, I should comply—not to do so could only be callousness or unkindness on my part. But now try to understand my side of the asymmetry: I receive on average (I promise that I am not exaggerating) two invitations to travel and lecture per day, about 25 unsolicited manuscripts per month asking for comments, 20 or so requests for letters of recommendation per month, about 15 books with requests for jacket blurbs. . . . I am one frail human being with heavy family responsibilities, in uncertain health and with a burning desire (never diminished) to write and research my own material. Thus, I simply cannot do what you ask. I can only beg your understanding and extend to you my sincere thanks for thinking of me. . . .

(I must confess to being the recipient of the letter for a request made in youthful ignorance of the way the world works.)

Gould's numbers also match those of Edward O. Wilson, Jared Diamond, and Ernst Mayr (some lower, some higher—see figures in chapter 10). My point is that with such accolades and public recognition comes an inevitable truncating and short-shrifting of the complexities of the scientific process and the subtleties of allocating credit or critique where it is due and in appropriate measure. It is simply much easier to say or write "Gould's theory of punctuated equilibrium" than it is "the theory of punctuated equilibrium, first proposed in 1954 by Ernst Mayr, published again in 1971 by Niles Eldredge, and solidified in 1972 by Niles Eldredge and Stephen Jay Gould. . . ."

What the future holds for punctuated equilibrium remains to be seen, but we have learned from this story that theories and paradigms are social in nature and the marketing of an idea is at least as important as its creation

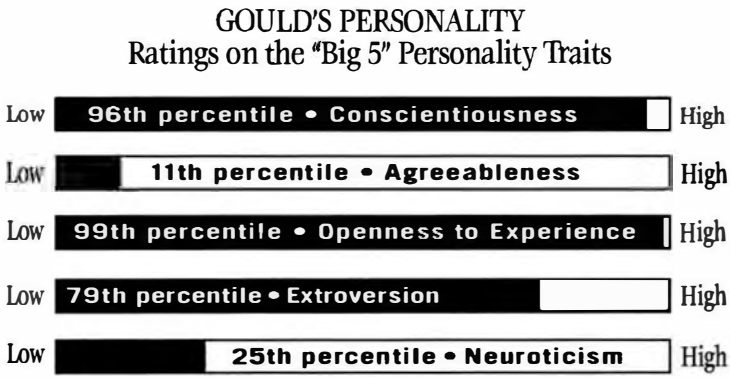
(though both in the end, one hopes, give way to evidence). Gould did not achieve his status as one of the best known and most respected writers and scientists today by coauthoring a paper on punctuated equilibrium. That was part of it, but his reputation has promoted the theory far more than the reverse. If there was a paradigm shift, the reason it was triggered in 1972 instead of 1954 or even 1971 is, primarily, because it was Gould who pulled the trigger.

Why, we might ask, was it Gould who led this paradigm shift? One way to get to an answer to this question is to examine his personality. As we shall see in the next section of the book, personality traits influence receptivity or resistance to revolutionary ideas. University of California, Berkeley social scientist Frank Sulloway has developed a model describing this relationship between personality and orthodoxy/heresy (described in detail in the next chapter), and to further test his hypothesis we had eight of Gould's colleagues take the Five Factor Personality Inventory, also known as the "Big 5," representing the five most dominant traits that best explain personality. They are *Conscientiousness, Agreeableness, Openness to Experience, Extroversion*, and *Neuroticism.* To test these, we had subjects complete a survey of 40 adjective pairs on a 1–9 scale, such as these:

I see Stephen Jay Gould as someone who is:
—Stubborn/headstrong 1 2 3 4 5 6 7 8 9 Acquiescent/compliant
—Untraditional 1 2 3 4 5 6 7 8 9 Traditional
—Leisurely 1 2 3 4 5 6 7 8 9 Energetic/fast paced
—Rarely depressed/sad 1 2 3 4 5 6 7 8 9 Often depressed/sad
—Deliberate 1 2 3 4 5 6 7 8 9 Hasty/impulsive
—Modest 1 2 3 4 5 6 7 8 9 Arrogant

Sulloway and I ran a correlation on all 40 adjective pair for all eight raters, and came up with a .92 interrater reliability index, an exceptionally high figure that gives us confidence that we have a good handle on the personality of this scientific revolutionary. The results are presented in Table 1 as percentile scores, comparing Gould to the more than 100,000 people already in Sulloway's database.

Gould scores exceptionally high in *openness to experence*, which is a key personality trait in the development of a revolutionary. But not all radical ideas are equal, so it helps to be high in *conscientiousness* to help one weed through the bogus revolutionary ideas. Gould is also exceptionally high in *conscientiousness*,



aiding him in finding that essential tension Thomas Kuhn speaks of between orthodoxy and heresy—finding the balance between being open-minded enough to recognize quality new ideas, but not too open that even nutty ideas are treated with equal respect. That balance is reinforced by Gould's low score on agreeableness: he's a tough-minded intellectual who does not suffer fools gladly, and that is a good trait to have when one is in the rough and tumble world of ideas where most are wrong, a few are acceptable, and only a handful really stick as legitimate revolutions. Gould has the personality profile that lends itself to leading and supporting scientific revolutions, without also being taken in by what might turn out to be a failed revolution. It would appear that punctuated equilibrium is one such successful revolution, and these data help us further understand why it was Gould who led it.

My assessment of punctuated equilibrium is that it is an improved theory for explaining the fossil record and thus meets the criteria for being progressive science. That is, in the cumulative growth of Darwinian gradualism, useful features were retained and nonuseful feature abandoned, based on the rejection or confirmation of testable knowledge. But Darwinian gradualism has not been displaced by punctuated equilibrium, just modified to include the latter as a more accurate description and interpretation of some sequences in the fossil record. Whatever it is, punctuated equilibrium is not a new mechanism of evolutionary change. It is a new description, and seeing it as such helps us resolve the paradigm paradox. Its status as new paradigm is restricted to this level—a nontrivial contribution to the science, but not on the level of the Darwinian paradigm.