The Lying Stones of Marrakech

LSM 1. The Lying Stones of Marrakech

On a visit to Morocco, Gould finds some fake fossils in local shops, and uses these as inspiration to revisit a famous story in the history of paleontology: the case of the Lying Stones (*Lügensteine*) of Dr. Berringer. (This is also the title of a book by Jahn and Woolf that Gould draws on for details.) The events take place in Würzburg, Germany, in 1726. The story has two forms: the canonical version that is repeated in the introductory sections of many paleontology textbooks, and the true version, which differs considerably.

Both versions of the story hold that a pompous, not-too-bright professor (Berringer) finds a set of remarkable "fossils" in a nearby mountain: not shells and bones like those found elsewhere, but complete three-dimensional birds with feathers and eyes, spiders with webs, snails with their eggs, lizards with skin – all exquisitely preserved. (It was a fake lizard "fossil" that Gould found in a Marrakech shop, actually a high-quality cast cemented to a real rock, which started him thinking about Berringer.) But Berringer found more; his collection (as documented in his 1726 book *Würzburg Lithography*, which included several plates of illustrations) included heavenly objects, such as comets with tails, a crescent moon with rays, and even carved Hebrew letters spelling out "Jehovah." In the canonical version of the story, Berringer only realizes that he has been the victim of a prank played by artistically talented students when he finds a "fossil" that spells out his own name. Humiliated, he spends his few remaining years trying to buy back all the copies of his book. As is required of tales of this sort, there are moral lessons: "do not engage in speculation beyond available evidence, and do not stray from the empirical method of direct observation." These are fine lessons, Gould writes, but in this case at least, the story behind them is partially false.

Dr. Berringer did find the planted objects (or, at least in some cases, they were "found" by paid assistants, one of whom was involved in the deception), and he did believe that they were naturally produced, rather than fabricated either recently or by ancient tribes. However, the perpetrators were irritated colleagues bent on damaging Berringer's reputation, not students playing a prank. As Jahn and Woolf describe the case, the two perpetrators realized they had gone too far, and tried to talk Berringer out of publishing. One of their attempts at dissuasion involved showing him similar objects that had been locally fabricated, suggesting that "someone" might have planted similar items for him to find; Berringer would have none of it, instead choosing to believe that his rivals were trying to deny him credit for a discovery that would make him famous. (Gould references the Piltdown Man hoax [TPT 10, HTHT 16 & 17] as another example of how difficult it is to recognize even obvious fraud if one's mind is not open to the idea.) When the law became interested, the proponents were exposed and discredited; there was never any evidence that a "fossil" of Berringer's name was ever produced. While there was no doubt much embarrassment on Berringer's part, he survived the incident, and went on to live another 14 years, with more successful publications. Rather than trying to buy back copies of *Würzburg Lithography*, Gould notes that it actually had a second printing after his death.

The crux of the essay is to point out that, while Berringer could have and should have avoided the trap, it was not as obvious in 1726 as it is today that the *Lügensteine* had to have been fakes. Many of the fields of study that would become sciences were in their infancy, and not yet capable of producing a consistent, coherent explanations for natural phenomena. At the end of the era that believed in spontaneous generation – heat on rotting meat could create maggots, for example – it did not seem unreasonable that moonbeams shining on a rock could result in the creation of some of Dr. Berringer's "fossils." After all, the earth was known to be able to produce crystals, stalactites, and banded agates; why not moonbeams? And while today it is universally recognized that true fossils are remnants of living organisms, there were other "mainstream" views as well [see the next two essays].

The actual story of the *Lügensteine* is thus more interesting, if less morally instructive, than the canonical tale. This episode reflected an ongoing battle between intellectual factions with different paradigms regarding the nature of reality. It is a testament to how far we have come since 1726 that the only consequence of buying a fake fossil in Marrakech today is financial – and probably modest at that.

LSM 2. The Sharp-Eyed Lynx, Outfoxed by Nature

The Academy of the Lynxes was founded in 1603 in what is now central Italy by Federico Cesi, an 18-year-old nobleman from an important family. After an inauspicious beginning, it went on to become the first scientific society in modern European history; the Lynx was selected as mascot based on legends of its powerful sense of sight, or observation. At first, there were only four members; one was Francesco Stelluti, who was only 26 in 1603. In 1611, however, the Lynxes snagged a big name: Galileo (1564 – 1642). The previous year, Galileo had published a document (usually translated as "Starry Messenger") that described the moon, certain clusters of stars and the Milky Way, and the moons of Jupiter – all seen through his recently-constructed "telescope" (although that term did not yet exist). The Lynxes continued to grow in numbers and stature – no mean feat in the highly conservative age of the counter-reformation – until two misfortunes struck. The first was the untimely death of its founder, Cesi, in 1630. His financial support and political skills – the latter being important to keep suspicious popes and cardinals at bay – would ultimately prove irreplaceable. The second was that their star member, Galileo, published his famous work advocating a sun-centered solar system in 1632: *A dialog on the two great systems of the world, Ptolemaic and Copernican*. Perhaps because Cesi was no longer around to edit Galileo's tone or grease the political wheels, the Pope – who, up until that time, had been supportive of the Lynxes – apparently felt betrayed, and had Galileo arrested. The Lynxes continued to operate at a reduced level for another 20 years, but formally disbanded in 1652.

The Academy of Lynxes functioned at the dawn of what we now call science, and had some brilliant successes. In this essay, however, Gould focuses on two errors – one by Galileo, the other by Cesi and Stelluti – both of which illustrate the same pitfall. Science, it has been stated, replaces man's approach to "knowing" from appealing to authoritative sources such as Aristotle or the Bible, or from revealed inspiration, to the methods of direct observation and experimentation. But as Gould notes elsewhere in these essays, there is no such thing as pure, unbiased observation; we have no choice but to filter "objective" data through our personally- and culturally-shaped minds [see, for example, ELP 13]. The Lynxes, Gould will argue, made the mistake of confusing what they "observed" with what was true; this, he continues, is a cautionary tale that all scientists today should learn from. [This essay originally appeared in two parts, in consecutive months of *Natural History* magazine. This is the first of four such two-part essays, all of which appear in this collection. The others are LSM 5, 6, & 7.]

Galileo's interpretation of what he saw through his telescope was brilliantly insightful, if not always completely correct. He saw craters and mountains on the moon, and recognized that this repudiated Aristotle, who believed that the moon was a perfect sphere. [In Aristotle's view, the heavens were perfect and eternal, while on earth, objects were imperfect and decayed.] In seeing that star clusters such as the Pleiades showed about ten times as many stars with his telescope as with the naked eye, he correctly extrapolated that the Milky Way was itself a collection of stars too numerous and faint to make out individually; this implied that the universe was even more vast than previously believed. Perhaps most importantly, he recognized that the planet Jupiter was orbited by moons of its own. This demolished the Greek (and thus the Western) view that all heavenly bodies orbit a single center, whether it be the earth or the sun. With his discovery, it became apparent that *all* astronomical bodies could act as orbital "centers," thus paving the way for Newton's law of universal gravitation. But when he turned his telescope on Saturn, his conclusion was that the body was "threefold"; that is, one bright star with a dimmer star on each side. Today we know that he was seeing Saturn's famous rings, but between the quality of his telescope and his own internal assumptions about what was possible, he interpreted his observations incorrectly. In an era before peer-reviewed journals and rules to award precedence of discovery, what one published to establish primacy was a key phrase in the form of a puzzle in Latin – typically an anagram. Galileo's translated solution was "*Altissimum planetam tergeminum observavi*" – translated as "I have observed that the farthest planet is threefold." [Uranus, farther from the sun than Saturn, was not discovered until 1781.] Gould's concern is with the last Latin word. In this short phrase, at least, Galileo did not write, "Saturn appears to be three adjacent globes." Rather, he wrote that Saturn *is* three adjacent globes, stating that it must be so because "I have observed it." This is Gould's point: observation is a powerful tool, but total reliance on it alone can lead to errors as surely as total reliance on authority can. When overthrowing dogma, it is important not to simply replace it with another dogma.

Gould's second example draws on the work of Cesi and Stelluti, based on some partially petrified wood found by Cesi on his estate. As discussed in the next essay, an intellectual battle was taking place in the 17th and early 18th centuries as to whether "fossils" represented formerly living plants or animals, or whether nature produced similar forms in the mineral, vegetable, and animal kingdoms. There was another struggle taking place as well – whether living and non-living objects were composed of the same substances. [We retain the terms "organic" and "inorganic" today, although the precise definition has evolved. This question was not firmly settled until 1828, when German chemist Friedrich Wöhler synthesized urea, the key ingredient in urine, from non-biological chemicals.] One view, shared by Cesi and Stelluti, was that a continuum existed between the mineral and living worlds. Today, we recognize that wood placed in silica-rich water will "petrify" fairly quickly, as minerals precipitate and crystallize in the hollowed-out plant cells. What Cesi had found was a branch that had been partially submerged in mineral-rich water, and so was organic wood at one end and "inorganic" fossil at the other. Stelluti later published his "observation" that he had found a mineral that was in the process of transforming itself into wood – exactly backward! His observations were meticulous and accurate; again, it was his interpretation that was incorrect. Gould presents what is perhaps his definitive argument for the *combination* of (testable) theory and observation to produce true understanding:

> Utterly unbiased observations must rank as a primary myth and shibboleth of science, for we can only see what fits into our mental space, and all description includes interpretation as well as sensory reporting. Moreover, our mental spaces house a complex architecture built of social constraint, historical circumstance, and psychological hope . . . . We can be terribly fooled if we equate apparent sight with necessary physical reality. The great Galileo, the finest scientist of his or

> any other time, *knew* that Saturn . . . must be a triple star because he had so observed the farthest planet with good eyes and the best telescope of his day, but through a mind harboring no category for rings around a celestial sphere. Stelluti *knew* the fossil wood must grow from earths of the mineral kingdom because he had made good observations with his eyes and then ran an accurate sequence backward through his mind. . . . And thus, nature outfoxed the two Lynxes at a crucial claim in their careers – because both men concluded that sight alone should suffice, when genuine solutions demanded insight into mental structures and strictures as well.

LSM 3. How the Vulva Stone Became a Brachiopod

Brachiopods are a phylum of marine invertebrates that superficially resemble clams, in that they have two valves ("shells") that can open and close along a hinge. These organisms are relatively rare today, but were more common in the past, and are plentiful in the fossil record. Sometimes, if the ground water is mildly acidic, the fossil shell itself will dissolve away, and what is left is a cavity enclosing an internal mold of hardened sediment. Hundreds of years ago, it was not at all obvious what these relatively flat internal casts were; these objects did not look very much like a shell. In fact, they often resembled female genitalia to a greater or lesser degree on one side (Gould reproduces some illustrations); in some cases, the other side would more loosely resemble male genitalia as well. As a result, in the 16^{th} century, these objects came to be called hysteroliths – or woman stones, or vulva stones. In this essay, Gould takes us through two centuries of time, during which the true nature of these objects came to be correctly understood. More was required, he argues, than the simple collection of enough data (although that was important); additionally, the way people *thought* about the world around them had to change as well. As he has noted elsewhere, a worldview is required to make sense of our observations; but this worldview shapes the way we interpret those observations, and is itself a function of our biases.

Rather than use his own terminology to discuss how these biases can constrain us, he turns to Francis Bacon (1561 – 1626). This great English thinker was, in many ways, the grandfather of the scientific revolution, although he did not share the mathematical bent of the major players that followed. He shares Gould's views (or rather, vice versa) that all "objective" data must pass through the filter of the human mind, and that this mental machinery has both inherent limitations and specific biases that reflect the background and culture of the host. Bacon defines four classes of constraints, which he calls *idols*, in the introduction to his magnum opus, *Novum Organum* ("New Tool" or "New Instrument"; the title is borrowed from Aristotle's *Organum*, his writings on logic and reasoning). The first of these are *the idols of the cave*, which refers to limitations unique to the individual; one person might have an aversion to any mathematical expression, while another might be resistant to engage in a line of thought that challenges certain authorities. The second are *the idols of the marketplace*, and refer to linguistic limitations (marketplaces are where people gather to talk and socialize, as well as buy and sell things). For example, it is more difficult to understand or convey and idea when there is no *word* for that idea. The third are *the idols of the theater*, which refers to paradigms or worldviews. Gould offers the example that it is more difficult to grasp Darwin's theory of evolution – simply to comprehend, not necessarily to accept – if one operates under the view that the earth is only a few thousand years old. Finally, and most generally, are *the idols of the tribe*. Rather than referring to individual populations as this term suggests, it reflects modes of thinking that are common to all of humanity, and probably involves the underlying "hardware." This category includes visual pattern recognition, and is ultimately behind the perceived connection between internal brachiopod molds and female genitalia. But it also includes pattern recognition at a more abstract level; it leads us to wonder if there is a deeper connection between these two types of objects, and to propose "stories" (or theories, or worldviews) to relate them – whether these deeper connections exist or not. Adults typically learn new concepts by relating them to those they are already familiar with: "This is like that." Gould notes that dichotomization, our common mental tactic of dividing things up into exactly two categories (good or bad, us and them, true or false, and – as illustrated in the grammars of many languages – male or female), also falls into this category. [He does not mention it here, but he would probably place anthropocentrism here as well – see TFS 25, DIH 25, and LMC 15. He would likely also include our propensity for ranking and otherwise grouping and ordering things.] Gould then takes us through the history of our understanding of hysteroliths, not in terms of new information, but rather in terms of overcoming mental obstacles expressed in terms of Bacon's idols. [See ELP 29 for another example.]

Fossils have been known since antiquity, and the paradigm that at least some of them – for example, shells – represent the remains of formerly living organisms, has with us for just as long. The Roman naturalist Pliny the Elder wrote about them, and even attributed shells on the sides of mountains to the elevation of ancient sea beds. However, other explanations also existed; one of the most powerful was the Neoplatonic idea that whatever forces led to the formation of certain shapes in the animal world also acted on the vegetable and mineral worlds. There were other objects dug out of the ground (the original definition of "fossil") that did not seem to resemble any form of life. These included not only crystals and colorful, patterned agates, but also small disks called wheel stones (today recognized as the disarticulated stem segments of crinoids); tongue stones (shark teeth; see HTHT 5); "bull's hearts" (internal molds of clams); and hysteroliths, as well as fabricated objects from vanished civilizations such as pottery shards and carved figurines.

Other than a few references to fossils in the 1300's, the first "modern" reference comes in 1546, when a German named Georgius Agricola wrote *De natura fossilium*. Agricola was operating under the intellectual worldview of the Renaissance. This implies that he rejected the medieval scholastic view that man could do nothing but degenerate from the heights of the Greek and Roman civilizations (and their corresponding academic emphasis on preserving what little of their knowledge remained), and instead believed that mankind *could* return to the intellectual days of old (Renaissance means "rebirth"), by rediscovering or reinventing the lost knowledge. (Bacon was operating under a third viewpoint – "empiricism" – that viewed the acquisition of natural knowledge as an indefinite and cumulative process, *not* limited to what the Greeks knew, and propelled by a connection between the gathering of data about the external world and the power of reasoning.) Pliny the Elder had written a book on rocks, minerals, and fossils, and Agricola was working to "recover" the information embedded in it by matching up contemporary samples with the descriptions in Pliny's book. One very brief reference was to an object called *diphyes* that "had the character of both sexes, white and black, male and female." Agricola identified these as hysteroliths, although he did not use this name; this was, in terms of the objectives of the Renaissance, a significant achievement. Some 20 years later, in 1565, Swiss polymath Conrad Gesner produced *De rerum fossilium* ("On fossil objects"). This was the first book to actually use the word "hysterolith." Also important was the manner in which Gesner classified fossils; he grouped them into fifteen categories, based primarily on their appearance. At the top were those objects that resembled perfect geometric shapes; next were those that resembled heavenly objects such as stars (crinoid stem segments appeared here). Hysteroliths were placed in a category near the bottom: "those that have some resemblance to men or quadrupedal animals, or are found within them." (Also in this category was a sample of native silver that resembled a mat of human hair.) Gould discusses the approach of these two 16th century thinkers in terms of idols of the tribe. First, obviously, is the comparison of unknown objects with things that we are already familiar with. Second, he notes that the dichotomous nature of the hysterolith – "top and bottom, male and female" – is what led Agricola to make the connection to Pliny.

Gould discusses the next "mental" battle over the nature of hysteroliths, which occupied the entire 17th century and a few decades on either side, in terms of idols of the theater – incorrect and, more importantly, fruitless paradigms. There were several theories about what fossils "were," including the one we hold today, but the most important of the alternatives was the Neoplatonic view. Gould beautifully describes this worldview, and the significance of fossils within it:

> Among the theatrical idols of seventeenth-century life, none held higher status among students of fossils than the Neoplatonic construction of nature as a static and eternal set of symbolic correspondences that reveal the wisdom and harmonious order of creating forces, and that humans might exploit for medical and spiritual benefit. A network of formal relationships (not direct causal connections, but symbolic resemblances in essential properties) pervaded the three kingdoms of nature – animal, vegetable, and mineral – placing any object of one kingdom into meaningful correspondence with counterparts in each of the other two. If we could specify and understand this network, we might hold the key to nature's construction, meaning, and utility.
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> Within this Neoplatonic framework, a close resemblance between a petrified "fish" enclosed within a rock and a trout swimming in a stream does not identify the stony version as a genuine former organism of flesh and blood, but suggests instead that plastic forces within the mineral kingdom can generate the archetypal form within a rock just as animate forces of another kingdom can grow a trout from an egg.

In the Neoplatonic paradigm, similar shapes indicated similar underlying forms and forces. Thus, in this view, it was not unreasonable to believe that wearing (or grinding up and swallowing) a hysterolith would alleviate medical problems with birth or the reproductive system. It is mentally difficult to consider the problem, "what organism produces a hysterolith," when the central debate was what sort of medical benefits, if any, they could provide. Gould presents examples of this debate from 17th-century texts. [What eventually undid the Neoplatonic paradigm, Gould mentions, was the scientific revolution; Galileo turned his telescope to the heavens in 1610, and Newton published *Principia* in 1687. This paradigm placed renewed emphasis on detailed observation and testable prediction, as well as replacing the Aristotelian concept of causality with our modern one. There were, however, some important pre-scientists who also recognized the flaws in the Neoplatonic paradigm. Gould discusses Leonardo da Vinci's brilliant 16th century criticism in LMC 1. Within the context of the scientific revolution, also see Steno's "Principle of Sufficient Similarity" from his 1669 work *De solido*, discussed in HTHT 5.] The last major defense of the Neoplatonic worldview came with Athanasius Kircher's 1664 work *Mundus subterraneus* (*Underground World*), but J. C. Kundmann wrote in support of the inorganic view as late as 1737. [LSM 1 discusses Dr. Berringer's 1726 "Lying Stones" that also assumed this worldview.]

Even with the collapse of the Neoplatonic paradigm, certain problems of terminology and classification – which Gould discusses in terms of idols of the marketplace – remained, well into the 18th century. [Illustrations, not just words, are also idols of the marketplace – see ELP 30.] First, the very name "hysterolith" remained in use for some time, easily misleading those new to the field. Second, the term "fossils" (and also "figured stones") still referred to everything dug out of the ground from agates to Roman coins. Even after it was generally understood that the resemblance of hysteroliths to sex organs was purely coincidental, authors continued to publish figures of them next to penis-shaped stalactites and similar objects (Gould presents an example from 1755). However, with the slow resolution of these issues, scientists could finally turn to the questions that required more-or-less "pure" observation to resolve. Where these objects molds or casts of an organism, or the fossilized remains of all or part of the organism itself? If the former is the case, are they casts of plants such as nuts, or animals – perhaps clams? These questions were all correctly resolved by 1753; Gould references a book describing the collection of a Swedish nobleman produced by none other than Linnaeus himself. The illustrations in this book place hysteroliths with internal molds of other brachiopods that do not resemble genitalia, and with the shells of the brachiopods related to those that produced them. [Fragments of the Neoplatonic paradigm continue to exist and occasionally reappear; see Geoffroy in LMC 17, Owen in ELP 4, and – in a way – Gould's own *Ontogeny and Phylogeny*.]

LSM 4. Inventing Natural History in Style

This essay appeared in its original form in the *New York Review of Books*, as a review of the 1997 book *Buffon: A Life in Natural History* by Jacques Roger. Georges-Louis Leclerc, Comte de Buffon (1707-1788) was the most famous French naturalist of his day, in large part because of his excellent writing style and his best-selling books. His life's work was the 44-volume, encyclopedia-like *Histoire naturelle (Natural History)*, which covered all aspects of the natural world, including minerals, life on earth, and anthropology. It became the standard textbook in many universities for a century, influencing many of the geologists and biologists that followed, including Lamarck, Cuvier, and later, Darwin. It was largely due to his success as a writer that he was made one of the "forty immortals" of the prestigious Académie Française in 1753. His induction speech, on the importance of writing well about scientific matters, produced what Gould refers to as his one "standard" quote, translated as "style is the man himself"; this quote is reflected in the essay's title.

Buffon is not nearly as well-known today as he was in his own time. This is in part because few of his concrete, specific views have turned out to be correct; but Gould argues that his overall influence was strongly positive. Rising from middle-class origins, he always chose to work within the social and political system of his time (and became very wealthy in the process). He was not an intellectual revolutionary, but he did raise and discuss many ideas – regarding the age of the earth, comparative anatomy, biogeography, and evolution (which he did not believe in). His proposals, as noted, were usually wrong, but he stimulated others to think about the concepts behind them, often for the first time. He *influenced* other thinkers and scientists for a century.

Gould elaborates on three specific areas of Buffon's interest. First, he produced a classification system for life on earth that was very different from that of his rival in Sweden, Linnaeus. While neither of these two men were evolutionists, Linnaeus's model is used today because its hierarchical structure is well-suited to the process of evolution [see IHL 21]. Buffon's system was nonhierarchical and matrix-like; each organism was assigned to several groups based on its function, its utility to man, and other aspects in addition to its similarity to other organisms. (For example, a bat "functions" like a bird, but has an anatomy like that of a mammal.) Second, while naturalists recognized that organisms were well-adapted to their climate, he was the first to explicitly note that this seemed to conflict with the hidden assumption that all life was created in a single place. This led others to think about the idea of animals "arising" locally; as such, he is considered to be the father of biogeography [but also see von Humboldt, discussed in IHL 5]. Third, he is credited as being the first to define "species" in terms of the members' willingness and ability to breed, rather than purely on physical characteristics. This differed from the prevailing Platonic view that abstract "forms" were what mattered, not how individuals differed from these forms. Platonism, as others have noted, is associated with "fixed," ideal archetypes; this "idol of the theater" [see the previous essay] had to be challenged before the concept of evolutionary thought could be systematically investigated.

Buffon's most important contribution, Gould offers, was the idea of natural history itself. The standard creationist view of the period was that the earth was about six thousand years old. While a great deal of human history has occurred during this time, the planet itself was believed to be pretty much the same now as it was when it began; thus, there was no need for "natural" history. The cosmological view of Newton, on the other hand, might allow for great lengths of time – but in this perspective, objects followed perfectly repeating cycles; again, no need for "history," which – as Gould notes – implies a story, with different things happening at different times. In 1778, Buffon published a volume entitled *The Epochs of Nature* [actually an expansion of his earlier 1749 work, *Theory of the Earth*; see DIH 3]. In it, he discusses the development of the earth from a molten fireball ejected from the sun [a mainstream idea at the time – see BFB 25 and LSM 7] to the world we know today – with each epoch having its own geology and, if supportable, (created) life. While wrong in virtually every detail, it was the first published work to present an ancient earth (Buffon's estimation was "at least" 75 thousand years) that passed through a series of unique periods. This volume predated James Hutton's presentation to the Royal Society of Edinburgh on this same subject by seven years [HTHT 6]. Buffon's *Epochs of Nature* also argues that knowledge of the events in this distant past is essential to understanding the present, and thus is the first to explicitly consider the importance of history in nature.

LSM 5. The Proof of Lavoisier's Plates

Antoine Lavoisier (1743-1794) is regarded as the father of modern chemistry, and was also one of the chief architects of the metric system; his life ended on the guillotine during the French Revolution [BFB 24]. Although not a chemist, Gould admires him almost as much as he does Darwin; this is not only because of his brilliance, he states, but because of the remarkable clarity of his writing. Perhaps surprisingly, Lavoisier also did some work in the field that would become geology. He only published one paper, and Gould tells us that his work probably did not have much influence (others were coming to the same understandings at about the same time). However, his efforts illustrate scenes from the discovery of earth's ancientness; that geological strata can tell us something about the planet's history, and that that history is vast. Gould writes:

> In 1700, all major Western scholars believed that the earth had been created just a few thousand years ago. By 1800, nearly all scientists accepted a great antiquity of unknown duration, and a sequential history expressed in strata of the earth's crust. . . . This discovery of "deep time," and the subsequent revolution of historical sequences by geological mapping, must be ranked among the sweetest triumphs of human understanding.

Gould's fascination with authenticity [ELP 15 & 16] appears at the end of this essay, where he tells us that he acquired at auction the seven original "plates," signed by Lavoisier himself, of this sole paper in his field.

[Steno (HTHT 5), who believed in a young earth, published his principle of superposition – younger strata lie above older strata – along with many other insights in his work *De Solido* in 1669. Buffon (DIH 3 and LSM 4) published *Theory of the Earth*, which discussed the notion of an extended natural history in 1749. James Hutton (HTHT 6), who proposed a cyclical mechanism for earth's crust and is often credited as the man who "officially" discovered deep time, presented his views in a 1795 book with the same title as Buffon's: *Theory of the Earth* (and based on an earlier 1788 paper). Thus, Lavoisier's life covers much of the period in which this extended paradigm shift took place.]

The first of the two related problems that Lavoisier worked on involved the origin of geological mapping. As a young man, he spent several years working for Jean-Etienne Guettard (1715 – 1786). In 1766, Guettard was commissioned by the French government to produce detailed mineralogical maps for the entire country – a task that all involved recognized would take decades. Only 45 of the proposed 230 maps were ever published, but Lavoisier worked with him from inception to the publication of the first 16 maps, which appeared in 1770. Gould writes:

> Guettard's productions do not qualify as geological maps in the modern sense, for he made no effort to depict strata, or to interpret them as layers deposited in a temporal sequence – the revolutionary concepts that validated deep time and established the order of history. Rather, as his major cartographic device, Guettard established symbols for distinctive mineral deposits, rock types, and fossils – and then merely placed these symbols at appropriate locations on his map.

(Gould references Rhoda Rappoport's 1973 article in the *British Journal for the History of Science*, "Lavoisier's Theory of the Earth," for much of this background.) It was the young Lavoisier, we are told, who was fascinated by the writings of Steno and Buffon, and who sought to integrate the myriad of data he and Guettard were collecting into some sort of coherent model. Gould continues:

> As he groped for a way to understand this history from the evidence of his field trips, and as he struggled to join the insights published by others with his own original observations, Lavoisier recognized that the principle of superposition could yield the required key: the vertical sequence of layered strata might record both the time and the order of history. But vertical sequences differed in all conceivable features from place to place – in thickness, in rock types, in order of the layers. How could one take this confusing welter and infer a coherent history for a large region? . . . Lavoisier therefore suggested that a drawing of the vertical sequences of sediments be included alongside the conventional maps festooned with Guettard's symbols. . . . If I wished to epitomize the birth of modern geology in a single phrase (admittedly oversimplified, as all such efforts must be), I would honor this passage . . . of Lavoisier's view of history, as revealed in sequences of strata. . . .
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> Lavoisier did not invent the concept of vertical sections; nor did he originate the idea that sequences of strata record the history of regions on an earth of considerable antiquity. Instead, he resolved an issue that may seem small by comparison, but that couldn't be more fundamental to any hope for a workable science of geology (as opposed to the simpler pleasures of speculating about the history of the earth from an armchair): he showed how the geological history of a region can be read *from variations in strata from place to place* – or, in other words, how a set of one-dimensional lists of layered strata at single places can be integrated by that greatest of all scientific machines, the human mind, into a three-

dimensional understanding of the history of geological changes over an entire region.

Lavoisier never stopped thinking about geology, even though he did not publish his only paper on the subject until 1789, almost twenty years after he ceased working for Guettard. The paper's extended title is *General observations on the recent horizontal beds that have been deposited by the sea, and on the consequences that one can infer, from their arrangement, about the antiquity of the earth*. Despite the "big picture" themes implied by this title, Gould notes that the work reflects the very best of the scientific method by focusing on a small but *testable* piece of an enormously complex problem.

The mainstream understanding of sedimentary strata in 1789 was that they were deposited over time, and under water, but that the entire deposition had occurred during a single (albeit extended) period of submersion. Lavoisier's thesis was that the strata actually indicated several different periods of deposition, corresponding to multiple cycles of lower and higher sea levels – and thus implying, among other things, even more time than geologists were assuming. Importantly, Gould notes, Lavoisier did not focus on the reasons that the sea level might have risen and fallen; he noted that this was an important question, but that it fell outside of the scope of his paper. Instead, he created a carefully simplified model for what strata in different locations would look like *if* sea levels rose and fell, and then compared this model to his geological observations. Clearly implied is that further "tests" of this model, in the form of observations from additional sites, could further support or derail it; this is the essence of the scientific method.

Gould takes us through the paper in some detail. Lavoisier's first simplification is that he considered only two types of sediments: *littoral* and *pelagic*. The former are associated with near-shore environments where wave action affects the sea floor; it is associated with well-worn pebbles (eroded from the shore) and the absence of intact shells. Pelagic sediments are associated with deeper, "open" ocean, where sediments are composed of fine precipitated particles and well-preserved shells. His second simplification was to study a region where the source of new sediment remained relatively constant over the eons; he found such a region in northern France. The soft chalk deposits there, interspersed with hard flint nodules, provided a source of raw material in the form of cliffs – the same formation that produced the White Cliffs of Dover. For a given sea level in the past, according to his model, deposits of large, coarse pebbles should be closer to the ancient shore, smaller and more rounded pebbles farther away, and pelagic strata would be still farther out. This is the pattern seen in his observations, he wrote; but there was more. The key argument (and the key plate, which Gould acquired) is that, in many locations, bands of littoral and pelagic deposits were *interspersed* – indicating that the sea level at those locations had risen and fallen multiple times in the past. In fact, the actual geologic history is very complex; Gould's appreciation for Lavoisier is centered on his ability to see the signal in the noise, and to demonstrate a practical approach by which that signal could be analyzed.

Gould concludes by discussing another observation in Lavoisier's paper. The underlying (and thus very old) strata, he argued, do not show this cyclical sea level pattern very clearly, presumably (he argued) because the evidence had been altered by time. He also noted – incorrectly, it turns out – that these older rocks contained no fossils. In the struggle between the paradigm of a young earth (in which there was no natural history to speak of) and that of Newton's mechanics (in which systems cycled endlessly but always returned to their starting point, precluding the need for "history"), Lavoisier was exploring a third paradigm. In earlier cycles, he speculated, the world was *different* – there was no life in the seas. That is, he argued [like Buffon in the previous essay], earth itself apparently had a history – one that could be read in the rocks.

LSM 6. A Tree Grows in Paris: Lamarck's Division of Worms and Revision of Nature

This is Gould's most extensive essay on Jean-Baptiste Lamarck (1744 – 1829), and it includes some original research. At 29 pages, it is also the longest essay in his monthly series (it was published in two parts in *Natural History* magazine). He begins with a sketch of Lamarck's life and major works, and then discusses his theory of evolution – which is incorrect, but which is much more extensive than the simple phrase "inheritance of acquired characteristics" would suggest. Lamarck was a good scientist, Gould continues, and made some important contributions to invertebrate biology (two words that he coined, we are told). The main theme of the essay, however, is the previously-unreported story of how Lamarck came to finally reject his own "ladder of evolution" view, and replace it with the "tree of life" or "bush" model that Darwin employed (and that we still use today). This, along with the fact that Lamarck worked in Paris, gives the essay its title. Gould references books on Lamarck by Richard W. Burkhardt and Pietro Corsi.

Some background is required in order to appreciate the story of Lamarck's conversion. Linnaeus published the definitive tenth edition of *Systema Naturae* in 1758, some fourteen years after Lamarck's birth. This work is noted for its hierarchical, nested, "genus-species" binomial-nomenclature classification system that, while highly modified, is still in use today. He divided the animal kingdom up into six "classes" [the term phylum was not introduced until later]. These were: mammals, birds, amphibians, fish, insects, and worms (Latin, "*vermes*"). Today, the first four of these are all placed in the phylum of vertebrates, or more accurately, chordates. In Linnaeus's original scheme, all other phyla – from jellyfish and coral to mollusks and annelids – are lumped into the two remaining categories.

Meanwhile, the medieval, Christian concept of the Great Chain of Being [Latin, *scala naturae*, literally "ladder of nature", discussed in TFS 17] was as powerful as ever; this paradigm postulated a unique, single-tracked ranking of all forms of life, from inanimate matter to single-celled organisms, through worms, insects, and fish – and finally up to man, with angles and then God Himself above them. When the concept of the transmutation of species began to appear, most versions (including Lamarck's) held on to the concept of the Great Chain, and considered evolution to involve a metaphorical "climb" up this linear, directional ladder [as the word *evolution* actually implies; see ESD 3 and IHL 18]. Thus, the debate over whether mollusks were higher on the chain than, say, crustaceans, shifted to which group was more "evolved."

With these two models functioning in Revolutionary France, Lamarck – up until then an expert on plants and mollusks – became a professor at the newly-created *Muséum d'Histoire Naturelle* in Paris in 1793. His assigned subject was "Insects and Worms" – the two non-vertebrate classes of Linnaeus's animal kingdom. A brilliant if sometimes arrogant man, he quickly turned to the problem of "rescuing" major groups from Linnaeus's "wastebucket" category (a legitimate semi-technical term, we are told) of *vermes*. At the beginning of each academic year, many professors would present an introductory lecture that would often be reprinted; Lamarck's first such presentation in 1793 listed five invertebrate classes, with mollusks and polyps (corals and jellyfish) extracted from the still-existent category of *vermes*. By 1809, with the help of a younger colleague destined for greatness named Georges Cuvier [HTHT 7], he had broken the two groups of worms and insects into ten categories. ("Insects" had originally included crustaceans and arachnids.)

But Lamarck was a theorist as well as a talented descriptive analyst. He operated under the school of thought known as "system builders" (*l'esprit de système*, or "the spirit of system building"). This perspective was common during the Enlightenment, and at its core were two assumptions: first, that nature followed a fundamental, harmonious, and generally predictable plan of some sort, which usually included "progress," and was presumably the work of a loving deity; and second, that the human mind was capable of recognizing and understanding the inviolate principles behind this plan (as Newton had done with gravity), perhaps because man "thinks" the same way God does, or perhaps because God wants us to appreciate His handiwork. Thus, "system" in this sense of the word implies an overarching "theory of everything" based on general and exceptionless principles.

Lamarck's evolutionary system, referred to by scholars as the "two-factor theory," has as its primary mechanism a materialistic, if undetermined, force of some sort that propels life progressively up the linear Chain of Being, from the simple to the complex (*la force qui tend sans cesse à composer l'organisation*, or "the force that tends incessantly to complicate organization"). But Lamarck was too good a naturalist to believe that every individual species could be ranked according to this principle. Instead, he limited this ranking (and evolutionary progress up the chain) to Linnaeus's *classes* – modified to include his revised view of the invertebrate world, with mollusks above insects, and insects above polyps. *Within* these classes, he recognized a second factor, or force: *l'influence des circonstances* (the influence of circumstances), which worked to adapt species to their local environments. The first and dominant factor moved animal life up the ladder; the second, weaker force spreads species and genera out "sideways" from the class's collective center, forming a band. It was possible, in his view, for a particular species of insect to actually be more complex than a particular species of, say, mollusk, especially one that had "degenerated"; this did not disturb his model, since it was the "principle mass" of each class that was associated with a given rung. Interestingly, it was

Lamarck's proposed mechanism for this second, weaker evolutionary force that is known as "the inheritance of acquired characteristics," and is all that is generally remembered today. (He did not invent this mechanism; it was considered "folk wisdom" at the time.)

Lamarck presented his theory of evolution for the first time in his opening lecture of the 1800 term, and this was reprinted in 1801 as the first 48 pages of the 398-page book *Système des animaux sans vertèbres* (*Treatise on invertebrate animals* – note the first word in the French title). He discussed modifications to this theory in all of his later major works: *Recherches sur l'organisation des corps vivans* (*Researches on the organization of living beings*), published in 1802; his two-volume magnum opus, *Philosophie zoologique* (*Zoological philosophy*), published in 1809; and his seven-volume *Histoire Naturelle des animaux sans vertèbres* (*Natural history of invertebrate animals*), the first volume of which appeared in 1815. However, Gould claims, most scholars have ignored his last major work, *Système analytique des connaissances positives de l'homme* (*Analytical system of positive knowledge about man*), which was published in 1820. This book is primarily about psychology (in today's terminology), but it does include a chapter on animal taxonomy that Gould will argue is very important when considering Lamarck's life as a whole.

Lamarck's theory is not, of course, accepted today. Gould tells us, however, that his views came under heavy fire from the very beginning, and that when he died in 1829 (decades before *Origin of Species*) – "lonely, blind, and impoverished" – very few supported his model. This was in part due to the fall from grace of the entire *l'esprit de système* paradigm, which was increasingly replaced by what Gould calls "a hard-nosed empiricist ethos in early-nineteenth-century geology and natural history." But Lamarck also had professional enemies, due to his arrogant and dismissive attitude toward other viewpoints; and he was often careless enough with his writing to allow critics to charge (unfairly, Gould claims) that he was a mystical "vitalist" rather than a mechanist. After he died, Cuvier – his former protégé, who was neither an evolutionist nor a system builder – wrote a "damning with faint praise" obituary that lowered his stature even further.

But things looked much brighter for Lamarck in 1800, when he first presented his evolutionary theory. Interestingly, Gould notes, it was during the next winter (1801-02) that the seed was planted that would eventually convince Lamarck that his theory, and his entire system-building worldview, was fatally flawed. This seed came from Cuvier himself, and involved his brilliant work on segmented worms – a group that includes earthworms and leaches. Lamarck had been struggling with another problem with *vermes*; some members, such as earthworms, had a much higher degree of organization (e.g., internal organs) than other members, such as tapeworms. By itself, this would not have been sufficient for him to remove one group or the other from the class (as he had done with, for example, mollusks); his adaptive, diversifying force could, in his mind, produce this degree of variation. However, it also appeared that most of the complex worms were free-living (what he called "external"), while most of the simple worms were parasitic, living inside other animals (what he correspondingly called "internal"). Then, that winter, when Cuvier showed that the circulatory system of the external worms included "tubes" (veins and arteries) that circulated red blood, while the internal worms only pumped a white fluid through body cavities, he committed to separating the groups. In his 1809 work *Zoological philosophy*, places external worms into their own class – the annelids – and credits Cuvier's work. The internal worms remain in the class of *vermes*.

Gould inserts an extended personal anecdote at this point of the story. Lamarck never published a second edition of his 1801 work *Treatise on Invertebrate Animals*, but he did have what was known in the trade at that time as an "interleaved copy"; this is a copy produced with a blank page between every printed page. Interleaved copies are given to the author by the publisher, so that any revisions for a follow-on edition would be reasonably contained and organized. Lamarck made several dozen entries into this workbook, but one in particular stands out: it is a sketch of an annelid circulatory system with supporting text, which he clearly made shortly after seeing Cuvier's lecture. In 1998, Lamarck's interleaved copy went up for auction – and, while Gould could not afford to acquire it for himself, he was allowed to study it by the winning bidder, and to publish his thoughts on what he found. This was the original motivation for this essay.

In 1802, the separation of annelids and *vermes* was only half of Lamarck's task; the other was placing the two categories in the correct order on the Great Chain. This was done by determining the relative complexity of each class. Annelids, it had now been established, had a complete circulatory system, which placed them ahead of insects, which did not. The internal worms that remained in *vermes* had to be placed after insects, since the latter had some well-developed organs and sensory devices such as eyes. However, *vermes* remained ahead of *radiaires* (today recognized as an inappropriate combination of jellyfish and echinoderms such as sea urchins), on the grounds that the former's bilateral symmetry was "more complex" than the latter group's radial symmetry.

At first, Lamarck viewed this "division of worms" in terms of another class rescued from Linnaeus's wastebucket. But soon he recognized a problem, one that he wrestled with for more than fifteen years. *Vermes* (now limited to internal worms) were more complex than *radiaires*, because of their bilateral symmetry. However, some of the *radiares* (specifically, the echinoderms) had a well-developed circulatory system, complete with tubes – although the fluid that was pumped about was sea water rather than blood. No remaining members of *vermes* had this feature. (He had been able to avoid this problem when *vermes* included annelids; then, *some* of the worms had complex circulatory systems, and all that his system required was that the average degree of vermes complexity be higher than that of the *radiaires*.) In terms of the later tree-of-life paradigm, this poses no problem; but in Lamarck's ladder paradigm, the proper ranking of these two classes was essential. Further, the entire paradigm of system building was premised on the idea that there could be *no exceptions* to the underlying rules of nature. He faced a fundamental, internal inconsistency in his model; a class cannot be more evolved in one way and less evolved in another.

Gould observes with fascination, via the publications of 1801, 1809, and 1815, as Lamarck struggles with his dilemma. In the main body of his 1809 book, he continues to express firm commitment to the ladder paradigm. However, in an annex, he postulates an alternative model that he hopes can address the recognized problem of his two-factor theory. Perhaps, he offers, there is not one chain of life, but *two*: one that began (by spontaneous generation) in an external body of water such as a pond, and another that started *inside* another animal. Each would evolve via the overarching law of increasing complexity, but the details would differ because of the different environments. In this view (he postulated), it might be possible that animals from the two chains could be staggered in their advancement; one ahead in symmetry, the other possessing a more complex circulatory system.

Once he had invented a concept of "branching," however, he quickly found that he could apply it to other problems that had been papered over. For example, he was always unhappy with the sequence of reptiles (or amphibians, depending on the version) to birds and then to mammals. In his mind, birds seemed to be as complex as most mammals; plus they were bipedal, like man. Perhaps birds and mammals both sprang from reptiles? He applied this "branching" design, tentatively, in other places as well. By the time of his 1815 work, he had developed a more fully-formed two-ladder model of life, with each trunk splitting into multiple categories.

This exciting solution solved the immediate problem (to his satisfaction), but it created two more. First, it "mixed up" the two forces of increasing complexity (internal to all life) and of circumstance (the result of interaction with, and adaptation to, the outside world) – especially at the branching points themselves. Second, and more importantly, it indicated that the branching force – which could, in this revised view, produce organisms as different as birds and mammals from reptiles – was at least as powerful the directive, progressive force. This undermined not only his theory of evolution; it eroded the entire system making worldview that simple, predictable, invariant laws can explain the living world around us.

Most scholars of Lamarck end their study of him with his 1815 publication. They conclude that, while he came to recognize serious flaws in his theory, he never embraced the "tree of life" model that Darwin would present – one in which there was no central path or ladder of evolution, but only a divergent bush where every branch was unique. But Gould disagrees, stating that these scholars have ignored Lamarck's 1820 work, *Analytical system of positive knowledge about man*. This book is rare and mostly off-topic, but (Gould discovered) it does have a chapter on animal taxonomy. In this chapter, Gould reports, Lamarck accepts the bush metaphor completely, with its implication that the contingent force of branching is almost entirely responsible for the diversity of life on earth today. He quotes from this work:

> Let us consider the most influential cause for everything done by nature, the only cause that can lead to an understanding of everything that nature produces . . . This is, in effect, a cause whose power is absolute, superior even to nature, since it regulates all nature's acts . . . . This cause resides in *the power that circumstances have to modify all operations of nature* [italics added], to force nature to change continually the laws that she would have followed without [the intervention of] these circumstances, and to determine the character of each of her

> products. The extreme diversity of nature's productions must also be attributed to this cause.

Gould closes by stating that many people will read this revised view of Lamarck's story as a tragedy; he based his life on a theory that, in the end, he was forced to abandon completely. This would be a mistake; in Gould's eyes, Lamarck is a heroic figure. This man of integrity never stopped looking for answers, even when it would have been easy to rationalize away the inconsistencies in his model. Further, by the end of his life – although he may no longer have been deemed relevant by his peers – he finally got a glimpse of the right answer (and yes, there is such a thing): the tree of life.

LSM 7. Lyell's Pillars of Wisdom

Gould wrote about Charles Lyell (1797-1875) and the development of modern geology based on gradualist (or "uniformitarian") principles in as essay almost 25 years earlier [ESD 18]. In this two-part essay, he begins by discussing Lyell's views and motivations, and recapitulates his struggle with the rival "catastrophists." In the second part, Gould explores a specific geologic example used by both sides in this debate: Mount Vesuvius.

Lyell's uniformitarian worldview is built on two fundamental postulates. The first, which Gould calls "the doctrine of gradualism," proposes that all geologic features on the surface of the earth can be explained in terms of forces acting today (or in historical times) and, just as importantly, that these forces have always acted at their current rates. That is, earthquakes (for example) were not bigger or more frequent in the distant past. This is related to his second postulate: a non-directional, steady-state earth. In Lyell's view, the planet might cycle through multi-million-year periods of warming and cooling, but it has been close to equilibrium for virtually all of its natural history. He extended this view to biology as well: species of mammals might come and go, but there had always been mammals, even in Precambrian times (he finally abandoned this specific example in the 1850's, we are told), and the "complexity" of life has remained essentially constant over time.

When a scientist proposes an overarching worldview, Gould again notes, it is often worthwhile to investigate the context – and to look for an alternative worldview that the author is struggling to modify or replace [also see LMC 17 and LSM 9]. In this case, Lyell was struggling with Cuvier, Agassiz, and the so-called catastrophists. As discussed in ESD 18, Lyell – a lawyer by training – left the *impression* in his book that his scientific opponents (who all accepted an ancient earth and exclusively natural mechanisms) were really dogmatic anti-rationalists who were trying to cling to the literal timescale of Genesis, with God as the prime mover in all cases. (He largely succeeded in this, Gould states.)

The uniformists and the catastrophists did have legitimate and important disagreements. Gould writes: "Catastrophists argued that most geological change occurred in rare episodes of truly global paroxysm, marked by the 'usual suspects' of volcanism, mountain building, earthquakes, flooding, and the like. Most catastrophists also held that the frequency and the intensity of such episodes had decreased markedly through time, thus contrasting a feisty young earth with a much calmer planet in its current maturity." This was consistent with their belief (widely, although not universally, held at the time) that earth began as a molten fireball, and had been cooling ever since – rapidly at first, and then ever more slowly. As it cooled, they reasoned, it contracted, which produced earthquakes and built mountain ranges. Thus, the catastrophists were advocating an earth with a highly directional history, versus Lyell's directionless steady-state. Lyell, for his part, was not arguing for uniformitarianism based on the geologic evidence (which often favored the catastrophists); rather, his motivation was that we would not be able to decipher earth's history *if* the catastrophists were right! From the essay: "In part, [Lyell] chose the substantive route of arguing that the world, as revealed by geological evidence, just happens to operate by gradual and nondirectional change . . . . Only such a uniformitarian approach, he argued, could free the emerging science of geology from previous fetters and fanciful, largely armchair, speculation." [Gould discusses these complementary metaphors of natural history in his 1987 book *Time's Arrow, Time's Cycle*. While both groups have proven to be partially correct, the catastrophists were wrong about planetary cooling leading to shrinkage and earthquakes; the earth's mantle is still molten and in equilibrium, due to radioactive decay at the core (TFS 8). The true mechanism behind major geological events – plate tectonics – was not established until the middle of the 20th century (ESD 20).]

Gould then turns to the battle of symbols between the uniformitarians and the catastrophists, which both sides recognized as important. The catastrophists' leading symbol was Mount Vesuvius in Italy, near Naples. The eruption of this volcano in 79 AD not only buried the cities of Pompeii and Herculaneum – then being excavated – but also resulted in the death of Pliny the Elder, the most famous Roman naturalist. Pliny's nephew wrote of the incredible darkness produced during the eruption, in addition to earthquakes, rocks from the sky, and sulfurous odors – surely signs of a catastrophe, one that could be extrapolated to even larger and more powerful events. Vesuvius remained intermittently active for the next two thousand years, providing other naturalists the opportunity to describe its ability to produce sudden destruction. Lyell, Gould tells us, recognized that he had to de-fang this powerful symbol in order for his view to prevail.

He attacked along two fronts. First, he (legitimately) argued that the magnitude of these eruptions, while large on a human scale, was relatively small at a global scale. In so doing, he was claiming events the size of volcanic eruptions for *gradualism*, and thus trying to capture the symbol of Vesuvius from his opponents. Second, he argued that the incompleteness of the geologic and fossil records amplified the *appearance* of catastrophe. This was in part because vast lava flows, ash fields, and long fault ruptures are preferentially preserved in the record over more gradual processes, and in part because the discontinuity of stopping and then later restarting a deposition process can give the *illusion* of a catastrophic change. (Cuvier, in his 1812 defense of catastrophism – *Discours préliminaire* – argued that the opposite conclusion could be drawn from the record. In an analogy to war and human history, he postulates a region that has been peaceful for centuries; it would be easy for a local to think that the world had always been that way. Yet, he continued, this current state is heavily dependent on those rare events; had a battle hundreds of years ago gone the other way, the valley might be farmed today by a completely different population.

Even better than capturing the opponent's symbol is the establishment of one's own. Lyell found a brilliant one, in the form of three standing Roman columns in the town of Pozzuoli, just outside of Naples and irresistibly close to Vesuvius. (This set of ruins is commonly known as the temple of Serapis, but is actually the entrance to a marketplace.) These three marble columns had been buried, but were excavated in 1750; they are about 40 feet tall, and Lyell saw them as a young man. Importantly, these columns exhibit the distinctive marks of boring clams up to a good 20 feet above their base. Since these clams can only live below the low-tide level, there is no escaping the conclusion that, at one time, the columns had been submerged to this depth. Since the Romans built them above sea level in the first or second century AD, the land under the columns must have subsided and then risen again by at least 20 feet – in less than two thousand years, and while remaining upright. (There presence also refuted the claim that land was invariably stable, and that submersion therefore required changes in sea level.) Gould, paraphrasing Lyell, writes:

> If such geological activity can mark so short a time, how could anyone deny the efficacy of modern causes to render the full panoply of geological history in the hundreds of millions of years actually available? And how could anyone argue that the earth has now become quiescent, after a more fiery youth, if the mere geological movement of historical time can witness so much mobility?

Lyell was so taken with the illustrative importance of the columns of Pozzuoli that he made them the frontispiece of *Principles of Geology*. Gould himself visited this location on a trip to Naples, and found – as Lyell had before him, and others since – that the site is even more geologically dynamic than had originally been thought. It has risen and fallen, at various rates, numerous times – including elevation changes on the order of two feet or more since Lyell's first edition appeared in 1830. Lyell, we are told, kept tabs on them for the rest of his life. Perhaps most deliciously (from his perspective), he recognized that it was probably the buildup and then discharge of volcanic material below Vesuvius itself that was responsible for these elevation changes.

Gould adds a concluding section, pointing out that while Lyell's symbol is both brilliant and correctly interpreted, this does not mean that his larger worldview is completely right, or that the catastrophists were completely wrong – as the comet or asteroid impact now recognized at the end of the Cretaceous period shows [HTHT 25]. Interestingly, a colleague of Lyell's – Charles Babbage, who among other things also invented an early form of computer – referenced the work of a young Charles Darwin on the subsidence of coral atolls in support of uniformitarianism. This was particularly helpful in that it allowed the extension of subsidence claims from local to global. However, Babbage went too far (so easy to do, Gould reminds us) by speculating that the craters on the moon – then believed to be volcanoes – were actually a similar subsidence phenomena, now exposed by the loss of all water there. In fact, we now know that these craters are not volcanic in origin, but remnants of meteor impacts – a catastrophic phenomenon.

LSM 8. A Sly Dullard Named Darwin: Recognizing the Multiple Facets of Genius

The original version of this essay was a book review for *Voyaging*, the first volume of Janet Browne's biography of Darwin and published in 1995. It appeared in the *New York Review of Books* rather than in his monthly column. [Browne's second volume appeared in 2002.]

In his youth, Charles Darwin did not impress anyone with either his intelligence or his motivation – not his family, his friends, or his teachers. A family friend who knew both Charles and his older brother Erasmus while they were growing up considered the latter to be the more intelligent of the two. Before sailing off on the *Beagle*, Charles had dropped out of medical school, greatly frustrating his physician father; he then acquired a degree from Cambridge "with gentleman's C's" (Gould's assessment) in a field that would prepare him for the default profession for second sons of the upper class, the clergy. Yet this same man developed a revolutionary theory that shook the world. What had happened? Who was this man, and how was he able to produce something that convinced the best minds in Europe that his views about evolution – if not his mechanism (that would come later, raising his stock still further) – were correct? Gould begins by taking us through the brief period in 1837, after his return, when he made the conceptual breakthrough that allowed him to recognize that evolution indeed occurred. [He discussed this story previously, in TFS 23.]

Gould's thrust is that there was no one single source of Darwin's success; rather, it was a combination of factors, some internal and some external. The external ones included a wealthy and influential father as well as a famous grandfather, and all the connections that came with being an upper class Victorian gentleman. Another, obviously, was the opportunity to spend five years in his twenties exploring the natural world. A third was the chronic illnesses that afflicted him; he (with the help of his wife) used these to avoid the normal social duties of his class. Gould writes:

> He used his wealth, his illnesses, his country residence, his protective wife for one overarching purpose: to shield himself from ordinary responsibility and to acquire precious time for intellectual work. Darwin knew what he was doing when he wrote in his autobiography: "I have had ample leisure from not having to earn my own bread. Even ill-health, though it has annihilated several years of my life, has saved me from the distractions of society and amusement."

But the internal factors are just as important; these tell us something about how Darwin came to effectively use the time made available to him. While he was not mentally "quick" in the sense of making rapid deductions or being able to solve mathematical puzzles, he did have an underlying *tenacity*; this is exemplified by the four volumes on the taxonomy of barnacles he wrote over an eight-year period. Further, once he found his calling, he discovered – perhaps to his own surprise, given his history – that he was highly driven to pursue it. He had a vision for "big picture" theory, and simultaneously a fascination with details that most people ignored. Finally, his intellectual interests were very broad, and he came to acquire knowledge like a sponge. He read books on all subjects – including Adam Smith's *Wealth of Nations*, as well as the works of other scientists and philosophers in all fields – from cover to cover. He also discussed subjects related to nature with anyone he felt he could learn from, including the hired help – something that was not commonly done in Victorian times. He sought; he compiled; he integrated and synthesized. Gould argues that Darwin was not the best at any of these things individually, but that it was this *combination* of his talents that led Darwin to get the most out of the time that fortune had bestowed upon him. Gould uses this point to illustrate his view that intelligence is not one single thing that can be tested for, as proponents of IQ suggest. (He references the second edition of his book *The Mismeasure of Man*.)

LSM 9. An Awful Terrible Dinosaurian Irony

Richard Owen (1784 – 1856) was prickly and ego-driven, but he was also one of the greatest comparative anatomists in British history [see ELP 4 and LMC 6]. It was he who, as a young man, analyzed the mammals and terrestrial vertebrate fossils that Darwin brought back from South America on the *Beagle*, and who inadvertently helped inspire him to think about evolution [TFS 23, LSM 8]. In the 1830's, Owen was commissioned by the British Academy for the Advancement of Science to produce a major report on British fossil reptiles. He described the aquatic ichthyosaurs and flying pterodactyls, among others, as well as three large but very distinct terrestrial vertebrates – a carnivore, *Megalosaurus*; a herbivore, *Iguanodon*; and an armored herbivore (an ankylosaur), *Hylaceosaurus*. Owen observed that these three animals shared a number of important features other than their size; most notably, the fusion of several sacral vertebrae to the pelvis (creating strength), and the positioning of the limbs directly under the body, rather than splayed out to the sides as in modern lizards and crocodiles. In 1842, he coined the name Dinosauria for this group.

The term dinosaur, as most people know, literally means "terrible lizard." Gould tells us that Owen's choice of the term *deinos*, or terrible, was carefully chosen to make a point. To understand that point, he explains that Owen used this word in the 19^{th}-century fashion, where it meant "awesomely powerful," rather than "really bad" or even "fearsome." (Gould also notes that the word "awful," which meant "to inspire awe" at the time, has suffered a similar change in contemporary meaning; this gives the essay the first part of its title.) Owen wanted the collective descriptor for what he (correctly) suspected was a very diverse group to imply magnificence, wonder, and awe. Today it would be easy to assume that he did this for purely objective reasons – but this is not entirely the case. Owen had his own agenda: one that used the concept of dinosaurs to enhance the perception of a worldview of an important sponsor, while simultaneously working against a key rival. (Gould draws on a biography entitled *Richard Owen: Victorian Naturalist* by Nicolaas A. Rupke for details.)

The sponsor was the Reverend William Buckland [HTHT 2, TFS 7], a confirmed creationist but also a dedicated scientist, and the first official professor of geology at Oxford. Buckland himself had identified and named *Megalosaurus* in 1824; later, he would go on to write one of the Bridgewater Treatises, which collectively support the overarching theme of natural theology. The rival was Robert E. Grant, a recently-appointed professor of zoology at University College London. Grant believed in one of the versions of "species transmutation" that was circulating in the decades before Darwin published *Origin of Species* in 1859. (Gould reminds us that Darwin did not invent the idea of evolution; his two contributions in this field were to convince the intellectual community that the concept was true, and to suggest natural selection as a mechanism.) The relatively popular view of transmutation that Grant favored was known in the 1840's as "progressivism." This refers to the quasi-Lamarckian view that organisms worked over the eons to climb up the great chain, moving with progressive improvement toward the goal of a more perfect state [LSM 6]. Owen had sought Buckland's favors in the past, and his career was the better for it; he saw Grant as standing between himself and the path to recognized primacy in his field.

The paradigms of Buckland and Grant were both progressive, in that they both predicted that life became more "advanced" over the course of natural history. However, there was an important difference – one that could be compared against the fossil record. The progressivist transmutationists believed that life changed over a single track "from monad to man," with the implication that the most advanced animals of one era should be inferior to – but, at the same time, lead (via transmutation) directly to – the most advanced animals of the current era. Buckland's school of creationism believed in progress, but also an ancient earth with continuous, or at least multiple, creations – with each ecosystem optimized for the environment of the era. Importantly, they viewed the earth as progressively cooling from a molten state; on a warmer earth, cold-blooded reptiles would be the optimal design, while on the modern, cooler earth, mammals were superior. Creationism required no genealogical connection between the fauna of different eons, and in fact argued that there should be none.

This brings us to the heart of Owen's worldview, circa 1842: dinosaurs as a group probably dominated the ecosystem of their day (he argued), and they were not mammals – nor were they directly related to mammals. (Owen himself had also identified, via skull characteristics, a different group of more mammal-like reptiles; they were not nearly so "impressive.") The transmutationists were attacked on a second front as well. Their paradigm implied that "the best" animals that lived in the distant past should be cruder, less complex, and generally inferior in design to modern animals. Dinosaurs, Owen stated – as their name was meant to imply – were magnificently designed animals, from their intricate teeth and tails to the orientation of their legs. If a genealogical lineage did exist, he implied (incorrectly), then reptiles had *degenerated* to modern lizards and snakes, rather than improved over time. This view supported those of Owen's superior, Buckland (Gould closes by telling us that he acquired Buckland's personal copy of Owen's 1842 report, probably handed to him by Owen himself), while simultaneously discrediting his transmutationist rival. Gould notes that, while Grant is not explicitly named in the article, his earlier paper on the subject is the only one of his that is referenced; this would have clearly identified him to contemporary readers.

Thus, the irony of the title is that dinosaurs – the most popular example that life changes over time (presumably by evolutionary processes) – received its name as part of an effort to impugn the – or, more accurately, a – concept of evolution. Gould notes that Owen's views on evolution changed over time; after Buckland's death, he offered his support for the general concept, although he opposed Darwin's theory of natural selection.

LSM 10. Second-Guessing the Future

Gould begins this essay with a brief biography of Alfred Russel Wallace (1823 – 1913), the second name associated with the mechanism of natural selection. Wallace was born into the middle social class of British society, but his family was relatively poor; as a result, he had to support himself (mostly by writing), which allowed far less time than Darwin had for research and thinking. Nonetheless, while struggling with malaria in Indonesia in 1858, while on his second major scientific voyage, he independently developed a theory of evolution via natural selection. He knew of Charles Darwin, as a respected naturalist interested in "the species question," but had no idea that he was working on evolution; Wallace sent him the paper for his thoughts and comments. Darwin had developed the idea twenty years earlier, in 1838, and had not simply put the idea on a shelf; he had been quietly working on details, examples, and problems for the entire period. However, he had no immediate plans to publish his results, and without Wallace precipitating this crisis might only have done so posthumously. The "delicate solution," as Darwin's friends Lyell and Hooker called it, was to read both Wallace's paper and some of Darwin's earlier work together at a meeting of the Linnaean Society of London in July 1858; Darwin got to work and wrote *Origin of Species,* published the next year. Some have complained that this was unfair to Wallace, but both his public and private statements show that Wallace himself was perfectly happy with the arrangement. The two got along well for the rest of their lives. [The two models of evolution by natural selection were not identical, however, and this did lead to some friction. Gould discusses the important differences in TPT 4.]

Wallace lived a long life, and remained a public figure for most of it. He championed a number of causes in his career, some of which would be considered noble today, others a bit kooky. Gould wrote this essay to celebrate the 100th anniversary of a book Wallace wrote late in life and at the end of the 19th century (in 1898) entitled *The Wonderful Century: Its Successes and Failures*. The first part – on successes – discusses many of the scientific and technical advances of the ongoing industrial revolution, from transportation (railroads), communications (the telegraph and telephone) and labor-saving machinery powered by electricity, to theoretical advances in physics, geology, and, of course, biology and evolution. The second part, on failures, is an odder collection. It includes "advances" that Wallace believes had been unfairly bypassed, including phrenology and hypnotism, and another that he believed had been criminally inflicted on society: vaccination. An important underlying theme in Wallace's book, Gould tells us, is that while science and technology made tremendous advances, social and moral attitudes did not keep up. As a result of new weapons, the national leadership could now kill millions instead of thousands, but invariably did so for the same old causes – dynastic squabbles, control of resources, and the like. Capitalism has channeled the new wealth produced by technology into the hands of a small number of super-rich, leaving most people actually poorer than when the century began. He also objected to "the plunder of the earth," and the environmental pollution and deadly working conditions that were ravaging large segments of the population.

Gould, for his part, does not entirely agree with Wallace's assessment of this theme, and argues that there has been quite a bit of moral progress in the last millennium; we no longer burn witches, taunt the insane, or condone slavery, for example. Wallace's book does allow him to elaborate on two familiar themes. The first of these is the role of science in society, as discussed. The second is the unpredictability of "history," both human (Wallace's subject in this book) and natural. (Wallace does not say very much about what he expects for the 20th century in this volume, but Gould's essay includes a set of drawings made at about the same time that predicted what life would be like a century in the future. These include mail delivery by small, personal aircraft and people living underwater "fishing" for birds – similar in tone to the 1960's animated television show "The Jetsons." He returns to this theme in LSM 20.) Gould's point is that it is the course of human history is very difficult to extrapolate from its past. He offers his argument of the Great Asymmetry [BFB 24 & 35, ELP 19] as a major factor for this: a single disaster can cause as much change as a thousand small advances, and the disasters invariably affect society in ways that are impossible to predict. He argues that, if we could replay the "tape of life" (on a human scale, rather than that of natural history) starting again from the birth of Jesus, he argues that it is by no means inevitable that "the West" would be the dominant power in the world in the 20th century.

11-16. The next six essays are short pieces that Gould groups under the section heading, "Six Little Pieces on the Meaning and Location of Excellence." Only the first was originally published in his monthly column "This View of Life" in *Natural History* magazine.

LSM 11. Drink Deep, or Taste Not the Pierian Spring

This essay begins with a famous misquote, "A little knowledge is a dangerous thing." It is taken from Alexander Pope's *Essay on Criticism* (actually a poem), an excerpt of which reads:

> *A little learning is a dangerous thing;*
> *Drink deep, or taste not the Pierian spring;*
> *There shallow draughts intoxicate the brain,*
> *And drinking largely sobers us again.*

Knowledge and learning are not the same thing, in Gould's view; the former is mere factual data, while the latter involves a deeper understanding based on a careful synthesis of factual data and theory. He next tells us of his brief exercise to determine what a

"Pierian spring" is; Pieria, it turns out, is a region in Thessaly that, legend has it, is the home of the muses. Rather than continuing with the theme of the poem [with its implication that – whether knowledge or learning – a small amount of it can lead us into arrogant folly], he instead explores the statement that most Americans have only a "little learning" about science. While too many Americans are woefully ignorant of this essential part of the modern world he claims, this is not because the material is too hard or that most people have no interest in learning it. Rather, he suggests, our overarching teaching methodology is largely to blame for this; people are inherently interested in how the world works, but the teaching of science focuses too heavily on attempting to train professionals. He offers some metaphors: people can enjoy music without being able to play an instrument professionally, and can enjoy Homer's *Iliad* without being able to read ancient Greek. Those like him in the teaching professions, he continues, should expand our target audience to include people who will never become professional scientists, but will go on to be amateur astronomers, garden club members, car mechanics, weekend sailors or hunters, and people whose interests include anything in nature from sea shells to dinosaurs.

LSM 12. Requiem Eternal

Gould wrote this piece as "liner notes" for a Penguin Music Classic Series CD of Mozart's Requiem (Colin Davis, conductor) released in 1998. Gould tells the story of a man who observed an 8-year-old Mozart perform, and (like all who saw him) was amazed at his technical abilities. This observer wrote that he hoped that Mozart would live into his seventies, as Handel had, and also his fear that he would instead die young, as so many child prodigies seemed to do. Mozart lived to age 35, with Requiem being his last – and not completed – work. (Gould notes that he has sung the choral parts many times over his life, and loves it.) Gould speculates: how much richer would our culture be if Mozart had lived twice as long? History is a contingent thing, he remarks; he expresses gratitude that Mozart did not die in his early youth, leaving us without any of his great works.

LSM 13. More Power to Him

Written as a column for the Wall Street Journal in 1998, after Mark McGwire hit his 60th home run but before he had hit 70, this is a loving tribute to the slugger and to Gould's favorite game. He loves that baseball, unlike most team sports, is dominated by individual or one-on-one moments; he then adds [ironically, as we now know] that the game had remained sufficiently unchanged over its modern existence that McGwire's feat truly stands out as both legitimate and amazing. Gould writes, "I don't care if the thin air of Colorado encourages home runs. I don't care if expansion has diluted pitching. I don't care if the ball is livelier or the strike zone smaller. And I deeply don't care if McGwire helps himself to train by taking an over-the-counter substance regarded as legal my Major League Baseball."

[Of course, not long after Gould wrote this, the steroid scandal broke wide open. McGwire's record lasted only three years, falling to Barry Bonds' 73 home runs in 2001

– the same year McGwire retired. He pleaded the fifth in his testimony before Congress in 2005, and publically admitted using steroids – not just over-the-counter "supplements" – over his entire career. This episode does illustrate another of Gould's themes, however: no one, including brilliant scientists, can accurately predict how the future will unfold.]

LSM 14. Bright Star Among Billions

This is a eulogy to Gould's friend and fellow popularizer of science, Carl Sagan. It first appeared as an editorial in the journal *Science,* and it castigates the professional audience for what Gould considers shabby treatment by Sagan's colleagues. Gould feels that it was the fact that Sagan was a popularizer of science in addition to being a scientist that caused him to be disliked by many in his community; his popularity and fame induced jealousy and envy. He defends his friend, and the service he gave to science by his popular works. He calls Sagan "a fine scientist and the greatest popularizer of the twentieth century." The title is borrowed from Sagan's television series *Cosmos*, where he often described the subject matter with the phrase "billions and billions," pronounced in his iconic fashion. Gould notes that they both grew up in New York (Gould in Queens, Sagan in Brooklyn), and both were the descendents of Jewish garment workers.

LSM 15. The Glory of His Time and Ours

This is a eulogy for Gould's boyhood (and adulthood) hero, the great Yankee center fielder Joe DiMaggio, who died in 1999. Gould has written many essays that touch on baseball, but he once wrote an entire essay on the statistical significance of DiMaggio's famous 56-game hitting streak [BFB 31, "The Streak of Streaks"]. He tells of how much he enjoyed watching him play as a child, and of the few actual interactions he had with him both as a boy (getting a ball signed) and as a man.

LSM 16. This Was a Man

Mel Allen was the long-time announcer for the New York Yankees, and Gould wrote a remembrance of him for the *New York Times* when he died in 1996. Gould says he spent more time a child listening to Allen than any man other than his father. He recalled his famous catch phrases, some of which irritated him with their shameless tie-ins to sponsors; a home run, for instance, was a "Ballantine Blast" (after the beer). But he loved, and now misses, the uniqueness of the way he would call a game, something that vastly increased revenue precludes today. He recalls a story in which he berated a fan for booing a young Mickey Mantle, who had recently replaced Joe DiMaggio in center field. The essay's title is a line from Shakespeare's *Julius Caesar*, and refers to how the subject was capable of both great and not-so-great actions.

LSM 17. A Tale of Two Work Sites

In 1971, Gould spent a term at Oxford as a visiting researcher. His office, located in the University's museum, had been partitioned from a much larger room. Gould noticed a plaque on the wall which identified it as the site of the first public debate on the subject of Darwin's theory of evolution, with Thomas Henry Huxley squaring off against Bishop "Soapy Sam" Wilberforce. [Gould discusses the legendary and actual versions of this engagement in BFB 26.] Much later, in the 1990's, Gould accepted a part-time appointment as a visiting research professor of biology at NYU in Manhattan. His office there was on the tenth floor of the Brown building, which, he was informed, used to be called the Asch building – which was the location of the infamous Triangle Shirtwaist fire of 1911. Further, most of the 146 fatalities occurred on the eighth, ninth, and tenth floors. This struck a chord in Gould, because two of his grandparents were immigrants working in New York sweat shops at that time; both were garment workers in factories very similar to the one that burned. He offers a connection between these two worksites in terms of extremes: his Oxford office, with too little Darwinism (ideally none at all, according to Bishop Wilberforce); and the Asch/Brown building, with "too much" Darwinism (in the everyday, rather than the scientific sense), in the form of Social Darwinism. Most of the essay is a discussion of Herbert Spencer and his role in the formation of this doctrine, which actually preceded the publication of *Origin of Species* by almost a decade.

[Herbert Spencer (1820 – 1903) was the most well-known English philosopher of his time, and his books sold phenomenally well. In an age where advances in science and technology were leading many to doubt the tenants of traditional religion, Spencer offered a complex worldview where everything progressively "evolved" toward a more advanced state, from life on earth to human culture to the universe at large. His views of evolution were based on those of Lamarck, not Darwin, but he adopted parts of Darwin's mechanism of natural selection when it swept the land. Darwin, for his part, accepted most of Spencer's support, coming to use both the term "evolution" for his theory (Darwin had originally used "descent with modification") and his phrase "survival of the fittest."]

The doctrine that would later come to be known as Social Darwinism first appears in Spencer's 1850 book *Social Statics*. Spencer, actually a liberal of sorts during this period [he became more conservative later in life], argued that government-sponsored programs to help the sick and poor were detrimental to society at large, on the grounds that their premature deaths were part of the process required to keep the race evolving in a positive direction. His line of reasoning involved three errors, Gould tells us, and he takes us through each of them in turn. First, he held an admittedly common misunderstanding about how biological evolution worked; specifically, he believed in a rapid and continuous change (following Lamarck), where if a species was not moving forward than it was degenerating. Death of sick and weak organisms, he believed, was necessary to maintain the forward momentum of the species as a whole. [Modern genetics has discredited this view, but he worked long before that knowledge was available.] Second, he believed that it was reasonable to make an analogy between this (false) view of biological evolution and human cultural evolution. He believed that a single underlying set of laws controlled both processes, and therefore that any government involvement in public life – from mandated public education to the building of sewer systems – worked against natural law. Third, again seeking commonalities across different domains, he saw an analogy between the organs that comprise an organism and the individuals that comprise a society. Just as the digestive tract must do its part to keep the organism healthy while the eyes and brain "run things," so must the lower classes of society toil in poor conditions while their natural superiors lived better. Anyone could rise by virtue of their own talents and efforts (he believed), but it was wrong for government to try to offer even the most basic assistance to those who failed to do so.

Gould is careful to note that the manifestations of social conservatism – low wages, unsafe working conditions, a small circle of the wealthy and powerful – would have occurred regardless of anything Spencer wrote. What Spencer's writings did do, he continues, was to justify and rationalize decades of delay in instituting reform, and in particular government regulation of businesses and products. The Triangle Shirtwaist fire took place three years after Theodore Roosevelt left office, with many reforms to his credit; but the laws were still limited, and the government did not have the ability to effectively enforce them. This, he writes, leads to the more important story behind the deaths in 1911: it was not simply cruel management at one factory, but rather the weakness of the regulations and the inability to enforce the ones in place that would have made the working conditions safer.

LSM 18. The Internal Brand of the Scarlet W

The first part of this essay tells the story of how a false understanding of genetics, developed shortly after the field's establishment in 1900, led many scientists to support conservative social policies limiting immigration. The technical arguments were weak to begin with, and were abandoned within a few decades, but not before thousands of southern and eastern Europeans were denied entrance to the United States during the rise of Hitler in the 1930's. The second part of the essay presents Gould's argument that we are still laboring under a more subtle version of the erroneous genetic arguments of the early 20th century – specifically, that complex human behaviors such as thrill-seeking or homosexuality are genetically controlled. [He discussed his criticism of genes, human nature, and biological determinism in his first collection of essays: ESD 30-32.]

The genetic concepts of Gregor Mendel, first published in an obscure journal in 1866, were "rediscovered" in 1900 [by Hugo de Vries and Carl Correns, independently]. Mendel was able to demonstrate that genes had to be discrete particles, and that individuals possessed, not one, but a pair of each. These genes were not always identical; certain characteristics of pea plants – white flowers or purple, smooth peas or wrinkled – proved that different forms existed. Offspring, he showed, inherited one copy from each parent, although it appeared that only one – the so-called dominant gene – would manifest itself. (A dominant gene could come from either parent.) Nonetheless, the offspring preserved the recessive gene, and in half the cases this version of the gene would be passed to its own offspring. If a descendent received two copies of the recessive gene, then the associated recessive attribute – flower color, for example – would appear. This discovery demolished the "blending" paradigms of the day, which focused on the far more common traits that appeared to vary continuously rather than discretely, such as height or skin tone. The blending paradigms inferred that the genetic material was a continuous fluid of some sort, produced by each parent, which mixed to produce the offspring [see BFB 23].

In the first decades of the 20^{th} century, most scientists assumed that most features, and even most *behaviors*, were the result of a single gene. The standard technique to finding a given gene was to examine genealogical "family trees" and compare ancestors with distinct traits, looking for the same patterns that Mendel had observed in pea plants. This technique had some notable early successes, including the identification of genes for hemophilia and color blindness. However, geneticists soon discovered that most physical traits are affected by multiple genes, and that there are usually more than two forms of any given gene. (Together, this yields the "appearance" of continuous blending of parental characteristics.) But in the science's infancy, the concept of one gene per feature was presumed to be the rule, rather than the exception. [The origin of eugenics – which views talents and intelligence as inheritable, genetically-controlled characteristics – predates 1900, but the movement latched on to Mendel's genetics when it appeared. Most early geneticists also believed in eugenics.]

While scientists hypothesized, analyzed, and publicized, some members of the social and financial elite followed the story. Already concerned about the "dilution" of northern European blood in America by waves of immigrants from southern and eastern Europe, these people latched onto the new genetic paradigm as justification to restrict immigration from these regions. In the blending paradigm, it had been argued, the differences in their genetic makeup would eventually be diluted to insignificance in the melting pot. Mendelism, on the other hand, seemed to imply a larger threat: that these genes would remain in play indefinitely. These immigrants, and thus their genes (via the earlier argument), were "clearly inferior." In addition to their odd appearances and customs, early IQ tests (often involving tests of literacy, and usually given in English) "proved" quantitatively that not only were they less intelligent than established Americans, but that most were "feeble-minded" – an official medical designation at the time.

One group, however, tended to do better on literacy and intelligence tests than most: the Jews. Rather than show consistency and abandon efforts to restrict Jewish immigration, certain individuals – Gould identifies Mrs. E. H. Harriman and John D. Rockefeller – sponsored scientists who found other "scientific" argument to keep them out. One such scientist, Charles B. Davenport (1866 – 1944), came to their attention; Harvard-educated in biology, he wrote what would become the leading genetics textbook entitled *Heredity in Relation to Eugenics* in 1911. (It was dedicated to Mrs. Harriman.) In this book – a textbook, Gould emphasizes, not a political tract – he argues for a second criterion to evaluate the worthiness of potential immigrants: their moral character, also presumed to be under genetic control. He specifically identifies Jews as being of relatively high intelligence, but of low morals, as exhibited in "their intense individualism and ideals of gain at the cost of any interest . . . ." A year earlier, he had become director of the Carnegie Institution's Station for Experimental Evolution at Cold Springs Harbor, New York, where he founded the so-called "Eugenics Record Office" (with financial backing from the previously-named conservative elite). From this position, he studied and tested thousands of immigrants and their genealogies. In 1915, he wrote an influential monograph entitled *The Feebly Inherited*; Part 1 was entitled “Nomadism, or The Wandering Impulse, With Special Reference to Heredity.” His intent is clear from the text itself, which Gould quotes:

> A word may be said as to the term “feebly inhibited” used in these studies. It was selected as a fit term to stand as co-ordinate with “feeble-minded” and as the result of a conviction that the phenomena with which it deals should properly be considered apart from those of feeble-mindedness.

How does one quantitatively define “feebly inhibited?” Davenport chose a strategy that was considered weak even at the time by many colleagues: he identified “nomadism” as the genetically-correlated feature that defined a race of ne’er-do-wells, including gypsies and hobos. (“Primitive” hunter-gatherer peoples that European colonizers had found around the world continually moved looking for food, instead of building cities and holding down jobs, like, say, the British. Recapitulation theory [ESD 27], also popular at that time, argued that there was a legitimate correlation between adults of “primitive” cultures and the children of “modern” Western cultures.) One weakness of this argument is obvious – everyone in America at that time, save the few remaining Indians, had descended from people who had moved there from somewhere else. Further, this pioneering spirit – which continued to manifest itself in the continuing western migration – was viewed as a source of initiative and cultural greatness. Davenport claimed he and his staff at the Eugenics Record Office were able to distinguish between virtuous adventurers and responsibility-avoiding nomads. He took the genealogies of selected subjects and, based on his survey data, marked presumed genetic nomads with the letter “W” for wanderlust, the German term for “urge to roam.” (He apparently used a red, or scarlet, pen for this task, thus leading to the essay’s title via a pun with Nathanial Hawthorne.) His work is recognized as nonsensical today, but it served its purpose in pressuring the government to pass laws limiting Jewish immigration during the 1920’s and 30’s, with tragic results. [Davenport established and maintained contacts with various Nazi institutions before and during World War II, and helped shape their racial policies as well.]

Social aspects aside, Gould identifies certain false assumptions in Davenport’s line of reasoning. All involve Gould’s view that the so-called “reductionist” approach that can work so well in mathematics and the physical sciences is not, generally, applicable to biology [TFS 25]. Genes themselves are a factor in making us who and what we are, of course, and if testable and reproducible data yield “politically incorrect” results, we must accept them. However, he states, this is not the case here; the *interactions* of the multiple genes that affect the same structure, combined with the additional interaction of the developing organism with its environment, positively precludes the association of one gene, or group of genes, with anything more complex than, say, eye color. The interactions themselves, which cannot be predicted from the genome itself, are a dominant factor in biological development. Gould writes:

> Wholes *can* be bigger than the sums of their parts, and interactions among objects cannot always be disaggregated into rules of action for each object considered separately. . . . [Even] water cannot be explained as two-thirds of the separate properties of hydrogen gas mixed with one-third of the oxygen's independent traits . . . . I cannot be understood as one-eighth of each of my great-grandparents (though my genetic composition may be roughly so determined); I am a unique product of my own interactive circumstances of social setting, heredity composition, and all the slings and arrows of individual and outrageous natural fortune.

Yes, Gould acknowledges, genes make enzymes, enzymes affect brain chemistry, and brain chemistry affects behavior; but there is no unique or direct path from the start to the end of this process. We err when we claim that a certain behavior is, say, 40 percent genetic and 60 percent environmental, even if a simplified mathematical model allocates it in this way. Similarly, if five genes are known to affect a trait, and the genetic component of this trait is estimated to be 50 percent genetic, it is all too common to infer that each gene controls about 10 percent of the trait. Those scientists who announce to the public that a certain version of a gene is more commonly found in gay men than strait men may think they are helping society by suggesting that a "gay gene" has been found (implying that gays should not be persecuted for "choosing" their lifestyle); but they are not. Not only is it technically incorrect to say that there is a gene, or a group of genes, that are even partially responsible "for" a complex behavior, he states, it opens the door for others to abdicate personal responsibility ("I can't stop drinking, I have a bad gene") or to deny assistance to others ("more resources to schools will not help a particular disadvantaged group, as they are genetically incapable of doing better").

Gould offers another example, this one published in the January 1996 issue of *Nature Genetics* and reported on the front page of the January 2, 1996 *New York Times* under the headline "Variant Gene Tied to a Love of New Thrills." There does appear to be a correlation between a variant of a gene called the D4 dopamine receptor and self-identified "novelty seeking behavior," although another study finds a correlation between the same gene and heroin addiction. (Dopamine absorption in the brain is associated with sensations of pleasure.) The standard errors appear in the articles, Gould states: the reporter identifies that "about half" of novelty seeking behavior as under genetic control, with the rest associated with ill-defined environmental factors. Further, the author of the technical paper notes that the D4 receptor only affects the difference in dopamine levels observed by about 10 percent – which, he tells the reporter, suggests that there are probably four or five other genes involved (and thus implying that each gene *produces* a certain fraction of the behavior). Finally, Gould challenges, is "novelty seeking" any more of a real, measurable feature than Wanderlust? He writes:

> Genes do not make "novelty-seeking" or any other complex and overt behavior. Predisposition via a long chain of complex chemical reactions, mediated through a more complex series of life's circumstances, does not equal identification or even causation. At most . . . D4 induces a chemical reaction that can, among

> other possible effects, generate a mood leading some people to greater openness toward behaviors defined by some questionnaires as "novelty seeking."

A related, contemporary article ties this discovery to C. R. Cloninger's theory of personality, which postulates four basic temperamental building blocks: novelty seeking, avoidance of harm, reward dependence, and persistence. Such quantizations of personality may be interesting and perhaps even useful, but are they any more "real" than the four Greek humors of choleric, phlegmatic, sanguine, and melancholic? Maybe the Greeks had it almost right after all, Gould states, but simply identified the wrong four; more likely, what we are really observing is the human mind's attraction to reductionist arguments, whether applicable or not.

LSM 19. Dolly's Fashion and Louis's Passion

Most people agree that the personalities and character traits of individuals are the result of a *combination* of internal, genetic factors and external, environmental circumstances. People disagree, however, on their relative importance. In this essay, Gould argues that the *perception* of the importance of each factor, in society at large, is a function of the political climate. In more liberal periods, the view is that the environment plays a significant, even dominant role; in more conservative periods, it is more widely accepted that environment makes little difference in who we are and what we can achieve. Since nature itself does not change during these political and cultural swings, Gould argues that much of the perceived importance of environmental factors reflects popular opinion, not reality; it is, in his words, "fashion." [Gould's own view, as expressed in the previous essay, is that the genetic and environmental factors cannot be disaggregated; it is the interaction, more the components themselves, which produce us.] He writes:

> Among oscillating fashions governed primarily by the swing of our social pendulum, no issue can claim greater prominence for an evolutionary biologist, or hold more relevance to a broad range of political questions, than genetic versus environmental sources of human abilities and behaviors. This issue has been falsely dichotomized for so many centuries that English even features a mellifluous linguistic contrast for the supposed alternatives: nature versus nurture. . . . [A] preference for either nature or nurture swings back and forth into fashion as political winds blow, and as scientific breakthroughs grant transient prominence to one or another feature in a spectrum of vital influences. . . . Today [he wrote this in 1997] genetic explanations have returned to great vogue, fostered by a similar mixture of social and scientific influences: a rightward shift of the political pendulum (and the cynical availability of "you can't change them, they're made that way" as a bogus argument for reducing government expenditures on social programs); and an overextension to all behavioral variation of genuinely exciting results in identifying the genetic basis of specific diseases, both physical and mental.

To support this argument, he offers two examples: the cloning of Dolly the sheep, and the appearance of an important book on the role of birth order in history by his colleague and long-time friend, Frank Sulloway. His discussion does not dwell on the events themselves, but rather on the terms used by the press to discuss them – which focuses strongly on internal genetics. If either of these events had occurred twenty years earlier, he suggests that the tone of the reporting might have been significantly different.

In the 27 February 1997 issue of *Nature*, I. Wilmut and others announced the successful birth of a sheep (named Dolly) that had been cloned from an adult animal, the first time this had been achieved in a mammal. The process involved inserting the nucleus from a single adult sheep cell into an embryonic "stem cell" of another sheep that had had its own nucleus removed. The hybrid cell was then implanted into the uterus of the second sheep, where it grew as an embryo to full term, and was then born. The national interest in this story, Gould states, emphasizes the potential implication that beloved pets, or, perhaps in the future, people, could be resurrected after death via this form of cloning. The underlying, and usually unstated, question is whether the resulting clone would be "the same" as the original, including – for lack of a better word – the soul. The answer, Gould tells us, is "of course not"; we know this from hundreds of years of experience with identical twins, who share far more things in common than a genetic code (for example, a womb). While there are many eerie similarities, it is quite clear that identical twins do not have identical personalities, and are not "the same person." Gould's point is that the current "fashion" of favoring genetic over environmental origins for personality traits partially explains the way in which the story is reported and discussed.

The second story involves the publication of the book *Born to Rebel: Birth Order, Family Dynamics, and Creative Lives* by Frank Sulloway. Sulloway worked on it for twenty years, and Gould states that he let his friend bounce his thoughts off him for the entire period. Gould accepts large parts of Sulloway's thesis: that firstborns, because of their upbringing, tend to be confident and work within the status quo, while later children, because they are rarely ever the biggest or the only child, seek more unorthodox channels in life (at first, simply to get their parent's attention). That is, firstborns tend to be confident and conservative, and are more likely to become business and political leaders, while laterborns learn to make do, are more open to change, and are more likely to become revolutionary thinkers in anything from science to politics. In one particular case study, Sulloway argues that the course of the French Revolution was impacted by this situation. Gould explains:

> The moderates initially in charge tended to be firstborns. As the revolution became more radical, but still idealistic and open to innovation and free discussion, laterborns strongly predominated. But when control then passed to the uncompromising hard-liners who promulgated the Reign of Terror, firstborns again ruled the roost. In a brilliant stroke, Sulloway tabulates the birth orders for several hundred delegates who decided the fate of Louis XVI in the National Convention. Among the hard-liners who voted for the guillotine, 73 percent were firstborns; but 62 percent of the laterborns opted for the compromise of conviction with pardon. Since Louis lost his head [the "passion" of the essay's title] by a margin of one vote, an ever-so-slightly different mix of birth orders among delegates might have altered the course of history.

Gould does not dwell on the validity of this argument, but instead calls attention to an analogy Sulloway makes between birth order and natural selection. In this analogy, the "limited resource" is parental attention. Birth order, in this analogy, places children into different "niches"; the firstborns have the advantage of moving in to an open niche and establishing themselves there, while laterborns must struggle to find an alternative niche. As an analogy for the purposes of illustration, Gould has no problem with this. However, he states, almost every reviewer (both positive and negative) took the claim in a more literal way: that genetics-based natural selection (that is, "nature") was the parameter in play. Gould, in his words, finds himself stunned by this. Siblings, by definition, have the same parents, and thus the same basic genetic makeup (and any differences cannot be attributed to birth order); therefore, any consistent differences in personality based on birth order would have to be environmental in origin ("nurture")! Sulloway's thesis, if valid, illustrates the power of environment, not genetics, in shaping personalities. The notable absence of this argument from the debate over this book must be attributable, at least in part (Gould states), to the current social preference for nature over nurture.

LSM 20. Above All, Do No Harm

When it comes to predicting how a new science or technology will develop, it might seem that those most closely involved would have an advantage. In practice, Gould writes, this rarely turns out to be true; the contingent nature of history precludes anyone, even scientists and technologists, from making accurate predictions. If the concept under consideration involves weaponry – Gould explicitly excludes dual-use technologies such as cloning that can both benefit and harm society as a whole – then moral and social restraint in the development, testing, and operational use of these technologies may be both effective and the only feasible solution. Interestingly, he continues, the scientists working in these fields often oppose such moral restraints. While one may argue that professional interest and financial reward are strong motivators, the scientists themselves often rely two lines of reasoning. The first is that the technical problems that they are struggling with are so large that it will not soon make an effective weapon anyway, so there is no need for concern; the second is that the path of development can be controlled, and the effects of any hypothetical horrors can be limited. The combination of ignorance (we really don't know how history will unfold) and arrogance (believing that we do) can lead society down some unpleasant pathways.

Gould illustrates this with the specific example of chemical warfare, and the work and writings of J. B. S. Haldane (1892 – 1964). (Later in his career, Haldane would help develop the field of population genetics, which in turn became the foundation for the modern evolutionary synthesis. [Gould presents another Haldane story in DIH 29].) Haldane, Gould tells us, was a brilliant but enigmatic British mathematical biologist. He was, for example, a pacifist, but wrote with great fondness of his time on the front lines of the First World War (where he was twice wounded). He was from an aristocratic family, but joined the British Communist Party and wrote dozens of popular essays for the *Daily Worker*. After the first gas attacks, he was pulled away from the front to work with his father on developing an effective gas mask. During this time, he used himself as a human guinea pig to test the effects of many different kinds of gases, including mustard gas, with and without a mask (!). As a scientist with first-hand experience of both trench warfare and chemical weapons, it is perhaps odd to find him as the author of a short volume arguing *against* British ratification of the 1925 Geneva Protocol to ban first use of chemical and biological weapons. (The British signed it anyway, although the United States did not do so until much later.)

His publication, entitled *Callinicus: A Defense of Chemical Warfare*, suggested that the use of chemical weapons allowed warfare to be more humane. He based this argument on his knowledge of gas weapons of the time; they were not yet terribly lethal, and the physiological damage was usually mild enough so that it would heal with time. He envisioned that, after a gas attack, those on the receiving side would be merely "stunned," and thus easily taken prisoner. He also argued that there was no real way to prevent its use, and – as a patriot – he preferred to be on the winning side of any future war that involved it. In any case, he added, all war was equally horrible; until science could find a "cure" for it, it made sense to develop and use all the tools available.

Gould avoids the larger philosophical questions about total war and the comparative horror of different kinds of death, and instead limits himself to the problem of whether Haldane had any better insight into the future than his contemporaries. He chooses two examples, one involving the contingency of history, and the other illustrating our inability to see how cultural influences affect our views. In the first, Haldane challenges the argument that interest in chemical and biological warfare could lead to the development of other technologies, including nuclear weapons. He replies that we will have bases on the moon long before this problem is solved, in a tone that clearly suggests that neither nuclear weapons nor moon landings are in the foreseeable future. Secondly: his early studies with mustard gas suggested that blacks were less susceptible to its effects than whites; thus, when attacking in such an environment, black troops should lead the way – but with white officers, of course! This egalitarian communist could not recognize the influence of his era's racism on his own thinking and envision a future military with black leadership; he assumed that his views were entirely objective. If Haldane could not foresee nuclear weapons, moon landings, or black officers, how can we trust him (or any other scientist) to tell us how their weapons technologies will be used in the future? Gould writes:

> [Humans] remain outstandingly inept in certain issues, particularly when our emotional arrogance joins forces with our intellectual ignorance. Our inability to forecast the future lies foremost among these ineptitudes – not, in this case, as a limitation of our brains, but more as a principled consequence of the world's genuine complexity and indeterminism. . . We could go with this flow, but our arrogance intercedes, leading us to promote our ignorant intuitions into surefire forecasts about things to come . . . . I know only one antidote to the major danger arising from this incendiary mixture of arrogance and ignorance. . . . [M]oral restraint may be our only salvation. The wisdom of the Geneva Protocol lies in understanding that some relatively ineffective novelties of 1925 might become the principal horrors of a not-so-distant future.

He closes with a quote from the famous Hippocratic Oath, for the physician dealing with sick when the actual problem and its solution are not clear: Above all, do no harm.

LSM 21. Of Embryos and Ancestors

One of Gould's recurring themes is that science advances in fits and starts, rather than in a slow and steady march as many believe. Often these spurts are the result of a new device (such as the telescope, the microscope, x-rays), or the overcoming of a physical or mental obstacle. In this essay, he presents two stories involving bursts of progress after extended frustration; both involve our understanding of early life. One story took place several decades earlier, and the other was breaking news at the time, and the motivation for this essay.

As a young man, Gould recalls being taught that there was no evidence of life prior to about a billion years ago. Since the earth is several billion years old, the inference was that even simple prokaryotes (bacteria and other simple single-celled organisms with no nucleus or other organelles) were so complex that only the immensity of deep time allowed them to appear at all. The first story of discovery involved the work of Elso Barghoorn and Stanley Tyler in the 1950's, who found distinct evidence of unicellular life in rocks that were some 2 billion years old. Barghoorn and Tyler succeeded by looking in an unconventional place – chert beds, which are composed of silicate material and thus usually associated with life-eradicating volcanic processes. However, there are certain ways in which this material can precipitate gently and continuously from seawater, and unicellular organisms embedded there can be preserved. [Gould discusses this work in TPT 21.] Once this breakthrough was made, older chert beds of the appropriate type were explored, and prokaryotes were always found – even in rocks 3.5 to 3.6 billion years old, the oldest unreformed rocks on earth. As a result, the view of life's origin has changed from "exceedingly improbable" to "virtually inevitable" – at least for prokaryotes. [Gould argues that the inevitability of prokaryotic life should not be confused with the inevitability of intelligent life in LMC 18.]

By the early 1990's, it was not only recognized that prokaryotes appeared at least 3.6 billion years ago, but that eukaryotes – larger cells with nuclei containing chromosomes, and organelles such as mitochondria – appeared about two billion years ago. All multicellular life is comprised of eukaryotic cells, but the first multicellular life did not appear until between 1.8 and 1.0 billion years ago. (The first of these were, apparently, three different types of algae, which appear to have evolved independently from three different single-celled ancestors.) But what are the origins of our favorite multicellular group, the animal kingdom? Our oldest well-understood animal fossils come from the second and third phases of the Cambrian period, the Tommotian and the Atdabanian (530 -520 million years ago), and are associated with the famous Cambrian explosion. Many of these organisms grew hard, calcified shells or other coverings that are much more easily preserved than soft tissue. The first phase of the Cambrian period, about 543-530 million years ago, contains only disarticulated calcified plates, cups and spikes, which are collectively known as "small shelly fauna" or SSF [see ELP 23]. It was strongly suspected that the owners of these structures were animals of some sort, since trails, burrows, and other trace fossils often associated with them.

The period from about 610 million years ago until the start of the Cambrian period is associated with the Ediacaran fauna [TFS 15]. These enigmatic animals used to be considered ancestral to the "modern" animal fauna that appeared in the Cambrian period, but now appear to be either a dead end, or the ancestors only of such organisms as corals and jellyfish. These organisms appear to have had no mouth or anal openings, even though some grew several inches long; they were always flat, and presumably thin enough to require no internal organs. It appears that they were largely immobile. However, it was apparent from trace fossils such as trackways that more mobile animals – "worms" of some sort, and presumably our ancestors – also existed during this time, but no visible fossils had ever been found despite extensive searches. What were these organisms, and when did they first appear? Progress on this front was almost non-existent.

The next "big break" is Gould's second story of discovery; this one comes when researchers started to look for a different *size* of animal. It had been recognized that an unusual type of fossilization called phosphatization could preserve a hollow but exquisitely-detailed "shell" of calcium phosphate around soft organisms that were smaller than about 2 millimeters across [also discussed in DIH 9]. In the 1990's, discoveries of *animal embryos* preserved by this method, from the Cambrian period, were made in China and Siberia. A distinct sequence of one, two, four, eight, and 16-cell clumps associated with the characteristic early stages of embryotic cell division were presented in scientific papers (Gould reproduces some of these micro-photographs). Importantly, only triploblastic animals develop from embryos. (Triploblastic means "three body layers," and refers to an ectoderm, a mesoderm, and an endoderm, each of which develops into different types of structures in all complex animal phyla such as chordates, arthropods, mollusks, and even flatworms. This three-layer design seems to be a prerequisite for bilaterally symmetrical organisms with digestive tracts and sensory organs. Corals, sponges, jellyfish, and apparently the Ediacaran fauna are all diploblastic, or two-layered, and develop differently from fertilized cells.) Thus, it was realized, if we cannot find fossils of adult Precambrian animals, perhaps we can find their embryos! Gould discusses a paper by Xiao, Zhang, and Knoll that appeared in the February 1998 issue of *Nature*, in which such a find is reported. The authors describe several phosphatized fossils of both multicellular algae and (triploblastic) animal embryos that date to 570 million years, tens of millions of years before the dawn of the Cambrian period, and even before most of the Ediacaran fossils. (Gould notes that Andrew Knoll's advisor was none other than Elso Barghoorn.) We cannot tell what phylum these embryos might have developed into, and we still have no direct fossil evidence of whatever was burrowing around in the mud, but for the first time we have direct evidence that triploblastic animals predated the Cambrian period.

Gould adds a word of caution about the interpretation of this discovery. Some scientists, he notes, have argued or implied that the discovery of Precambrian embryos reduces the significance of the Cambrian explosion itself. Some also point to genetic evidence that suggests that the chordates and echinoderms last shared a common ancestor about 600 million years ago in support of a diminished role for the explosion. (The same type of evidence further suggests that the chordate-echinoderm branch last shared a common ancestor with the arthropod-annelid-mollusk branch about 670 million years ago.) Most scientists agree, Gould states, that while the facts are correct, the interpretation is not. He writes: "The Cambrian explosion represents a claim for a rapid spurt of anatomical *innovation within* the animal kingdom, not an argument about the times of *genealogical divergence* [his italics]."

He closes with a point about the appearance of progress in natural history. One can identify a series of events – first prokaryote, first eukaryote, first multicellular organism, first Ediacaran animal, first triploblastic animal, first chordate – and interpret it as a progressive sequence. But is it really so? The paper that identified Precambrian embryos also discussed the Precambrian record of the three major groups of algae, and found that all three had already developed many of the "modern" features we associate with each, and therefore have "progressed" little since then in these features. With regard to the animal kingdom, he notes, the Ediacaran fauna and the embryos appear to have coexisted for tens of millions of years, with the former group apparently "on top" (or at least much larger) for most if not all of this time; where is the "progress" in that? The Cambrian explosion seems to have occurred about ten million years after the Ediacaran fauna vanished; it has been suggested, he notes, that the rise of the rise to dominance of the triploblasts was the result of an externally-induced mass extinction, much as the rise of the mammals now appears to be due in part to the abrupt extinction of the dinosaurs.

LSM 22. The Paradox of the Visibly Irrelevant

Gould only mentions the terms microevolution and macroevolution once in what follows, and only in passing; but his view of the difference between them is the true subject of this essay. He begins by challenging the "urban myth" that evolution cannot be directly observed in a single human lifetime, and thus must be indirectly inferred from the fossil record [and genetics]. While most people accept the idea that infectious germs can become resistant to antibiotics, this does not really count; the urban myth is really about macroscopic animals. Gould proceeds by offering three examples of significant evolutionary change over shorter periods of time, and then discusses the attention that each received in the popular press (as evidence that the myth exists). However, he continues, these microscopic evolutionary changes, while important and interesting, should not be confused with the macroscopic changes documented in the fossil record, for the apparently paradoxical reason that these observed changes are actually far too rapid! He closes with a discussion of his concepts of stasis and punctuation in natural history, and his belief that evolution operates differently at different time scales.

The first example of rapid (microevolutionary) change involves guppies from the island of Trinidad. An earlier paper from the 1970's reported that two isolated populations of the same species differed in certain ways. The downstream population was exposed to many predators, while the upstream population was not. The authors grew a population of each in a controlled, predator-free environment, and found that the upstream population matured later and grew larger, while the downstream population not only matured more rapidly, but had a larger number of smaller offspring – the expected adaptive response. Next, the authors transplanted members of the downstream population into a portion of the predator-free upstream environment, and watched the results of natural selection over several years. The formerly-downstream males "evolved" to the same size as the upstream males in about four years, while the females took 10 years. (These results, by Reznick et al, were published in *Science* in March 1997.)

The second example involves the small lizard *Anolis*, which is represented by several species and many variations on the Bahama Islands. In 1977 and then again in 1981, a team transported small numbers (either five or ten) of these lizards from the large island of Staniel Cay to fourteen smaller, neighboring islands that contained no lizards. One of the predictions was that the limbs of the transplanted lizard populations would grow smaller over time. (Longer legs offer the adaptive advantage of speed, but require the presence of trees on which the lizards must perch; Staniel Cay is forested, but the neighboring islands contain only bushes. Without trees on which to climb and hide, the speed advantage of longer legs was overwhelmed by the need to climb bushes instead. Thus, the argument went, in the new environment, natural selection should favor shorter limbs.) Over about twenty years, this was what was found (Losos et al, *Nature*, 1997.) (Reviewers noted, and the authors agreed, that a separate factor relating environment directly to development, rather than indirectly via natural selection, was not fully considered in this case.)

Example number three involves Gould's own research, with his long-time colleague David Woodruff, on the Bahaman land snail genus *Cerion*. One island, Great Inagua, is currently home to a large, ribby species called *C. rubicundum*. This species does not appear in any of the fossil beds on this island, although it does appear elsewhere. On the other hand, an even larger species called *C. excelsior* is found in the fossil beds of Great Inagua, but is extinct today. In one particular mudflat – a future fossil "bedding plane" – Gould and Woodruff extracted a collection of shells that showed a series of intermediate characteristics between the two species. The mudflat had apparently been present for ten to twenty thousand years, but shells contained within it could not be chronologically ordered by position, so there was no way to determine if the collection represented an actual evolutionary sequence. Later, however, Gould teamed up with colleague Glenn A. Goodfriend, who had developed a dating technique that could determine the age of each shell. Sure enough, the shells fell in a coherent sequence from old *C. rubicundum* to young *C. excelsior*, although Gould believes that the actual process involved hybridization with a *C. rubicundum* population that arrived from elsewhere, and that the remaining *C. excelsior* population did become extinct rather than blending completely into the other species. (The associated paper appeared in *Science* in 1996.)

Gould is happy for the public attention all three articles received, but does not feel that any of them – including his own – warrants any more publicity than hundreds of other papers. Why so much publicity (relatively speaking) for these particular cases? Gould argues that there are two fallacies at play here, the first of which he refers to as "the fallacy of the crucial experiment." People like "stories," and like to point to specific, defining events to explain the world, or how we came to our present understanding of that world [see BFB 3 and DIH 27]. However, despite the attraction of thinking in this way, none of these stories "proves" that evolution actually occurs; they are about rates, frequencies, and the relative power of natural selection versus genetic drift. We have known that evolution is "true" for more than a century; and in any case, a single example in a field as complex as biology can never prove or disprove a general, overarching theory [he elaborates on this in ELP 31].

The second and more complex fallacy behind the attention these articles received, he continues, involves one of the great traditions in Western thought: reductionism, which is the view that complex systems can be completely explained in terms of the functioning of their constituent components [TFS 25, DIH 27]. In this case, he argues, many people – including many scientists, and even the authors of some of these papers – believe [as Darwin did] that large-scale evolutionary change is the simple product of the small-scale changes discussed here plus vast amounts of geologic time. He writes:

> Reductionists assume that documenting evolution at the smallest scale of a few years and generations should provide a general model of explanation for events at all scales and times – so these cases should become a gold standard for the entire field, hence their status as front-page news. The authors of our two studies on decadal evolution certainly nurture such a hope. Reznick and colleagues end their publication on Trinidadian guppies by writing: "It is part of a growing body of evidence that the rate and patterns of change attainable through natural selection are sufficient to account for the patterns observed in the fossil record." Losos and his colleagues say much the same for their lizards: "Macroevolution may just be microevolution writ large – and, consequently, insight into the former may result from the study of the latter."

But these observed microevolutionary changes cannot be linearly extrapolated to the macroevolutionary changes shown in the fossil record, because they are "*vastly too rapid* to represent the general modes of change that build life's history through geological ages" [Gould's italics]. Quantitative measures of this degree of change, one of the author's reports, are four to seven orders of magnitude higher than what is observed in natural history. Gould calls this "the paradox of the visibly irrelevant": these changes are actually too powerful to represent large-scale evolution, and the problem of scaling is actually one of trying to "slow down" (or "average out") such effects!

Perhaps, regular readers of Gould's essays might be thinking, these changes reflect "punctuations" associated with his model of punctuated equilibrium. In fact, Gould states, some of them might be; if one population strays too far in physiology or genealogy from its parent stock, speciation can occur. But most of punctuated equilibrium, he counters, is about *stasis*: the apparent fact that species remain remarkably unchanged for most of their existence. In the presence of so many significant microevolutionary changes, he continues, the very existence of stasis demands one or more explanations. In the case of the *Anolis* lizards, the altered population could merge back into the parental stock if a land bridge forms, or the next hurricane could wipe them out completely. [While he does not explicitly address the point here, some microevolutionary changes are clearly easier than others; larger size is not the same type of change as the appearance of a new feature. Many types of change apparently oscillate over time (as the size of some of the Trinidadian guppies did), and perhaps average out over time. These views are discussed in ELP 27, and in both his first and last books: 1977's *Ontogeny and Phylogeny* and 2002's *The Structure of Evolutionary Theory*.] Evolution appears to operate differently at different time scales, he concludes. Both are important, but one cannot be extrapolated directly into the other.

LSM 23. Room of One's Own

One of the basic "laws" of ecological biology taught to undergraduates goes by the name of the "competitive exclusion" principle, which states that no two species can occupy the same ecological niche. This is more an inference from the principle of natural selection rather than an empirical observation, Gould states; if two different species occupied the same niche (same range, food source, dwelling styles, and so on) then they would be in direct competition with each other, and the one with a selective advantage would displace the other. In practice, of course, niches are difficult to define quantitatively, and species seem remarkably adept at finding new ones. Further, the ecosystem is a function of all the organisms that it includes, so the addition or subtraction of one species can, in principle, affect multiple niches. Gould has no new insight to offer. However, he does rephrase the puzzle using analogies, including the Church of the Holy Sepulchre in Jerusalem, which is contentiously shared by six different Christian sects. The groups have broken the church up into a number of spatial regions which each controls exclusively; some regions are shared, others used by different groups at different times, but each has some unique space. By analogy, he writes: "[L]arge numbers of species can be crammed into a common territory only if each can commandeer some room of its own and not always stand in relentless competition with a maximally similar form."

Once "all" of the niches are filled, another puzzle appears: how a new species can arise? One dominant method of species formation [introduced by Ernst Mayr] is called "allopatric speciation," where allopatric means "in another place." A significant fraction of the work in this field studies how new, isolated regions can form: a new island appearing, a river changing course, and so on. An additional class of mechanisms, collectively called "sympatric speciation," has also garnered interest in the past several decades. The phrase means "in the same place," and the subject involves ways in which one species can diverge from its parent group, while members of this group are still within mating range. Some proposed mechanisms are feeding at a different time of day, favoring a different type of tree to live in within the same valley (for animals whose niches include only one subset of the ecosystem), and mating at a different time of the year. [There are a number of genetic mechanisms that have been proposed as well.] Gould spends a large part of this essay in speculation about sympatrically isolating species via *scale*, such as different "rates" of life [see LMC 20], or of different physical size. He includes a number of personal anecdotes while doing so, including one about his brother Peter [who had died a few years earlier; see the dedication of *Dinosaur in a Haystack*].