TIME'S ARROW

TIME'S CYCLE

Myth and Metaphor in the Discovery of Geological Time

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AWFUL CHANGES.

MAN FOUND ONLY IS A FOSSIL, STATE,——REAPPEARANCE UK ICHTHYOSAUUt.

Figure 4.1

De la Beche's caricature of Charles Lyell as the future Professor Ichthyosaurus, as produced in the frontispiece of Frank Buckland's *Curiosities of Natural History,* and misinterpreted as a joke about his father, William Buckland.

CHAPTER FOUR

Charles Lyell, Historian of Time's Cycle

The Case of Professor Ichthyosaurus

Few scientists are so full of fun and color that their anecdotes outlive their ideas. Yet professors of geology still tell stories about the Reverend William Buckland (1784–1856) who ended his career as the prestigious Dean of Westminster, but began as England's first great academic geologist, reader at Oxford, and teacher of Charles Lyell, among others. Remember the time Buckland identified the ever-liquefying "martyr's blood" on the pavement of a continental cathedral as bat urine—by the most direct method of kneeling down and having a lick. And, oh yes, what about the day that he served crocodile meat for breakfast at the deanery, after horse's tongue the night before. Even the ever-genial Charles Darwin professed a distaste for Buckland, "who though very good humored and good- natured seemed to me a vulgar and almost coarse man. He was incited more by a craving for notoriety, which sometimes made him act like a buffoon, than by a love of science."

When Buckland was commissioned to write one of the Bridge-water Treatises "on the power, wisdom and goodness of God, as manifested in the creation," he devoted a chapter to the ichthyosaur as a primary illustration of divine benevolence. He presented all the conventional arguments for inferring God's handiwork from the anatomical perfection of this oddly fishlike reptile—"these deviations [from ordinary reptilian form] are so far from being fortuitous, or evidencing imperfection, that they present examples of perfect appointment and judicious choice . . . We cannot but recognize throughout them all, the workings of one and the same eternal principle of Wisdom and Intelligence, presiding from first to last over the total fabric of Creation" (1836, 1841 ed., 145– 146). Yet Buckland could never bypass his fascination with odd illustrations of nether ends. So he devoted an even longer section to the corroboration of good design provided by the structure of an ichthyosaurus invisible intestine as inferred from the form of its coprolites, or fossil feces—reveling in the proof of God's immense care and attention to detail, as provided by the "beneficial arrangements and compensations, even in those perishable, yet important parts" (154).

Frank Buckland followed his father's footsteps in girth, conviviality, and zoophagy.[1] He was also the foremost popularizer of natural history in England, a David Attenborough for the 1850s. Frank found among his father's papers a copy of a remarkable lithograph (Figure 4.1) drawn by Sir Henry De la Beche, English to the core despite his francophonic name, and first director of the British Geological Survey. This celebrated lithograph (made so by Frank's publication as the frontispiece to his four-volume collection, *Curiosities of Natural History*) shows Professor Ichthyosaurus, surrounded by a crowd of attentive students of that ilk, and lecturing upon a peculiar fossil from ancient times—a human skull. Immediately we grasp the incongruity and the humor. We do not contemplate an ancient Jurassic ichthyosaurus, shedding its coprolites into the waters of Lyme Regis, but a *future* Professor Ichthyosaurus lecturing on the ancient stratigraphy of our present day. De la Beche's title affirms this interpretation: "Awful changes. Man found only in a fossil state. Reappearance of Ichthyosauri."

1. Not so bizarre a hobby as it might seem today. Naturalists in the heyday of Victorian expansionism hoped that the game herds of Asia and Africa might be domesticated to advance the British palate beyond beef and mutton. A systematic gustatory survey seemed both adventurous and potentially useful.

Since William Buckland had lectured so often on these beasts, and since he and De la Beche had been fast friends, Frank made the reasonable inference that this lithograph had been drawn for his father, and that the bedecked professor represented Buckland himself. Frank wrote in the preface to the first edition of his *Curiosities:*

The frontispiece ... is ... a drawing made many years ago for Dr. Buckland by the late lamented Sir Henry de la Beche. ... It was originally, drawn as a sort of quiz upon his geological lectures at Oxford, when he was treating upon Ichthyosauri, a race of extinct fish-like lizards. The subject of the drawing may be thus described—Times are supposed to be changed. Man is found only in a fossil state, in the same condition as the ichthyosauri are discovered at the present epoch; and instead of Professor Buckland giving a lecture upon the head of an ichthyosaurus, *Professor Ichthyosaurus* is delivering a lecture on the head of a fossil man. (1874 ed., vii)

I bought Frank Buckland's volumes in 1970, during a sabbatical term in England; they enlivened many a train journey between Oxford and the British Museum in London. But I also remember a puzzle and a discovery, for I read Buckland's interpretation of his frontispiece and knew that he had erred. De la Beche's drawing had deeper and sharper meaning. Frank Buckland had, in ignorance of the true context, interpreted the drawing (quite naturally) as gentle and innocent fun directed toward his father. I inferred that the lithograph had to be a pointed, almost bitter barb of satire directed against the most curious passage in all three volumes of Charles Lyell's *Principles of Geology*—the book that most geologists regard as the founding document of their discipline's modern era. Lyell wrote about milder climates of a geological future:

Then might those genera of animals return, of which the memorials are preserved in the ancient rocks of our continents. The huge iguanodon might reappear in the woods, and the ichthyosaur in the sea, while the pterodactyle might flit again through umbrageous groves of tree-ferns. (1830, 123)

Surely, De la Beche had drawn his future Professor Ichthyosaurus to mock this peculiar reverie. In support of this interpretation, De la Beche dated his lithograph in the lower-right-hand corner as 1830, year of publication for volume I of Lyell's *Principles.*

Martin Rudwick (1975) has since proven that Lyell, not Buckland, was the target of De la Beche's sketch. First, De la Beche did not draw the figure for Buckland, but distributed copies quite widely among his friends. More important, and conclusively, Rudwick discovered a series of satirical sketches and caricatures drawn by De la Beche in the back of a field notebook compiled during 1830 and 1831. Lyell, generally depicted as a vain theoretician in his barrister's wig, and contrasted with an honest field geologist in working clothes, is the butt of this series. The last sketch is a trial run for the final product. It depicts Professor Ichthyosaurus, the human skull, and one attentive student below, all placed in the same positions occupied in the later lithograph. Any lingering doubts about the identification with Lyell are dispersed by De la Beche's caption to the trial run: "Return of Ichthyosauri etc. 'Principles etc.'" The entire series, Rudwick infers, represents De la Beche's several attempts to create a caricature for his unhappiness with Lyell's thoughts and methods; Professor Ichthyosaurus finally satisfied him.[2]

While we rejoice in the solution to a small puzzle about a famous illustration in the history of geology, the identification of De la Beche's Professor Ichthyosaurus with Charles Lyell underscores an important paradox in the traditional reading of Lyell's role in the history of geology. The Lyell of textbook epitomes is, after all, the

2. Ironically, the evidence that initially persuaded me to identify Professor Ichthyosaurus with Lyell—the stated date of 1830—is incorrect. Rudwick shows that De la Beche made the sketch in 1831, then misremembered later when he transferred it to Solnhofen stone for lithography. Since De la Beche knew that he was satirizing a statement in Lyell's 1830 book, his error does become evidence of a different sort for the identification with Lyell.

hero of geology—a status won by wresting this discipline from the domination of vacuous, armchair, theologically tainted speculation, and establishing it as a modern science by hard reason based on empirical observation from the field. Consider, as we have in previous chapters, the assessment of Sir Archibald Geikie:

With unwearied industry he marshalled in admirable order all the observations that he could collect in support of the doctrine that the present is the key to the past. With inimitable lucidity he traced the operation of existing causes, and held them up as the measure of those which have acted in bygone time . . . Not only did he refuse to allow the introduction of any process which could not be shown to be a part of the present system of nature, he would not even admit that there was any reason to suppose the degree of activity of the geological agents to have ever seriously differed from what it has been within human experience. (1905, 403)

If Geikie's Lyell accurately depicts the man himself, we face quite a conundrum of historical interpretation: why, in heaven's name, was the hero of rational empiricism engaging in reveries about returning ichthyosaurs and future pterodactyls right in the heart of the great work that established geology by eschewing fatuous speculation? Was Lyell merely providing some comic relief, following the principle of necessary variety known to every great dramatist? Do his returning ichthyosaurs function like the gravediggers contemplating Yorick's skull in *Hamlet,* or like the unctuous courtiers Ping, Pang, and Pong who make us forget for a moment that Princess Turandot will slay any suitor who can't answer her question? Or was Lyell perfectly serious—in which case, the traditional hagiography is dead wrong?

In this chapter I shall demonstrate that Lyell meant every word about future ichthyosaurs. Once again, our key to understanding the importance and seriousness of this passage lies in the metaphors of time's arrow and time's cycle. Lyell was no impartial empiricist, but a partisan thinker committed to defending time's cycle against a literal record that spoke strongly against a directionless world, particularly in its evidence for organic progress from fish to reptile, to mammal, to man.

The argument needs, and shall receive, more elaboration (see pages 137–142). For now, and to allay the discomfort of unresolved puzzles, I simply point out that future ichthyosaurs represent but one of Lyell's speculative forays for saving the steady state of life's complexity from a fossil record that spoke for progress. We may see, Lyell argues, an advance in design from fish to ichthyosaur to whale, but we view only the rising arc of a great circle that will come round again, not a linear path to progress. We are now, Lyell wrote just before his reveries on ichthyosaurs, in the winter of the "great year," or geological cycle of climates. Tougher environments demand hardier, warm-blooded creatures. But the summer of time's cycle will come round again, and "then might those genera of animals return . . ."

Charles Lyell, Self-Made in Cardboard

Lyell's Rhetoric

As De la Beche had noted in caricature, Charles Lyell was a lawyer by profession—a barrister no less, skilled in the finest points of verbal persuasion. Thus, although early sections in previous chapters on Burnet and Hutton treat cardboard histories as preached by textbooks, the Lyellian myth is a double whammy. The legends of Burnet and Hutton are later constructions, but Lyell built his own edifice with the most brilliant brief ever written by a scientist. This brief, moreover, established forever the cardboard history that fueled the emerging legends of Burnet and Hutton as well. Lyell constructed the self-serving history that has encumbered the study of earthly time ever since.

The first volume of Lyell's *Principles of Geology* (published in three volumes between 1830 and 1833) begins with five chapters on the history of geology and its lessons for establishing a proper approach to a modern study of the earth. Lyell's great treatise is not, as so often stated, a textbook summarizing all prevailing knowledge in a systematic way, but a passionate brief for a single, well-formed argument, hammered home relentlessly. All sections of the text, including the introductory history, push the same theme, while the order of sections also records the smoothly unfolding brief. The famous sentence penned by Darwin to introduce the last chapter of the *Origin of Species* would serve as well for Lyell's three installments: "this whole volume is one long argument."

Roughly characterized, Lyell holds that geological truth must be unraveled by strict adherence to a methodology that he did not name, but that soon received the cumbersome designation of "uniformitarianism" (in a review by William Whewell, written in 1832). Lyell captured the essence of uniformity in the subtitle to his treatise: "an attempt to explain the former changes of the earth's surface by reference to causes now in operation." The proposition seems simple enough. Science is the study of processes. Past processes are, in principle, unobservable; only their frozen results remain as evidence for ancient history—fossils, mountains, lavas, ripple marks. To learn about past processes, we must compare these past results with modern phenomena formed by processes that we can observe directly. In this sense, the present must be our key to the past (Figure 4.2).

If Lyellian uniformity only advocated this evident statement of method, it would be uncontroversial and not particularly enlightening. But Lyell held a complex view of uniformity that mixed this consensus about method with a radical claim about substance—the actual workings of the empirical world. Lyell argued that all past events—yes, every single one—could be explained by the action of causes now in operation. No old causes are extinct; no new ones have been introduced. Moreover, past causes have always operated—yes, always—at about the same rate and intensity as they do today. No secular increases or decreases through time. No ancient periods of pristine vigor or slow cranking up. The earth, in short, has always worked (and looked) just about as it does now. (I shall present a taxonomy of the various, and partly contradictory, mean-

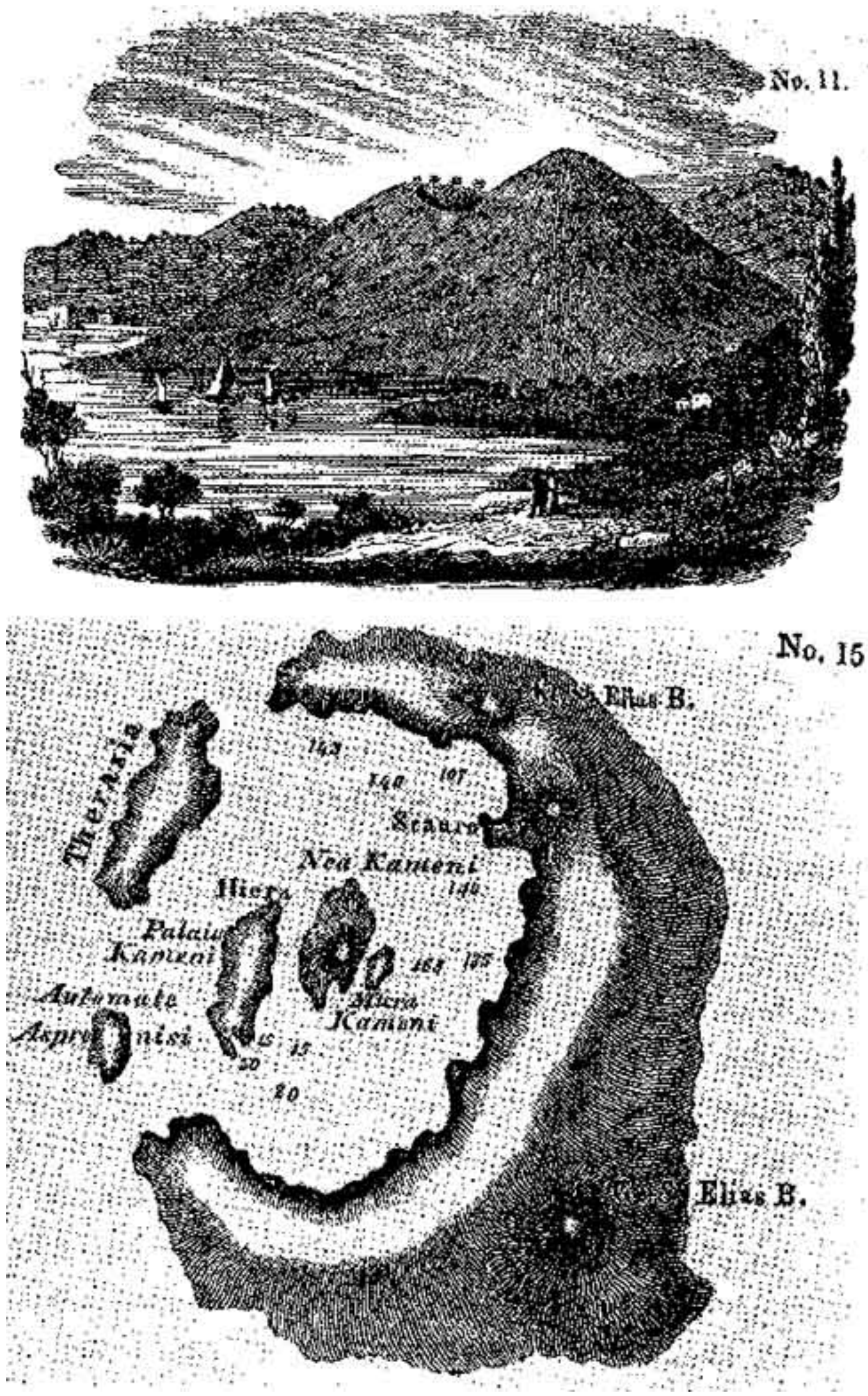


Figure 4.2

Two illustrations from the first edition of *Principles of Geology* to show Lyell's working method of comparing ancient results with modern (and visible) causes that produce the same outcomes. Top: a modern volcano in the Bay of Naples observed in eruption during historical times. Bottom: Greek islands showing, by their topography, that they surround a volcanic vent. The large island is Santorin, favored candidate for Plato's Atlantis.

ings of uniformity, in the next section. For now, let me simply note that Lyell derived much mileage from their creative confusion.)

Lyell presents a double defense for his inclusive concept of uniformity. He unites the logical argument presented above with a historical justification rooted in an idiosyncratic view of Western science. In LyelPs historical tale, told in the Manichean tradition, forces of darkness are aligned to impede progress. The small flame of truth finally begins to nicker and, through the struggle of right- thinking men, eventually burns brighter to conquer superstition and perfidy. The forces of darkness are those men who see the past as different in form and cause; they make true science impossible and proceed only by vain speculation. Uniformity is the source of light, and progress in geology may be defined by its slow and steady growth in popularity. "A sketch of the progress of geology is the history of a constant and violent struggle between new opinions and ancient doctrines, sanctioned by the implicit faith of many generations, and supposed to rest on scriptural authority" (I, 30).[3]

To grasp LyelPs impact, we must admit a factor only reluctantly considered by scientists. Truth is supposed to prevail by force of logical argument and wealth of documentation, not by strength of rhetoric. Yet we will never comprehend the reasons for Lyell's triumph unless we acknowledge the role of his verbal skills. Science self-selects for poor writing. The profession has harbored several good writers, but very few great stylists. Charles Lyell was a great writer, and much of his enormous success reflects his verbal skills— not mere felicity in choice of words, but an uncanny ability to formulate and develop arguments, and to find apt analogies and metaphors for their support.

The premier example of Lyell's persuasion by rhetoric[4] is the famous chapter five on "causes which have retarded the progress of

3. Since I shall be quoting extensively from the three-volume first edition of Lyell's *Principles* (if only to convey some sense of the power of his prose), I shall adopt the convention of citing only the volume number and then the page. Volume I was published in 1830, volume II in 1832, and volume III in 1833.

4. A term that I use, by the way, in the literal, not the pejorative, sense.

geology." Here, Lyell's comprehensive argument by history proceeds through several stages:

1. Old and unfruitful views shared the common property of imagining (for such beliefs could be defended only by speculation) that the ancient earth operated under different causes working at different rates from modern processes—a "discordance" between past and present modes of change, in Lyell's phrase. "The sources of prejudice . . . are all singularly calculated to produce the same deception, and to strengthen our belief that the course of nature in the earlier ages differed widely from that now established" (I, 80).

2. Empirical observation of the earth permitted geologists to overcome these superstitions about dissimilar pasts.

The first observers conceived that the monuments which the geologist endeavors to decipher, relate to a period when the physical constitution of the earth differed entirely from the present, and that, even after the creation of living beings, there have been causes in action distinct in kind or degree from those now forming part of the economy of nature. These views have been gradually modified, and some of them entirely abandoned in proportion as observations have been multiplied, and the signs of former mutations are skillfully interpreted . . . Some geologists [now] infer that there has never been any interruption to the same uniform order of physical events. (I, 75)

3. The undoing of anti-uniformitarian superstition by geologists parallels the general path of enlightenment in human history.

We must admit that the gradual progress of opinion concerning the succession of phenomena in remote eras, resembles in a singular manner that which accompanies the growing intelligence of every people ... In an early stage of advancement, when a great number of natural appearances are unintelligible, an eclipse, an earthquake, a flood, or the approach of a comet, with many other occurrences afterwards found to belong to the regular course of events, are regarded as prodigies. The same delusion prevails as to moral phenomena, and many of these are ascribed to the intervention of demons, ghosts, witches, and other immaterial and supernatural agents. By degrees, many of the enigmas of the moral and physical world are explained, and, instead of being due to extrinsic and irregular causes, they are found to depend on fixed and invariable laws. The philosopher at last becomes convinced of the undeviating uniformity of secondary causes. (I, 75–76)

Lyell then illustrates this equation of uniformity with righteousness not by actual examples but with metaphors based on ingenious thought experiments constructed to parallel real events by analogy. He invokes former belief in a young earth, correctly noting that uniformity cannot be supported by those committed to cramming our history into a few thousand years. Suppose, he argues, that an expedition led by a hypothetical Champollion discovered the monuments of ancient Egypt when Europeans thought that humans had first reached the Nile at the beginning of the nineteenth century. What would they make of the pyramids, obelisks, and ruined temples? These monuments "would fill them with such astonishment, that for a time they would be as men spellbound—wholly incapacitated to reason with sobriety. They might incline at first to refer the construction of such stupendous works to some superhuman powers of a primeval world" (I, 77).

But suppose the expedition then found "some vast repository of mummies" apparently indicating that humans had lived long ago to build these monuments. Honest observers (incipient uniformitarians) would then revise their fancies and admit that ordinary men had built the pyramids, but those committed to the old ways would have to invent even more outlandish theories to harmonize the mummies with their persistent conviction that no men had then inhabited Egypt. Lyell offers some suggestions: "As the banks of the Nile have been so recently colonized, the curious substances called mummies could never in reality have belonged to men. They may have been generated by some plastic virtue residing in the interior of the earth, or they may be abortions of nature produced by her incipient efforts in the work of creation" (I, 77).

We now begin to grasp Lyell's strategy. His story of Egypt recounts the great seventeenth-century debate about the nature of fossils. Many scientists then doubted that fossils could be remnants of organisms because the chronology of Moses was too short to support such plenitude. Theories of the *vis plastica* or *virtus formativa* then abounded.

As knowledge progresses, and all admit an earth of some antiquity, Lyell changes metaphors. We no longer deny human presence completely, but now try to compress history into far too short a time.

How fatal every error as to the quantity of time must prove to the introduction of rational views concerning the state of things in former ages, may be conceived by supposing that the annals of the civil and military transactions of a great nation were perused under the impression that they occurred in a period of one hundred instead of two thousand years. Such a portion of history would immediately assume the air of a romance; the events would seem devoid of credibility and inconsistent with the present course of human affairs. A crowd of incidents would follow each other in thick succession. Armies and fleets would appear to be assembled only to be destroyed, and cities built merely to fall in ruins. There would be the most violent transitions from foreign or intestine wars to periods of profound peace, and the works effected during the years of disorder or tranquility would be alike superhuman in magnitude. (I, 78–79)

Lyell also relied upon turn of phrase to convey his message. Consider some snippets from his most impassioned section—chapter 1 of volume III, with its restated epitome of the general doctrine, and its running head: "methods of theorizing in geology." Again, we read of a contrast between vain speculators, who view the past as different from the present, and patient empiricists, who uphold uniformity in modes, rates, and amounts of change. Note Lyell's pejorative descriptions of anti-uniformitarian reprobates (III, 2–3): "They felt themselves at liberty to indulge their imaginations, in guessing at what might be, rather than in inquiring what is"; "they employed themselves in conjecturing what might have been the course of nature at a remote period"; they preferred to "speculate on the possibilities of the past, than patiently to explore the realities of the present"; they "invented theories." "Never was there a dogma more calculated to foster indolence, and to blunt the keen edge of curiosity, than this assumption of the discordance between the former and the existing causes of change." Students were "taught to despond from the first." Geology could "never rise to the rank of an exact science"; it became "a boundless field for speculation." And finally, LyelPs most famous metaphor: "we see the ancient spirit of speculation revived, and a desire manifested to cut, rather than patiently to untie, the Gordian knot" (III, 6).

By contrast, consider the favorable phrases that describe uniformitarian heroes. They devote themselves to "inquiring what is," to "investigation of... the course of nature in their own times." They try "patiently to explore the realities of the present" by "candid reception of the evidence of those minute, but incessant mutations . . ." They have "hope of interpreting the enigmas"; they "undertake laborious inquiries" on the "complicated effects of the igneous and aqueous causes now in operation." Theirs is an "earnest and patient endeavor" (III, 2–3).

In illustrating three modes of Lyell's rhetoric—the invocation of history, the use of metaphor, and the contrast of adjectives—I have tried to show how he set up his preferred form of geology as the right (and righteous) side of a strict dichotomy between vain speculation and empirical truth, defined, respectively, as belief that causes worked differently on an ancient earth versus conviction that our planet has remained in a dynamic steady state throughout time.

The reality of history is so much more complex and interesting; the irony of history is that Lyell won. His version became a semiofficial hagiography of geology, preached in textbooks to the present day. Professional historians know better, of course, but their message has rarely reached working geologists, who seem to crave these simple and heroic stories.

Modern Cardboard

If Lyell cast his version in cardboard, later retellings of the great dichotomy became even more simplistic. First of all, the two sides received names—catastrophism for the vanquished, uniformitarianism for the victors. Names wrap any remaining subtlety into neat packages. Secondly, the catastrophist position became more foolish and caricatured in the constant retelling. In particular, Lyell noted that the 5000-year time scale of Genesis had faded from respectability by 1800, and that his scientific colleagues could only stand accused (at most) of not allowing sufficient millions in their revised estimates (this switch in opinion prompted Lyell's transition in metaphors from Egyptian mummies to accelerated centuries). But later textbooks have usually blurred this distinction and imagined that the catastrophists of Lyell's *own day* still adhered to the Mosaic chronology. This ludicrous error then permits the final step—the enthronement of Lyell as the man who made geology a science by rejecting the explicitly miraculous (the only way to cram the complexities of history, as unraveled by 1830, into a mere 5000 years). Catastrophists, in short, became biblically motivated miracle-mongers, actively preventing the establishment of geology as a proper science. Later in this chapter, I shall show that catastrophists of Lyell's day were fine scientists who accepted both an ancient earth and the methodological meanings of uniformity. The notion that catastrophism implies biblical chronology is a logical error, for the two flanks of the central argument are not symmetrical. A 5000- year time scale does commit any adherent to global paroxysm as a mode of change, but belief in worldwide catastrophe need not imply a young earth. The earth might be billions of years old, and still concentrate its changes into paroxysmal moments.

For example, Loren Eiseley, in the best-known modern article about Lyell, confuses old-style biblical literalism, quite passé among scientists by 1830, with LyelTs true opponents among scientific catastrophists, and therefore depicts Lyell as the white knight of truth: "He entered the geological domain when it was a weird, half-lit landscape of gigantic convulsions, floods, and supernatural creations and extinctions of life. Distinguished men had lent the power of their names to these theological fantasies" (1959, 5).

The game of dichotomy requires standard-bearers for each side. In textbook cardboard, Georges Cuvier is Lyell's catastrophist enemy. He accepts the biblical chronology (or at least an earth of very short duration); he advocates the total extirpation of life (and its subsequent miraculous recreation) at each catastrophe; he works, probably consciously, for the church against science. What a vulgar misrepresentation! Cuvier, perhaps the finest intellect in nineteenth- century science, was a child of the French Enlightenment who viewed dogmatic theology as anathema in science. He was a great empiricist who believed in the literal interpretation of geological phenomena (see pages 132–137). His earth, though subject to intermittent paroxysm, was as ancient as Lyell's. He argued that many faunal changes following catastrophes represented migrations of preexisting biotas from distant areas. The real debate between Lyell and Cuvier, or of uniformity and catastrophism, was a grand scientific argument of substance—and its main subject was time's arrow and time's cycle. Yet consider some further textbook cardboard, from three best-sellers of the 1950s through the 1970s:

Gilluly, Waters, and Woodford (1959, 103) on Cuvier: "These [catastrophes], he believed, destroyed all existing life, and following each a whole new fauna was created: this doctrine, called Catastrophism, was doubtless in part inspired by the Biblical story of the Deluge." By the third edition (1969), their confidence had increased, and they substituted "unquestionably" for "doubtless in part."

Longwell and Flint (1969, 18): "One group of geologists, though admitting that the Earth had changed, supposed that all changes had occurred within the time scale of the biblical chronology. This meant that the changes had to be catastrophic."

Spencer (1965, 423): "Most students of the earth subscribed to the idea that the earth was no more than a few thousand years old, and that its history had been punctuated by one or more catastrophes during which all living beings had been wiped out and newly created beings followed."

Or Stokes (1973, 37), in the leading text of historical geology: "Cuvier believed that Noah's flood was universal and had prepared the earth for its present inhabitants. The Church was happy to have the support of such an eminent scientist, and there is no doubt that Cuvier's great reputation delayed the acceptance of the more accurate views that ultimately prevailed."

Finally, a new book on popular science by one of America's finest science writers: "Until Lyell published his book, most thinking people accepted the idea that the earth was young, and that even its most spectacular features such as mountains and valleys, islands and continents were the products of sudden, cataclysmic events, which included supernatural acts of God" (Rensberger, 1986,236).

These texts then identify fieldwork as the fuel for change to uniformitarian enlightenment: "Hutton's ideas never caught on, though, until Lyell reintroduced them with massive documentation from his field studies" (Rensberger, 1986, 236). "The idea that catastrophism might be wrong may have been a reaction against theological dogmatism, but for most men it was an outgrowth of actual observation of nature" (Stokes, 1973, 37). "As geologic knowledge expanded, the job of rationalizing a growing list of events with a small but fixed supply of time became hopeless" (Longwell, Flint, and Sanders, 1969, 18).

But why does it matter? What harm is a bit of heroic folderol about an illusory past, especially if it makes us feel good about the progress of science? I would argue that we misrepresent history at our peril as *practicing* scientific researchers. If we equate uniformity with truth and relegate the empirical claims of catastrophism to the hush-hush unthinkable of theology, then we enshrine one narrow version of geological process as true *a priori*, and we lose the possibility of weighing reasonable alternatives. If we buy the simplistic idea that uniformity triumphed by fieldwork, then we will never understand how fact and theory interact with social context, and we will never grasp the biases in our own thinking (for we will simply designate our cherished beliefs as true by nature's dictates). Moreover, I have a particular reason, in the context of this book, for fulminating against cardboard history. Once we recover Lyell's substantive objection to intelligible and intelligent catastrophism, we recognize that the real debate was not dogma versus fieldwork, but a conflict between rival empirics rooted in the theme of this book—a conflict of metaphor between time's cycle and time's arrow. Lyell was not the white knight of truth and fieldwork, but a purveyor of a fascinating and particular theory rooted in the steady state of time's cycle. He tried by rhetoric to equate this substantive theory with rationality and rectitude—and he largely triumphed. Thus, we cannot understand the importance of time's arrow and time's cycle in establishing our view of time and process until we break through this most enveloping of all cardboard histories. It shouldn't be difficult; cardboard is pretty flimsy stuff.

Lyell's Rhetorical Triumph: The Miscasting of Catastrophism

The Enigma of Agassiz's Marginalia

Louis Agassiz, the great Swiss scientist who made a home at Harvard and built the museum that I now inhabit, was a garden variety catastrophist. He developed the theory of continental glaciation, but advocated a global ice cover extirpating all life, with subsequent divine recreation. In the dichotomy that Lyell erected, Agassiz could only be an implacable opponent.

About ten years ago, I discovered Agassiz's copy of Lyell's *Principles* in the open stacks of our museum library. It contained some fascinating marginalia, incomprehensible if Lyell's great dichotomy accurately represents the geological struggles of his age. Agassiz penciled three comments in French on the margins of Lyell's preface to the third London edition of 1834, inscribed by the author to "Dr. Agassiz à Neuchâtel" (Agassiz and Lyell were close personal friends, whatever their professional disagreements).

The first two comments record just what we would expect from a catastrophist opponent. Agassiz first discusses the range in variation among modern causes, arguing by implication that Lyell had erred in ascribing large-scale events of the past to the accumulation of small, slow changes. Maintaining that many modern causes are substantial and abrupt, he pooh-poohs Lyell's claim that today's processes form a unitary set: "These causes are identical as the cause that produces good weather is identical with the cause that produces the tempest. But it never comes to anyone's mind to array them in the same category. There have always been different categories of causes."

The second comment extends this argument into the past and attacks a cardinal premise of uniformity: that phenomena of large scope arise as the summation of small changes. "But these changes, since they don't always have the same intensity in our own day, could not have so worked in former times. They have therefore differed at all times from considerable changes that never result from the addition of small changes."

So far, so good. But we then come to his summary statement, penciled on the blank left-hand page facing the beginning of Lyell's summary (Figure 4.3): "Les principes de Geologic de Mr. Lyell sont certainement 1'ouvrage le plus important qui ait para sur 1'ensemble de cette science, depuis qu'elle merite ce nom" (Mr. Lyell's *Principles of Geology* is certainly the most important work that has appeared on the whole of this science since it has merited this name). The statement is clearly in Agassiz's hand and represents his own comment, not the copied words of another reviewer (see Gould, 1979). How, after all Lyell's disparaging rhetoric, could a catastrophist praise him so highly? Something is very wrong. Either Agassiz was not a true catastrophist (but we can find none better), or he was trying to ingratiate himself (but not in private jottings), or he was either inconsistent or sarcastic (though he exhibited neither trait). I suggest another resolution: LyeU's dichotomy, wid- ened by later textbook cardboard, is false outright. Geology in the 1830s was not a war between uniformitarian modernists and a catastrophist old guard with a hidden theological agenda.

Multiple Meanings of Uniformity and Lyell's Creative Confusion

When I was studying freshman geology as an undergraduate at Antioch College, our professor took us to a hill of travertine (limestone deposited by a spring), and told us that it was 15,000 years old, according to a principle called uniformitarianism. A colleague, he told us, had measured the current rate of accumulation. The principle of uniformity permitted us to assume that this rate had been constant—and a millimeter per year (or whatever) extrapolated to the bottom of the pile yielded an age of 15,000 years. If we do not accept the constancy of nature's laws in space and time, my professor added, we will be unable to apply any science beyond the immediate present.

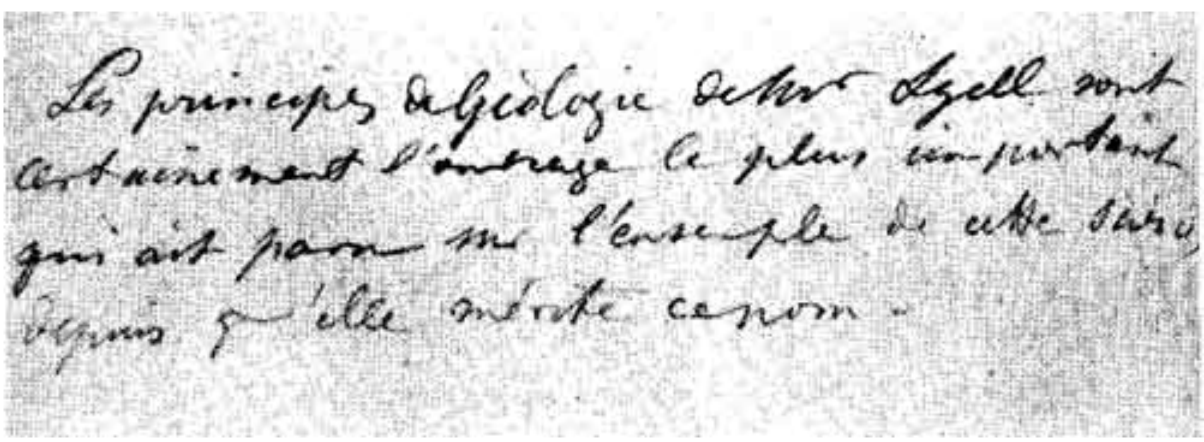

Les principes de Géologie de Mr Lyell sont certainement l'ouvrage le plus important qui ait paru sur l'ensemble de cette science depuis qu'elle mérite ce nom.

Figure 4.3

Agassiz's comment of highest praise jotted alongside his criticisms in his copy of Lyell's *Principles.*

At that stage of juvenility, I rarely challenged professorial pronouncements, but this argument seemed wrong. I could grasp the part about nature's laws, but constancy in accumulation of a travertine mound in southwest Ohio was a thing, not a principle. Why shouldn't the travertine have built twice as fast ten thousand years ago, or not at all for long stretches between periods of deposition? I turned to Lyell and to the classical sources on uniformitarianism.

Lyell, of course, never made such a crude confusion between principles and particulars, but I soon discovered that he had gathered a motley set of claims under the common umbrella of uniformity—in particular, he had made, in far more subtle form, the very same conflation of methodological principles with substantive claims that had fueled my professor's error about the travertine mound. I published my very first paper (Gould, 1965) on the multiple meanings of uniformitarianism and on the confusion that pervaded the geological literature, as debaters spoke past each other, one side invoking a meaning of uniformity to support a claim, while the other side tore it down with a different definition.

All lives contain moments of pride, and many more times better forgotten. It shall always be one of my greatest satisfactions that, as a teeny neophyte scholar alone in a little Ohio college, I noted this central confusion at the same time as a major revisionist movement to reassess Lyell's cardboard history was brewing among professional historians. Many have contributed to this revision, though I must single out the works of Hooykaas (1963), Rudwick (1972), and Porter (1976). (My own work is a belated and insignificant ripple in this tide—especially since I missed entirely the historical purpose and meaning of what Lyell had done.) Unfortunately, the message has not seeped through to practicing geologists, and textbook cardboard continues unabated.

All revisionists agree on a central point: Lyell united under the common rubric of uniformity two different kinds of claims—a set of methodological statements about proper scientific procedure, and a group of substantive beliefs about how the world really works. The methodological principles were universally acclaimed by scientists, and embraced warmly by all geologists; the substantive claims were controversial and, in some cases, accepted by few other geologists.

Lyell then pulled a fast one—perhaps the neatest trick of rhetoric, measured by subsequent success, in the entire history of science. He labeled all these different meanings as "uniformity," and argued that since all working scientists must embrace the methodological principles, the substantive claims must be true as well. Like wily Odysseus clinging to the sheep's underside, the dubious substantive meanings of uniformity sneaked into geological orthodoxy—past an undiscerning Cyclops, blinded with Lyell's rhetoric—by holding fast to the methodological principles that all scientists accepted.

We shall probably never know whether Lyell perpetrated this ruse consciously—I suspect that he did not, since his strong commitment may have engendered a personal conviction that all meanings must be true *a priori.* In any case, Lyell's rhetorical success must rank among the most important events in nineteenth-century geology—for it established an "official" history that enshrined, as the earth's own way, a restrictive view about the nature of change. If any scientist ever tries to convince you that history is irrelevant, only a repository for past errors, tell him the story of Lyell's rhetorical triumph and its role in directing more than a century of research in geology.

Using my two categories of methodological and substantive claims, Rudwick (1972) has discerned four distinct meanings of uniformity in Lyell's *Principles.*

1. *The uniformity of law.* Natural laws are constant in space and time. Philosophers have long recognized (see, in particular, J. S. Mill, 1881) that assumptions about the invariance of natural law serve as a necessary warrant for extending inductive inference into an unobservable past. (Induction, as C. S. Peirce noted, can be regarded as self-corrective in an observable present, but we can never see past processes, and no amount of current repetition can prove that present causes acted in the same way long ago—hence our need for a postulate about the invariance of nature's laws.) Or,

as James Hutton wrote with admirable directness: "If the stone, for example, which fell today were to rise again tomorrow, there would be an end of natural philosophy, our principles would fail, and we would no longer investigate the rules of nature from our observations" (1795, I, 297).

2. *The uniformity of process.* If a past phenomenon can be rendered as the result of a process now acting, do not invent an extinct or unknown cause as its explanation. This principle bears the confusing name "actualism" in reference to the meaning of its cognate (*actualisme, Aktualismus*) in most continental languages—where actual means "present," not "real" as in English. Hence, actualism is the notion that we should try to explain the past by causes now in operation. Philosopher Nelson Goodman (1967) recognized that actualism is little more than geology's own way of expressing a general rule of scientific methodology, the so-called principle of simplicity: don't invent extra, fancy, or unknown causes, however plausible in logic, if available processes suffice.

These two meanings of uniformity are statements about methodology, not testable claims about the earth. You can't go to an outcrop and observe either the constancy of nature's laws or the vanity of unknown processes. It works the other way round: in order to proceed as a scientist, you assume that nature's laws are invariant and you decide to exhaust the range of familiar causes before inventing any unknown mechanisms. Then you go to the outcrop. The first two uniformities are geology's versions of fun- damental principles—induction and simplicity—embraced by all practicing scientists both today and in Lyell's time.

But Lyell's other uniformities are radically different in status. They are testable theories about the earth—proposals that may be judged true or false on empirical grounds.

3. *Uniformity of rate, or gradualism.* The pace of change is usually slow, steady, and gradual. Phenomena of large scale, from mountain ranges to Grand Canyons, are built by the accumulation, step by countless step, of insensible changes added up through vast times to great effect (Figure 4.4). Major events do, of course, occur-

especially floods, earthquakes, and eruptions. But these catastrophes are strictly local; they neither occurred in the past, nor shall happen in the future, at any greater frequency or extent than they display at present. In particular, the whole earth is never convulsed at once, as some theorists held. Speaking of floods, for example, Lyell writes:

They may be introduced into geological speculations respecting the past, provided we do not imagine them to have been more

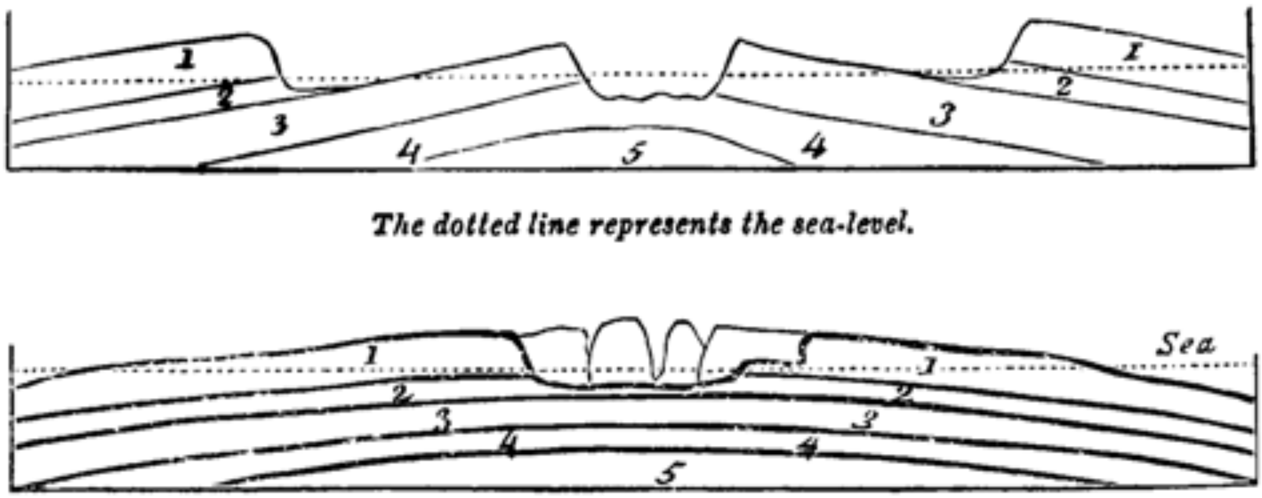


Figure 4.4

A classic example of Lyell's gradualism—the "denudation of the Weald." The geological structure of this eroded basin (top) is a great dome, bowed up after deposition of the Chalk in Cretaceous times (number 1 in both figures). The bottom figure represents the dome soon after its formation, with breakage and erosion just beginning in chalk deposits at the dome's summit. The top figure shows that, by gradual erosion of the Chalk and underlying layers, the modern basin has formed, with a substantial separation (by denudation) of the North and South Downs (the upstanding sides of the original dome, labeled as number 1). Lyell's premier example of gradualism led Darwin into one of his most famous errors. In the first edition of the *Origin of Species,* he used the denudation of the Weald to illustrate the insensible slowness of gradual change in geology. He estimated the time required for this denudation as 300 million years (though the actual time since deposition of the Chalk is only 60 million years or so). In later editions, Darwin dropped this calculation after receiving severe criticism. (Illustrations from the first edition of Lyell's *Principles.*)

frequent or general than we expect them to be in time to come. (I, 89)

Lyell defends the third uniformity with his characteristic ploys of rhetoric. He marshals, for example, his whiggish view of historical progress to assert that lingering notions of worldwide paroxysm are vestiges of a savage past when men huddled in fear before the thunderbolt.

The superstitions of a savage tribe are transmitted through all the progressive stages of society, till they exert a powerful influence on the mind of the philosopher. He may find, in the monuments of former changes on the earth's surface, an apparent confirmation of tenets handed down through successive generations, from the rude hunter, whose terrified imagination drew a false picture of those awful visitations of floods and earthquakes, whereby the whole earth as known to him was simultaneously devastated. (I, 9)

The replacement of catastrophe by accumulated slow change is die very essence of progress:

The mind was slowly and insensibly withdrawn from imaginary pictures of catastrophes and chaotic confusion, such as haunted the imagination of the early cosmogonists. Numerous proofs were discovered of the tranquil deposition of sedimentary matter and the slow development of organic life. (I, 72)

(Note how the progress of mind mirrors nature's own way—"slowly and insensibly.")

Catastrophism, by its very nature, is antimpirical:

Instead of confessing the extent of their ignorance, and striving to remove it by bringing to light new facts, they would be engaged in the indolent employment of framing imaginary theories concerning catastrophes and mighty revolutions in the system of the universe. (I, 84)

Thus, we may reject, as unintelligible in principle, the idea of worldwide, or even substantial regional catastrophe, for it would be

contrary to analogy to suppose, that Nature had been at any former epoch parsimonious of time and prodigal of violence— to imagine that one district was not at rest while another was convulsed—that the disturbing forces were not kept under subjection, so as never to carry simultaneous havoc and desolation over the whole earth, or even one great region. (I, 88–89)

These five quotations illustrate Lyell's debating style. He establishes certain meanings of uniformity—law and process—as necessary postulates of scientific method, and then tries to win similar status for controversial ideas about the earth's empirical behavior by describing them in the same language of logical necessity.

4. *Uniformity of state, or nonprogressionism.* Change is not only stately and evenly distributed throughout space and time; the history of our earth also follows no vector of progress in any inexorable direction. Our planet always looked and behaved just about as it does now.[5] Change is continuous, but leads nowhere. The earth is in balance or dynamic steady state; therefore, we can use its current *order* (not only its laws and rates of change) to infer its past. Land and sea, for example, change positions in an endless dance, but always maintain about the same proportions. Floods, volcanoes, and earthquakes have wrought devastation at about the same frequency and extent throughout time. The earth had no early period of more vigorous convulsion.

Lyell also extended the uniformity of state to life. Species are real entities with points of origin in space and time, definite durations and moments of extinction. Their beginnings and ends are not

5. Like Hutton, Lyell eschewed speculation about ultimate beginnings and ends. These moments must, of course, depart from uniformity of state, but science cannot comprehend them. The uniformities apply to the vast panorama of time as recorded in the geological record.

concentrated in episodes of mass death or radiation, but are distributed evenly through space and time—another dynamic steady state as introductions are balanced by removals. Moreover, the timing of introductions displays no progress in organization or complexity, no advance through the chain of being. Lyell argued (see pages 137–142) that appearances of progress in stratigraphic origins (from fish to reptile to mammal to human in the history of vertebrates, for example) were illusory. He believed that mammals had lived during earliest Paleozoic times and that future exploration would recover their fossil remains from these ancient rocks.

Lyell's extension of the fourth uniformity to life strikes many people as intensely puzzling. They can appreciate the force behind a claim for uniformity of state in the physical world, but surely we know that life must change in a progressive manner. Yet, for Lyell, the link of life to the physical world was direct and necessary. He held that species arose (whether by God's hand or by some unknown secondary cause) in perfect adaptation to physical surroundings. Any progressive change in life's state could only mirror a corresponding alteration in the physical environment. Since uniformity of state pervades climate and geography, life must also participate in the nondirectional dance.

Lyell defended uniformity of state with the same devices of rhetoric that he had applied to gradualism—he conflated this testable and controversial theory about the nature of things with methodological canons that all scientists accept, thereby attempting to secure an *a priori* status for time's cycle as a necessary component of rationality itself.

Consider two examples. Lyell often argued against directional theories not by citing contrary evidence, but by holding that their claims for a different earth in the past could not be rendered accessible to inquiry or even made intelligible. He refutes the old Neptunian theory of original deposition from a universal ocean not with stratigraphic evidence, but in principle because it advocates an ancient earth different in state from our own:

If, at certain periods of the past, rocks and peculiar mineral composition had been precipitated simultaneously upon the floor of an "universal ocean," so as to invest the whole earth in a succession of concentric coats, the determination of relative dates in geology might have been a matter of the greatest simplicity. To explain, indeed, the phenomenon would have been difficult, or rather impossible, as such appearances would have implied a former state of the globe, without any analogy to that now prevailing. (III, 37—38)

In the most striking of all Lyellian statements, he sketches a series of tactics to preserve uniformity of state in the face of almost any conceivable evidence for directional change in the earth's history:

When we are unable to explain the monuments of past changes, it is always more probable that the difficulty arises from our ignorance of all the existing agents, or all their possible effects in an indefinite lapse of time, than that some cause was formerly in operation which has ceased to act; and if in any part of the globe the energy of a cause appears to have decreased, it is always probable, that the diminution of intensity in its action is merely local, and that its force is unimpaired, when the whole globe is considered. But should we ever establish by unequivocal proofs, that certain agents have, at particular periods of past time, been more potent instruments of change over the entire surface of the earth than they now are, it will be more consistent with philosophical caution to presume, that after an interval of quiescence they will recover their pristine vigor, than to regard them as worn out. (I, 164–165)

I have quoted this passage for years, but it never ceases to astound me. It begins with an acceptable statement of the second uniformity, then slides into substantive claims about uniformity of state. Finally, Lyell actually holds that we should reject directional change even if we have "unequivocal proofs . . . over the entire surface of the earth," because we have a right to anticipate that any apparently depleted cause will, in future, resume its former intensity.

Will the Reed Catastrophism Please Stand Up: The Solution to Agassiz's Paradox

This exegesis can resolve the paradox of Agassiz's private reactions to Lyell's brief. Agassiz did not view the professional world of geology in 1830 as a battleground between scientific empiricists and theological apologists. As a fellow scientist, Agassiz accepted the methodological uniformities of law and process. As a catastrophist who viewed the history of vertebrates as a tale of progress, he rejected the substantive uniformities of rate and state. On balance, praise for Lyell's forceful and beautifully crafted defense of proper method far exceeded unhappiness with their longstanding disagreement about the earth's behavior—for scientists then and now have recognized that their profession is defined by its distinctive modes of inquiry, not by its changing perceptions of empirical truth.

As we have our von Danikens, our "scientific" creationists, and our faith healers, science in Lyell's day also felt besieged by a periphery of charlatans and reactionaries, who often commanded much public support. Agassiz therefore welcomed most heartily Lyell's elegant defense of scientific method —this "most important work. . . since [geology] has merited this name." Once we abandon the cardboard version of Lyell's scientific light versus Agassiz's theological darkness, and grasp their substantial common ground by their own perceptions, Agassiz's general praise following his particular criticisms provokes no surprise. Lyell's dichotomy, exaggerated by subsequent textbook cardboard, presents a taxonomy that would not have been accepted, or even recognized, by most of his contemporaries. In Agassiz's classification, any primary division between supporters and detractors of fruitful science would have placed him and Lyell on the same side.

As evidence of support by catastrophists for the methodological uniformities of law and process, consider two primary 'Villains" of the cardboard version—men usually depicted as enemies of modern science. I have already demonstrated in Chapter 2 that Burner's strict adherence to uniformity of law not only defined his approach to the earth but also, and ironically, directly inspired the fanciful conjectures that have set his poor reputation in modern textbooks. Burnet accepted the Bible as literal truth. If he had been willing to admit miracles as agents of earthly change, his explanations would have been no more curious than those of Genesis. But Burnet was committed, by uniformity of law, to rendering even the most elaborate of biblical tales by the workings of Newtonian physics—and such an effort required some mighty tall and fancy conjectures about sources of water and formation of topography. Still, Burnet refused, on methodological grounds, to permit divine creation of flood-waters, and even used the metaphor of Lyell's most famous passage (see page 111) to defend the uniformity of law: "They say in short, that God Almighty created waters on purpose to make the deluge . . . And this, in a few words, is the whole account of the business. This is to cut the knot when we cannot loose it" (Burnet, 33).

The French geologist Alcide d'Orbigny usually wins a textbook nod as most outlandish of catastrophists among Lyell's contemporaries. He identified some twenty-eight episodes of global paroxysm, marked by volcanoes, tidal waves, and effusion of poison gases, and leading to the annihilation of life. Yet d'Orbigny embraced the actualist principle of uniformity of process. He recommended that inquiry always begin with modern processes: "Natural causes now in action have always existed . . . To have a satisfactory explanation of all past phenomena, the study of present phenomena is indispensable" (1849–1852, 71). And he followed Agassiz in praising Lyell for this proper emphasis (though he reserved greatest honors for a fellow countryman): "The happy thought that we should explain the earth's strata by causes now acting belongs entirely to Mr. Constant Prevost who first established it in his geological system. Science owes much to Mr. Lyell for the development of this system, supported by copious research as wise as it is ingenious" (1849–1852, 71).

D'Orbigny and Agassiz had no beef with Lyell about method— they all agreed that inquiry must begin with present processes and that modern causes must be entirely exhausted before any extinct or exotic process be considered. They differed in their judgment about the world's response to this common method. Lyell believed that modern causes would suffice to explain everything about the past. Agassiz and d'Orbigny viewed actualism as a method of subtraction for identifying the unchanging substrate of modern causes, thereby highlighting the phenomena that required special explanation by processes outside the current range.

Nonetheless, d'Orbigny also admitted that modern causes would greatly aid the understanding of past catastrophes—for paroxysms may be caused by modern forces greatly magnified in degree. D'Orbigny argued, for example, that any change in topography during an earthquake "is, for us, on a small scale, and with effect much less marked, the same phenomenon as one of the great and general perturbations to which we attribute the end of each geological epoch" (1849–1852, II, 833–834).

All agreed, therefore, that the most valuable of all possible tools for interpreting the past would be a proper catalogue of the variety, range, rates, and extent of modern causes. Lyell had provided the finest compendium ever assembled. I believe that this elaborately detailed catalogue, above all else, won for Lyell the bounteous praise that catastrophists like Agassiz gratefully accorded.

Thus, the real debate between Lyell and the catastrophists was a complex argument of substance among men who agreed about methods of inquiry. Lyell's substantive uniformities of rate and state commingle to form a powerful vision of a dynamic earth, constantly in motion but never changing in general appearance or complexity—a stately earth playing a modest portion of all its acts all the time, not concentrating single modes of change into global episodes, and not alternating worldwide periods of tumult and quiescence, uplift and erosion.

Lyell's attitude to James Hutton illustrates the mixture of his substantive uniformities. Lyell praised Hutton for his nondirectional world machine with endlessly cycling phases of uplift, erosion, deposition, consolidation, and uplift—an earthly mechanics beautifully consonant with the fourth uniformity of state. But Lyell criticized Hutton for viewing the stages of his cycle as a global succession and, especially, for the catastrophic character of his periods of uplift—a violation in the third uniformity of rate. He cited as "one of the principal defects" of Mutton's theory "the assumed want of synchronism in the action of the great antagonist powers— the introduction, first, of periods when continents gradually wasted away, and then of others when new lands were elevated by violent convulsions" (II, 196). Lyell insisted upon stately unfolding going nowhere.

No logical connection unites the two substantive uniformities of rate and state. One could, like Hutton, accept nondirection while advocating catastrophic periods of uplift. But Lyell's vision joined them neatly and tightly. I shall subsequently refer to Lyell's junction of rate and state, the essence of his world view, as "time's stately cycle."

Similarly, as "catastrophism" confutes by its name only the third uniformity (of rate), pretenders to this tide might espouse paroxysm without direction. But all prominent catastrophists of Lyell's day also linked the uniformities of rate and state—by denying them both. From Cuvier, d'Orbigny, and Elie de Beaumont in France, to Agassiz in Switzerland (and then America), to Buckland and Sedgwick in England, they agreed that occasional paroxysm had been the predominant mode of substantial change on an ancient earth. These catastrophes occurred as direct consequences of the primary and inherent directionality that had also provoked the progressive increase in life's complexity—cooling of the globe. So tight was this link between catastrophe and direction that Martin Rudwick and other historians prefer to designate this theory as "the directionalist synthesis."

Since the catastrophists of Lyell's day were fine scientists, not the vestigial miracle-mongers that Lyell described in his rhetoric, their characteristic linkage of catastrophe and direction rested upon respected theories of physics and cosmology. In simplified essence, the earth had formed hot (in a molten or gaseous state), as maintained by the nebular hypothesis of Kant and Laplace, then the leading theory for the origin of our solar system. As the physics of large bodies dictates, the earth had cooled steadily through time. As the earth cools, it contracts. The outer crust solidifies, but the molten interior continues to shrink and "pull away" from the rigid surface. This contraction creates an instability that becomes more and more severe until the rigid crust cracks and collapses upon the shrunken core. The earth's intermittent paroxysms are these geological moments of violent readjustment—and they explain a host of empirical phenomena, including the linearity of mountain chains as cracks of shrinkage or breakage. Since life adapts to environment, the harsher worlds of our cooling earth have engendered more complex creatures better able to cope.

How did Lyell respond to this powerful theory of the earth and life? In part, he reacted as the stated ideals of science profess—by defending his own vision with evidence and theoretical arguments (see the next section of this chapter). But he also counterattacked with the same successful rhetoric that secured the cardboard history of geology—he again conflated phenomena and procedures, arguing that the substantive claims of catastrophism are unintelligible in principle because all scientists accept the methodological uniformities of law and process.

Lyell begins his attack on Elie de Beaumont's physics of catastrophism in the historical introduction to his chapter "on the causes of vicissitudes in climate" (I, ch. 7). Lyell identifies his usual bugbear of different causes on an ancient earth as the wrong way to understand geological changes in climate. He designates as villain "the cosmogonist" who "has availed himself of this, as of every obscure problem in geology, to confirm his views concerning a period when the laws of the animate and inanimate world were wholly distinct from those now established" (I, 104). As illustrations, Lyell chooses the most outlandish of old and discredited ideas, especially Burnet's change in axial tilt following Noah's flood. He then makes a quick transition from these abandoned fancies to the respectable notion of directional cooling from an original molten state, but manages to place this physical basis of contemporary catastrophism into the same pot with discredited cometary collisions, thereby branding the best physics of his day as vain speculation. He then rejects directional cooling *a priori,* on methodological grounds:

When the advancement of astronomical science had exploded this theory [Burner's axial changes], it was assumed that the earth at its creation was in a state of fluidity, and red hot, and that ever since that era it had been cooling down, contracting its dimensions, and acquiring a solid crust—an hypothesis equally arbitrary, but more calculated for lasting popularity, because, by referring the mind directly to the beginning of things, it requires no support from observations, nor from any ulterior hypothesis. They who are satisfied with this solution are relieved from all necessity of inquiry into the present laws which regulate the diffusion of heat over the surface, for however well these may be ascertained, they cannot possibly afford a full and exact elucidation of the internal changes of an embryo world. (I, 104–105)

Lyell then presents his own recommendation:

But if, instead of vague conjectures as to what might have been the state of the planet at the era of its creation, we fix our thoughts steadily on the connection at present between climate and the distribution of land and sea . . . we may perhaps approximate to a true theory. If doubt still remain, it should be ascribed to our ignorance of the laws of Nature, not to revolutions in her economy;—it should stimulate us to farther research, not tempt us to indulge our fancies in framing imaginary systems for the government of infant worlds. (1,105)

Later (III, ch. 24), Lyell attacks Elie de Beaumont because his "successive revolutions . . . cannot be referred to ordinary volcanic forces, but may depend on the secular refrigeration of the heated interior of our planet" (III, 338–339). Lyell reasserts his preference for shifting foci of internal volcanic heat, constant in strength through time, but moving from place to place on the earth's surface—for this idea presumes "the reiterated recurrence of minor convulsions" rather than unacceptable "paroxysmal violence" (III, 339). Lyell attacks Elie de Beaumont not with facts that support his uniformity of state, but with a claim that directionalism is unscientific ("mysterious in the extreme"):

The speculation of M. de Beaumont concerning the "secular refrigeration" of the internal nucleus of the globe, considered as a cause of the instantaneous rise of mountain-chains, appears to us mysterious in the extreme, and not founded upon any induction from facts; whereas the intermittent action of subterranean volcanic heat is a known cause capable of giving rise to the elevation and subsidence of the earth's crust without interruption of the *general* repose of the habitable surface. (I, 339)

But what is inherently preferable about causes that preserve the general repose of the surface?

Lyell and the catastrophists were locked in a fascinating debate of substance about the way of our world, not a wrangle about methodological aspects of uniformity. Their struggle pitted a directional view of history as a vector leading toward cooler climates and more complex life, and fueled by occasional catastrophes, against Lyell's vision of a world in constant motion, but always the same in substance and state, changing bit by bit in a stately dance toward nowhere. This real debate, so lost at our peril in the success of Lyell's rhetoric, was the grandest battle ever fought between the visions of time's arrow and time's cycle.

Lyell's Defense of Time's Cycle

Lyell's Distinctive Method of Probing behind Appearances

Lyell's work may be awash in rhetoric but it is, as Agassiz fairly noted, an intellectual *tour de force* filled with meatier arguments of great interest.

Lyell and his catastrophist opponents differed not only in their interpretation of the geological record, but also in their basic approach to field evidence. In the light of Lyell's rhetorical brand, marking his opponents as anti-empiricists devoted to armchair speculation, their differences in approach present one of the great ironies in the history of science.

Read literally, then and now, the geological record is primarily a tale of abrupt transitions, at least in local areas. If sediments indicate that environments are changing from terrestrial to marine, we do not usually find an insensibly graded series of strata, indicating by grain size and faunal content that lakes and streams have given way to oceans of increasing depth. In most cases, fully marine strata lie directly atop terrestrial beds, with no signs of smooth transition. The world of dinosaurs does not yield gradually to the realm of mammals; instead, dinosaurs disappear from the record in apparent concert with about half the species of marine organisms in one of the five major mass extinctions of life's history. Faunal transitions, read literally, are almost always abrupt, both from species to species[6] and from biota to biota.

The characteristic method of catastrophism, promulgated particularly by Cuvier, was empirical literalism—an approach diametrically opposed to Lyell's unfair characterization of these scientists as speculators opposed to field evidence. The catastrophists tended to accept what they saw as reality: abrupt transitions of sediments and fossils indicated rapid change of climates and faunas. The defense of catastrophism was rooted in the most direct (or minimally "interpretive") reading of geological evidence.

Lyell did not deny this apparent evidence of abruptness—that is, he did not defend the uniformity of rate by citing different direct evidence for gradual transitions. He couldn't, since the literal record speaks too loudly for discontinuity. Instead, he supported uniform-

6. Niles Eldredge and I developed the theory of punctuated equilibrium to explain these transitions between species as an accurate reflection of the workings of evolution, not as artifacts of an imperfect fossil record.

ity of rate with a brilliant argument for "probing behind" literal appearances, and trying to find the signal of true gradualism in a record so riddled with systematic imperfections that insensible transitions become degraded to bits and pieces of apparent abruptness.

I do not gloat in this analysis to "show up" Lyell as less empirical or field-oriented than his catastrophist opponents. I find no particular virtue in empirical literalism and generally support Lyell's approach for balancing fact and theory in a complex and imperfect world. I just find it deliciously ironic that cardboard history touts Lyell's victory as the triumph of fieldwork, while catastrophists were the true champions of a geological record read as directly seen. Lyell, by contrast, urged that theory—the substantive uniformities of rate and state—be imposed upon the literal record to interpolate within it what theory expected but imperfect data did not provide.

Early in his first volume, Lyell admits the literal appearance of catastrophe as predominant in geology:

The marks of former convulsions on every part of the surface of our planet are obvious and striking . . . If these appearances are once recognized, it seems natural that the mind should come to the conclusion, not only of mighty changes in past ages, but of alternate periods of repose and disorder—of repose when the fossil animals lived, grew, and multiplied—of disorder, when the strata wherein they were buried became transferred from the sea to the interior of continents, and entered into high mountain chains. (I, 7)

To uphold the third uniformity (of rate) in the face of this admission, Lyell uses two arguments, both based on probes "behind appearance." First, he argues that local records cannot be extrapolated to wider regions, or to the whole globe. Abrupt transition in one section, for example, may be reconciled with a world in balance if we find opposite changes in other places at the same time. "There can be no doubt, that periods of disturbance and repose have followed each other in succession in every region of the globe, but it may be equally true, that the energy of the subterranean movements has been always uniform as regards the whole earth" (I, 64). Second, using his metaphor of the book (later adopted by Darwin for defending gradualism in fossil sequences), Lyell argued that slow and continuous change will degrade to apparent abruptness as fewer and fewer stages are preserved—as if, of the original book, an imperfect record preserved but few pages, of the pages few lines, of the lines few words, and of the words few letters. In Darwin's words:

For my part, following out Lyell's metaphor, I look at the natural geological record, as a history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page, only here and there a few lines. (1859, 310– 311)

Lyell expands this central theme of imperfection in a double metaphor (III, ch. 3). Compare the continuous origin and extinction of species with birth and death in human populations. Let preservation in geological strata correspond to the records of census takers. The appearance of true gradualism or illusory catastrophe then depends upon the density of preserved information. If a nation contains sixty provinces and a full census be taken every year in each, then the preserved record will match the actual character of slow and continuous change. But suppose that an impoverished or distracted government can employ only one team of census takers, who can, at best, visit only one province a year. Then the records for each province, spaced sixty years apart, will display an almost complete turnover of population from one recorded instance to the next—the illusory catastrophe that appears when continuity is sampled too sparsely. Of course, geological records are even more scanty and erratic. The geological "census takers" do not sample in strict rotation; some areas may remain "unvisited" for great stretches of time, while records duly made and entered may be destroyed by subsequent erosion. Lyell concludes that the literal record of catastrophic faunal turnover really represents a continuous change of life filtered through ordinary laws of sporadic sedimentation: "If this train of reasoning be admitted, the frequent distinctness of the fossil remains, in formations immediately in contact, would be a necessary consequence of the existing laws of sedimentary deposition, accompanied by the gradual birth and death of species" (III, 32–33).

Lyell then switches metaphors to illustrate the important corollary that signs of disturbance in an illusory transition need bear no relation to the actual causes of change. Suppose that a modern eruption of Mt. Vesuvius buried an Italian city atop Herculaneum. The abrupt change in language and architecture, as seen in the archaeological record, would not only be illusory, but also quite unrelated to the catastrophe of volcanic eruption.

As Lyell defended gradualism by probing behind the literal appearance of catastrophe, he supported the second substantive uniformity (of state) with a similar admission and resolution. He also granted that several vectors of directional change ran through the geological record read literally—older rocks tend to be denser, harder, and more altered by heat and pressure; climates (at least in the northern hemisphere) have become harsher, as indicated by sediments and the fossils they contain; life itself (at least for vertebrates) has become more complex. Lyell argued that each apparent vector is an illusion produced by directional biases of preservation acting upon a uniform world in steady state.

Lyell again relied upon metaphor to express these (then) unfamiliar and crucial arguments. Suppose that a collector of insects shipped specimens from a tropical land to England, with a minimum transport of two months, and suppose that these organisms lived little longer than two months (and did not breed in captivity). Englishmen would then see only aged adults. Likewise, old rocks are often contorted and metamorphosed, younger rocks evenly layered and less dense. Many geologists had viewed this directional change in strata as a sign of decreasing intensity in geological forces, perhaps the signature of a cooling earth. But Lyell argued, by his entomological metaphor, that forces of uplift and consolidation might be unvarying through time, as the uniformity of state required. The older the rock, the longer it might be subject to constant forces of alteration, and the more it might become baked and contorted. Only old rocks are so altered, just as all insects reaching England are adult—but as beetle life cycles flow from larva to adult in their native land, so too are rocks continually made in the bowels of the earth, but only receive the imprint of contortion and metamorphosis as they move toward the surface through time: "If the disturbing power of the subterranean causes be exerted with uniform intensity in each succeeding period, the quantity of convulsion undergone by different groups of strata will generally be great in proportion to their antiquity" (III, 335). Direction, in other words, is an illusion, as older rocks receive more "attention" from the constant forces of time's cycle.

The Worst Case as Crucial Test: Lyell Probes Behind Appearance to Deny Progression in Life's History

Most grand visions have crucial tests or tragic flaws. The paleontological record played this dual role as goad and bugbear through- out Lyell's career as he attempted to validate his vision of time's stately cycle. The problem is simply stated: no other aspect of geology seems so clearly progressive in our usual, vernacular sense— especially given our inordinate interest in ourselves, our smug convictions about human superiority, and the restriction of human fossils to the last microsecond of geological time.

The invertebrate record might easily be read in the light of time's cycle— since most anatomical designs first appear at roughly the same time in the oldest fossiliferous strata (as known in Lyell's time). But how could appearances of progress—at least in the parochial sense of increasing taxonomic proximity to *Homo sapiens*— be denied as reality in the record of vertebrates? Fish came first, then reptiles, then mammals, and finally human artifacts at the very top of the stratigraphic pile. Paleontologists had searched assiduously for vertebrate remains. Could this literal appearance also be ascribed to incompleteness of the record? Lyell quotes Sir Humphrey Davy on literal appearance as confuting uniformities of both rate and state: "There seems, as it were, a gradual approach to the present system of things, and a succession of destructions and creations preparatory to the existence of man" (I, 145).

Lyell responds to this greatest challenge in chapter 9 of volume I: "theory of the progressive development of organic life considered—evidences in its support wholly inconclusive." He divides the attack on uniformity into two separate questions requiring different responses: "First, that in the successive groups of strata, from the oldest to the most recent, there is a progressive development of organic life, from the simplest to the most complicated forms; —secondly, that man is of comparatively recent origin" (I, 145). The first claim, he argues, "has no foundation in fact"; the second, though "indisputable," is not "inconsistent with the assumption, that the system of the natural world has been uniform . . . from the era when the oldest rocks hitherto discovered were formed" (I, 145).

Lyell uses two kinds of arguments to refute the first claim, that vertebrates march up life's ladder in stratigraphic order. These arguments may not stand formally in contradiction; but they certainly illustrate LyelTs willingness to exploit both sides of a potential weakness.

First argument. Advanced vertebrates were present in the earliest strata as well, but we haven't found their remains yet. Lyell here invokes his most characteristic argument—the appearance of progress is caused by directional biases in preservation, not by progressive trends in actual history. First of all, apparent progress is not so marked or pervasive. Complex fish appear in the earliest strata, reptiles soon after, and still in old rocks (now called Paleozoic). The evidence for progress is entirely negative—the absence only of birds and mammals in Paleozoic rocks. Birds so rarely fossilize that biases of better preservation in more recent rocks might restrict their remains to later strata even if they had actually lived at modern abundances in Paleozoic times.

Lyell could not evoke the same argument for mammals—since their dense and massive bones fossilize more easily. He therefore invoked two biases of discovery to argue that Paleozoic mammals abounded, but have not yet been found as fossils. Our explorations have been largely restricted to Europe and North America, a small segment of the globe. This region was the center of an ocean during the Paleozoic, far from any continent that might yield a floating carcass to full fathom five. After all, we might dredge an equally large area of the central Pacific today, and find no signs of mammalian life:

The casualties must be rare indeed whereby land quadrupeds are swept by rivers and torrents into the sea, and still rarer must be the contingency of such a floating body not being devoured by sharks . . . But if the carcass should escape and should happen to sink where sediment was in the act of accumulating, and if the numerous causes of subsequent disintegration should not efface all traces of the body included for countless ages in solid rock, is it not contrary to all calculation of chances that we should hit upon the exact spot—that mere point in the bed of the ancient ocean, where the precious relic was entombed? (I, 149)

But Lyell's trump card was an empirical discovery, not a verbal argument. Thirty years before, the fossil record of mammals had provided even better signs of apparent progress—for their remains had been entirely confined to the latest, or Tertiary, rocks. None had been found throughout the entire middle realm, now called Mesozoic and popularly known as the age of dinosaurs. But, by 1830, a few small mammals had been discovered in the midst of Mesozoic strata. If the Mesozoic had fallen to assiduous exploration, could the older Paleozoic rocks be far behind?

Second argument. Perhaps advanced vertebrates really did not live during the early ages of fishes and primitive reptiles, but their absence is a contingent and reversible consequence of climatic change, not the mark of an inexorable vector of progress.

Following the old warrior's advice that one must be prepared for all contingencies, Lyell girds himself to defend time's cycle even if Paleozoic mammals are never found, and the vector of apparent progress is confirmed. If we accept Lyell's dubious premise that all species arise in perfect adaptation to prevailing environments, then the vector of progress might bear two interpretations, one fatal to time's cycle, the other consistent. Progress in vertebrate life might mean, as the catastrophists asserted, that our planet had cooled continuously, and that more complex life developed to weather the harsh decline from easy tropicality. But Lyell rejects this interpretation with his usual rhetorical flourish: "In our ignorance of the sources and nature of volcanic fire, it seems more consistent with philosophical caution, to assume that there is no instability in this part of the terrestrial system." (But why does caution urge nondirection, if vectors of cooling are consistent with the best physics and cosmology of Lyell's day?)

Or the absence of Paleozoic mammals might signify that cooling in the northern hemisphere since Paleozoic times recorded a contingent and reversible shift to more land and less sea (see pages 144–145 for details of Lyell's argument on ties of climate to relative positions and amounts of land and sea):

We have already shown that when the climate was hottest, the northern hemisphere was for the most part occupied by the ocean, and it remains for us to point out, that the refrigeration did not become considerable, until a very large portion of that ocean was converted into land, nor even until it was in some parts replaced by high mountain chains. (I, 134)

Trends in climate caused by the shifting dance of land and sea (rather than by inexorably cooling interiors of planets) are temporary and reversible. The uniformity of physical state suggests that any regional trend to greater continentality (and consequently increasing cold) will eventually reverse itself, since land and sea are continually changing positions, but always maintaining their rela tive proportions on a global scale. The northern hemisphere is now in "the winter of the 'great year,' or geological cycle"; but we may expect the future to bring "conditions requisite for producing the maximum of heat, or the summer of the same year" (I, 116).

Life, to say it once more, follows climates. If the passage from summer to winter of the great year has brought progress to vertebrate life in the northern hemisphere, the return of subsequent summer must engender a most curious result. We come then to that most stunning passage of the entire *Principles*—the line that marks Lyell as a theorist dedicated to consistency, not always to empirical restraint (as legend holds); the conjecture so *outré* (even to Lyell's contemporaries) that De la Beche captured it in caricature, while Frank Buckland, unable to grasp such a curious context, interpreted it as a jest about his father rather than a mordant dig at Lyell; the subject of the frontispiece and first section of this chapter. And so, once more with feeling: "Then might those genera of animals return, of which the memorials are preserved in the ancient rocks of our continents. The huge iguanodon might reappear in the woods, and the ichthyosaur in the sea, while the pterodactyle might flit again through umbrageous groves of tree-ferns" (I, 123).

But as zealously as Lyell probed behind appearance to impose uniformity of state upon the apparent record of vertebrate progress, he could not (or dared not) extend this argument to our own species. Humans are special; humans are different. The intellectual world is littered with systems that pushed consistency to the ends of the earth and the bounds of rationality, but then stepped aside and made an exception for human uniqueness. Lyell followed this tradition and placed a picket fence around *Homo sapiens.*

Lyell does note, quite fairly, that we often make too much of ourselves and that our physical bodies are poor and flawed indeed, displaying no mark of progress in our late appearance: "If the organization of man were such as would confer a decided preeminence upon him, even if he were deprived of his reasoning powers ... he might then be supposed to be a link in a progressive chain" (I, 155).

Even our strength of reason cannot stay nature's power:

We force the ox and the horse to labor for our advantage, and we deprive the bee of his [*sic*] store; but, on the other hand, we raise the rich harvest with the sweat of our brow, and behold it devoured by myriads of insects, and we are often as incapable of arresting their depredations as of staying the shock of an earthquake, or the course of a stream of burning lava. (I, 162)

Lyell admits, however, that this argument can extend only so far. The late appearance of our bodies does not violate uniformity, but humans do not challenge time's cycle as mere naked apes: "The superiority of man depends not on those faculties and attributes which he shares in common with the inferior animals, but on his reason by which he is distinguished from them" (I, 155).

Although human reason is a violation of time's cycle, it is too grand, too different, too godlike for inclusion in an argument about physical and organic history. One might almost say that God made human reason at the end of time so that something conscious might delight in the grand uniformity of time's stately cycle: "No one of the fixed and constant laws of the animate or inanimate world was subverted by human agency . . . the modifications produced were on the occurrence of new and extraordinary circumstances, and those not of a physical, but a moral nature" (I, 164).

Charles Lyell was struggling, not joyfully triumphing, with his most difficult case.

Time's Stately Cycle as a Key to the Organization of Lyell's **Principles**

Lyell published eleven editions of the *Principles of Geology* between 1830 and 1872 (see specifications of dates and major changes in the preface to the last edition—Lyell, 1872). Since Lyell regarded his great work as a lifelong source of income, he continually revised, shifted sections and chapters, and experimented with differing formats—-much as the author of a modern best-selling text produces new editions, perhaps too frequently, for commercial more than intellectual motives. Lyell's similar behavior has prompted the general misinterpretation of his great work as a textbook in the usual sense. As I argued above (see page 104), it is no such thing; *Principles of Geology* is a brief for a world view—time's stately cycle as the incarnation of rationality.

I believe that all truly seminal works of our intellectual history are coherent arguments for grand visions. Lyell's *Principles* lies squarely in this greatest of all scholarly traditions, and yet, as I argue above, it has usually been read as a work of the most opposite genre conceivable: the textbook, with its pseudo-objectivity and impassive compendium of accepted information.

Grand visions require keys to unbolt their coherence. Often we lose those keys when changing contexts of history bury the motivations of authors in forgotten concerns. Lyell's *Principles* has suffered this fate. The key to its coherence is Lyell's overarching vision of time's stately cycle—the combination of his uniformities of rate and state. But we now view his brief as a textbook because we no longer recognize this thread of unity. The real Lyell has been sacrificed, in part by his own rhetoric, for the cardboard hero of empirical truth. The great thinker, the scientist of vision, the man who struggled so hard to grasp the empirical world as imbued with distinctive meaning, becomes merely a superior scribe.

We can, at least, try to recover Lyell's vision by grasping the Principles as an argument, not a compendium, *Time's stately cycle is the thread of coherence, for Lyell's Principles is a treatise on method, dedicated to defending this vision in the face of a geological record that requires close interpretation, not literal reading, to yield its secret support.*

I have a personal theory that paradoxes of odd beginnings usually unlock the meaning of great works. Darwin's *Origin of Species* does not announce a revolution in thinking, but starts instead with a disquisition on variation among breeds of pigeons (as Burnet begins by puzzling about floodwaters, and Hutton with the paradox of the soil). When we recognize that Darwin's defense of natural selection is an extended analogy from small-scale events that we can watch and manipulate—artificial selection as practiced by agriculturists, breeders, and fanciers—to invisible events of grander scale in nature, his otherwise eccentric beginning makes sense. Ernst Mayr (1963) began our most important modern book on species and their origin with an empirical list of sibling species,[7] not with general theories or global frameworks. When we grasp Mayr's major aim—to substitute a dynamic view of species as natural populations defined by interbreeding and ecological role for the old taxonomist's idea of dead things that look alike in a museum drawer—we recognize that his choice for starters embodies his book's program: for sibling species are the test case of his vision—perfectly good species by the new criterion, unrecognizable under the old.

Following five historical chapters that tout the factual and moral benefits of nondirection, Lyell begins his substantive brief with three chapters on climate in the northern hemisphere and one on the hypothesis of progression in life's history. Chapter 6 of volume I bears the title "Proofs that the climate of the Northern hemisphere was formerly hotter." And so—mark the oddity—the first substantive chapter in a three-volume brief for time's cycle admits as its central theme the most favorable datum that Lyell's opponents, advocates of a directionally cooling earth, could possibly muster.

Chapter 7, "on the causes of vicissitudes in climate," then argues that varying distributions of land and sea are the most evident and easily ascertainable causes of climatic change. (A vast ocean dotted with a few small islands will bring warmer and more equable climates than a massive continent with little surrounding water at the same latitudes.) Chapter 8 bears an extended title: "Geological proofs that the geographical features of the northern hemisphere, at the period of the deposition of the carboniferous strata, were such as would, according to the theory before explained, give rise to an extremely hot climate." And now we understand the point and the program.

Carboniferous rocks are old. They represent a time of great swamps and lush tropical vegetation; their fossil remains supply

7. Sibling species are morphologically indistinguishable populations as clearly separated by behavior in nature as others more visually distinct.

most of our coal. Superficially, they provide firm support for the directionalist hypothesis of an inherently cooling earth.

Lyell admits the phenomenon—northern-hemisphere coal forests indicate hotter climates during the Carboniferous (I, ch. 6). If an inherent secular cooling caused the subsequent change, then uniformity of state is disproved. But Lyell offers an alternative based on current processes (I, ch. 7). As sea and land change position, climate alters in predictable ways. If the northern hemisphere had become more and more continental since the Carboniferous, then climate would become cooler as a result of fluctuating surfaces, not inexorably cooling interiors. Lyell then tries to demonstrate (I, ch. 8) that cooling climates in the northern hemisphere have been accompanied by increasing continentality since the Carboniferous.

This alternative explanation preserves the crucial uniformity of state. Interiors cooling from an original fireball are irreversible records of time's arrow. But exteriors that cool because continents rise impart no inherent direction to time, and permit no future extension to further frigidity. Continents rise by uplift and fall by erosion in a smooth and nondirectional way through the fullness of time, recording both substantive uniformities of rate and state: "The renovating as well as the destroying causes are unceasingly at work, the repair of land being as constant as its decay, and the deepening of seas keeping pace with the formation of shoals" (I, 473). As continents have emerged since the Carboniferous, they may yield again to ocean in the future—and cooling is but one segment of a reversible cycle. Lyell speaks of a "great year," or "geological cycle," and views falling temperatures in the northern hemisphere since Carboniferous times as the autumn of a geological succession that will see another summer.

The first three substantive chapters are, therefore, one long application of Lyell's method to an apparent (and central) case of disconfirmation. He probes behind appearance to render an admitted phase of cooling, occupying most of geological time and a large part of the earth, as but one arc of a grander circle.

Chapter 9 then applies this reasoning to the greatest problem for any supporter of time's cycle—the apparent increase in life's complexity through time. Lyell again admits the appearance but denies the inherent directionality (see previous section for details). New species always arise perfectly adapted to prevailing climates. If climates become cooler, new species will display increases of complexity suited to these more difficult conditions. Directional trends in life only record an underlying change in climate. If an apparent climatic "arrow" is really the segment of a circle rotating to nowhere, then life will also follow the future arc back—to Professor Ichthyosaurus of times to come.

Having marshaled history to his purposes (chs. 1–5) and dismissed the two most troubling cases of apparent directionality (climate and life, chs. 6–9), Lyell devotes the rest of volume I (chs. 10–26) to a catalogue of modern causes presented as a complete guide to the past. He arranges these chapters (ostensibly about the second methodological uniformity of process) as a subtle defense of his substantive uniformities of rate and state. For he discusses first the aqueous causes (Figure 4.5) that destroy topography (rivers, torrents, springs, currents, and tides) and then the igneous causes (Figure 4.6) that renew (volcanoes and earthquakes), suggesting all the while that both sets operate in continuous balance; neither ever dominates the entire earth, and neither imparts any inherent direction to the character of rocks, landforms, or life.

I shall discuss volumes II and III (Lyell's positive contribution) in the next section, but must briefly note here how they continue and fulfill the plan of a grand, coherent work on life and its nature. We usually remember volume II only for Lyell's refutation of evolution, particularly of Lamarck's theory (which he introduced to England, though only to dismiss). But the eighteen chapters of volume II are designed and sequenced to present a positive view of life's history that will lead to Lyell's greatest achievement, the subject of volume III—a new method for stratigraphic dating based on an unconventional view of life dictated by the uniformities of rate and state.

The focus of Lyell's argument—and the reason for lambasting evolution defined as insensible transition between species—rests upon a view of species as entities, not tendencies; things, not arbitrary segments of a flux. Species arise at particular times in particular regions. They are, if you will, particles with a definite point of origin, an unchanging character during their geological duration, and a clear moment of extinction. Most important, they are particles in a world of time's stately cycle. Their origins and extinctions are not clumped in episodes of mass dying or explosive radiation, but more or less evenly distributed through time, with births balancing deaths to maintain an approximate constancy in

Figure 4.5

A modern example of destruction by erosion. The Grind of the Navir (the breach between the two sections of this sea cliff in the Shetland Islands) is widened every winter by the surge passing between. (From first edition of Lyell's *Principles.*)

Changes of the surface at Fra Ramondo, near Soriano, in Calabria.

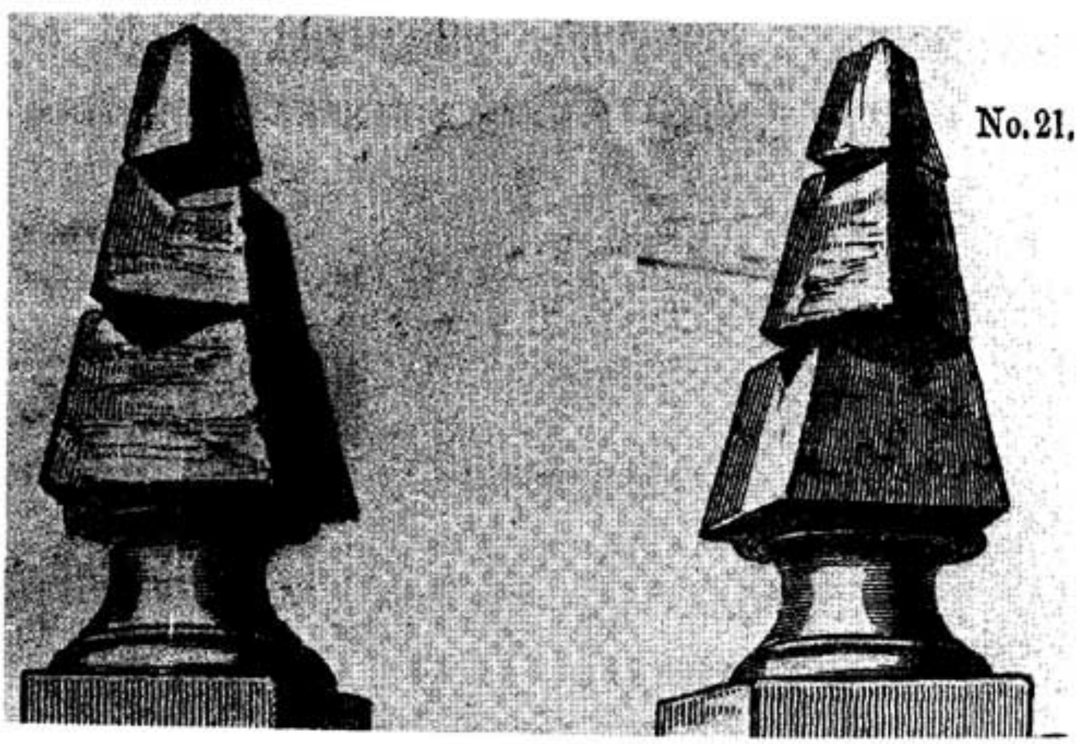


Figure 4.6

Modern examples of construction by earthquakes. Top: the surface at Fra Ramondo in Calabria. Note the breakage of olive trees between up—and downthrusted parts of the hill. Bottom: two obelisks on the facade of the convent of S. Bruno in Stefano del Bosco, Italy. Each is built of three sections, and repeated earthquakes have loosened the blocks and rotated them to different positions. (From first edition of Lyell's *Principles.*)

life's diversity. Their sequential origins display no vector of progress for a positive reason of theory, not a mere claim of observation (see previous section): Lyell espoused perfect adaptation between species and their environments; each species is a mirror of its surroundings. Therefore, any true direction in life's history can only record a corresponding arrow in the physical world. Since the physical world has remained in steady state (volume I), life has also maintained an unchanging complexity and diversity. Species turn over constantly; none alive today graced the Carboniferous coal swamps. But anatomical designs do not accrete or improve.

Volume III, in twenty-six chapters, presents a descriptive account of the earth's actual history, ordered, as a man committed to modern processes might, in a sequence opposite to modern conventions— starting with most recent times (where the work of modern processes can be assessed most readily) and working back to the oldest rocks. Many readers have dismissed volume III as dull and outdated description, but it embodies the central defense of Lyell's game plan. It presents his most important argument for time's stately cycle—for a vision in science is only as good as its application *and its utility.* Volume III, read as the ultimate test of time's cycle, embodies two major purposes. First, the striking vectors of geological history read literally must be interpreted, by Lyell's method of probing behind appearance, as the way that an imperfect record would render time's cycle in preserved evidence. Again and again, we learn (for example) how apparent mass extinctions are periods of nondeposition, and how greater contortion of older rocks records the longer time available for their subsequent modification by constant forces of metamorphism, not the greater vigor of a pristine earth.

Second, Lyell, as a great scientist, understood the cardinal principle of our profession—that utility in action is the ultimate test of an idea's value. Most of his earlier defenses of time's cycle had been rhetorical, verbal, or negative (by showing that directional appearances of the literal record do not disprove a steady state). To crown the success of his brief, Lyell now needed an achievement of substance—something major and practical that time's stately cycle could do to unravel the earth's history. Volume III is therefore, above all, a long illustration of a new method, striking in its originality and brilliant in its difference from conventional paleontology, for dating rocks of the Cenozoic Era (the last 65 million years, since the extinction of dinosaurs) by percentages of molluscan species still living. I shall show in the next section that this novel method flows directly from Lyell's unusual view of time's cycle applied to life's history.

Although (obviously, from early sections of this chapter) Lyell is not my foremost intellectual hero, I can only describe my reading of the first edition of the *Principles* as a thrill, a privilege, and an adventure. As I grasped its brilliant coherence about the vision of time's stately cycle, shivers coursed up and down my spine. Yet that thrill has been foreclosed to most readers. The first edition is difficult to obtain, and many reasons conspire to degrade its coherence through the subsequent editions that most geologists read. For one thing, Lyell extracted almost all of volume III, and placed his discussion of the earth's actual history into another book, the *Elements of Geology* (in later editions, the *Manual of Elementary Geology*]—thus divorcing his primary application from his verbal defense of time's cycle. For another, Lyell strongly muted his commitment to time's cycle when, late in his career, and with both great personal struggle and splendid honesty (see pages 167–173), he finally admitted the progressive character of life's history. Finally, he shifted and tinkered with so many chapters that the original coherence of argument dissipated, and the last editions almost became, after all, a textbook.

Lyell, Historian of Time's Cycle

Lyell's Explication of History

Hutton and Lyell are indissolubly linked in textbook histories as the two heroes of modern geology—Hutton as unheeded prophet, Lyell as triumphant scribe. Gilluly, Waters, and Woodford, for example, write (1968, 18): "The uniformitarian principle, proposed by James Hutton of Edinburgh in 1785, was popularized in a textbook by the great Scottish geologist Charles Lyell in 1830." We have seen that methodological versions of uniformity were the common property of all scientists, defended by both Hutton and Lyell, but scarcely original with them. (We cannot even label Hutton as a champion of actualism, for he argued that forces of subterranean consolidation were invisible on today's earth, and must be inferred from the character of ancient rocks exposed by uplift.) Hutton and Lyell shared, above all, the controlling vision of time's cycle, the uniformity of state. Even here they differed, for Hutton promoted a sequential view, and held that periods of uplift might be global and catastrophic, while all stages of Lyell's cycle operate locally and simultaneously, giving the earth a timeless steadiness through all its dynamic churning. An observer might visit Hutton's earth and see only the quietude of subterranean deposition, while another visitor, a million years later, might find a planet convulsed by uplift. The pieces of Lyell's globe shift constantly, but all processes are always working somewhere—at about the same intensity and amount.

I do not, however, view Lyell's union of rate and state (time's stately cycle), and Hutton's more catastrophic notion of uplift, as their most important difference. We need to recapture the dichotomy of their day—time's arrow versus time's cycle—to grasp their deeper divergence in different attitudes toward the meaning of time's cycle.

Hutton carried out his strict version of the Newtonian program so completely that his view of our planet became idiosyncratic—to a point where he actually denied the subject that students of the earth have always advanced as their fundamental motivation: history itself, defined as a sequence of particular events in time. Temporal distinction has no meaning in Hutton's world, and he never used the language of historical uniqueness to describe the earth. The corresponding events of each cycle are so alike that we can scarcely know (or care) where we are in a series that displays no vestige of a beginning, no prospect of an end. (I also noted that John Playfair, Mutton's Boswell, did not follow Hutton's idiosyncrasy, but used the ordinary language of historical narrative in his explication of Hutton's theories. Therefore, since most scientists know Hutton only through Playfair, this special character of Hutton's system has been lost.)

Lyell shared Hutton's commitment to time's cycle, but not his ahistorical vision, for reasons both personal and chronological. The fifty years separating Hutton and Lyell had witnessed a transformation in practice among British geologists. Hutton crowned a tradition of general system-building, or "theories of the earth." The next generation had abjured this procedure as premature and harmful speculation. The nascent science of geology needed hard data from the field, not fatuous, overarching theories. The eschewing of "interpretation," and restriction of discussion to facts alone, was (however impossible the ideal), actually written into the procedures of the Geological Society of London, founded in 1807. As a primary approach to field evidence, embraced for its plethora of exciting results, the Geological Society adopted the stratigraphic research program. The primary task of geology must be defined as unraveling the sequence of actual events in time, using the key to history that had just been developed to the point of general utility by Cuvier and William Smith—the distinctively changing suite of fossils through time.

Lyell was a willing child of this transformation in procedure. He was a historian, and the primary data of history are descriptions of sequential events, each viewed as unique (lest any lack of distinction blur utility as indicator of a particular moment). Lyell could scarcely embrace Hutton's antihistorical viewpoint. But how could a committed historian defend *and use* time's cycle? And how could non-directionalism aid the stratigraphic research program as a tool for unraveling historical sequences?

The very first line of Lyell's *Principles* stakes out his difference from Hutton's ahistorical vision: "Geology is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature" (I, 1). The statement seems so innocuous, but search far and wide in Hutton and you will never find its like; major upheavals in thought often sneak past our gaze because their later success makes them seem so obvious.

Lyell's first words show a profound understanding of both the meaning and the joy of history. He begins by acknowledging the distinctive character of historical inquiry—the explanation of present phenomena as contingent results of a past that might have been different, not as predictable products of nature's laws. The original historical prod may be tiny and forgotten, but results cascade to a magnitude that often seems to belie their origin:

We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great state, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connexions brought to light, when we carry back our researches into the history of nature. (1,2)

A static analysis of current function may yield some insight, but consider the expansion provided by historical context:

A comparative anatomist may derive some accession of knowledge from the bare inspection of the remains of an extinct quadruped, but the relic throws much greater light upon his own science, when he is informed to what relative era it belonged, what plants and animals were its contemporaries, in what degree of latitude it once existed, and other historical details. (I, 3)

Recognizing the importance of taxonomy, Lyell sought to rank geology properly among the sciences. He refused to follow several predecessors because they had placed geology with physical sciences based on laws of nature that impart no distinctive historical character to present phenomena. Thus, Werner had viewed geology as "a subordinate department of mineralogy" (I, 4), and Desmarest as a branch of physical geography. But minerals owe their properties to chemical composition, landforms to physical agents of uplift and erosion. Neither discipline acknowledges the irreducibly historical character of geological phenomena. Another proposed union with cosmogony must also be rejected; for, while geology requires a place among sciences of history, it must be defined as an empirical study of preserved records, and not linked with mental excursions about the origins of things.

As a direct study of history, geology owes its stunning success to a great transformation of practice, then just a generation old—the stratigraphic research program, using fossils as the key to ordering by age: "In recent times, we may attribute our rapid progress chiefly to the careful determination of the order of succession in mineral masses, by means of their different organic contents, and their regular superposition" (I, 30).

In a forceful passage, Lyell identifies the distinctive method of history—we need not ape the quantitative procedures of physical science, but must celebrate the power of what others with less understanding might deem a humdrum occupation, the ordering of events in time.

By the geometer were measured the regions of space, and the relative distances of the heavenly bodies—by the geologist myriads of ages were reckoned, not by arithmetical computation, but by a train of physical events—a succession of phenomena in the animate and inanimate worlds—signs which convey to our minds more definite ideas than figures can do, of the immensity of time.

Physics used its techniques to expand space; we have employed ours to enlarge time—results scarcely matched for significance in the history of thought, but won by different methods.

Lyell recognized that real history must be a "succession of phenomena." Precise cyclical recurrence would blot the distinctive character of historical moments. Lyell ridicules the old cyclical theories of Egypt and Greece, the *ewige Wiederkehr* or eternal return, but this passage might apply just as well to Hutton's ahistorical vision:

For they compared the course of events on our globe to astronomical cycles . . . They taught that on the earth, as well as in the heavens, the same identical phenomena recurred again and again in a perpetual vicissitude. The same individual men were doomed to be re-born, and to perform the same actions as before; the same arts were to be invented, and the same cities built and destroyed. The Argonautic expedition was destined to sail again with the same heroes, and Achilles with his Myrmidons, to renew the combat before the walls of Troy. (I, 156–157)

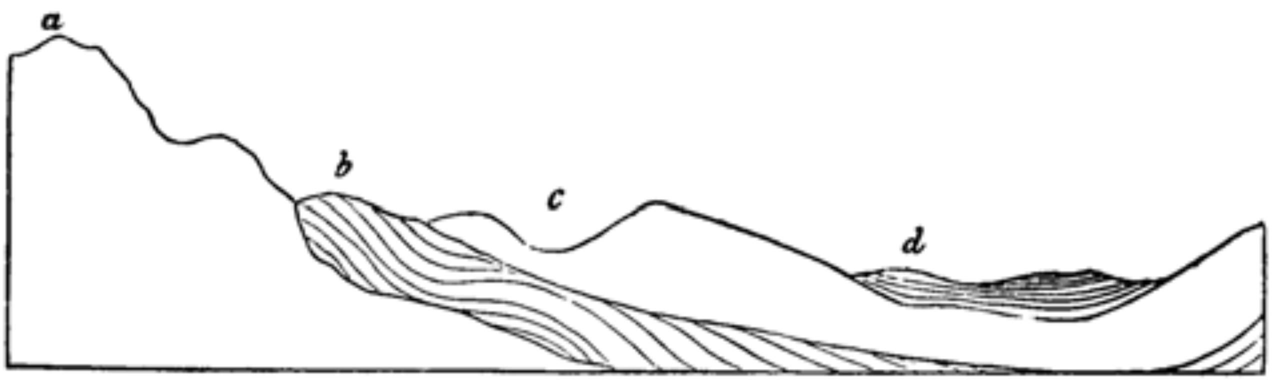
Finally, we must never lose the simple and unvarnished joy of discovering a past that had disappeared from view: "Meanwhile the charm of first discovery is our own, and as we explore this magnificent field of inquiry, the sentiment of a great historian of our times [Niebuhr, author of the *History of Rome*] may continually be present to our minds, that 'he who calls what has vanished back again into being, enjoys a bliss like that of creating'" (I, 74).

Dating the Tertiary by Time's Stately Cycle

Since preservation improves with recency in the geological record, we might anticipate that the youngest rocks would be most easy to resolve by the stratigraphic research program. Old (Paleozoic) rocks are often twisted and metamorphosed, their fossils distorted, pulverized, or entirely leached away. Geologists did struggle with the Paleozoic, and its resolution was a triumph and test of ultimate utility for the stratigraphic research program (see Rudwick's brilliant account of the Devonian controversy, 1985).

Tertiary strata of the "age of mammals" (all but the tail end of the last 65 million years by modern reckoning) should have succumbed first to resolution, as a test case for the new techniques. Paradoxically, by contingent bad fortune of the particular history of Tertiary times in Europe, these youngest rocks provoked puzzle rather than resolution. The middle or so-called Secondary strata (including what we now call Mesozoic and the top part of the older Paleozoic) yielded first to the new methods. These rocks are ordered throughout Western Europe in the nearly ideal configurations of textbook dreams—as extensive sheets of minimally distorted, flat-lying or gently tilting beds, easily traced over large areas. For example, the distinctive "chalk" (forming, for example, the White Cliffs of Dover), top layer of the Secondary, blankets this region with little complexity in deposition or later distortion—you really can't miss it, as the saying goes.

By contrast, the younger Tertiary strata are deposited as a complex patchwork in isolated basins—the bane of any stratigrapher's existence (Figure 4.7). Geologists work by correlation and superposition—fancy words for the obvious techniques of ascertaining what beds lie atop others (superposition), and then tracing this order from place to place (correlation). But if strata are clumps



a, Primary rocks.
b, Older secondary formations, *c*, Chalk.
d, Tertiary formation.

Figure 4.7

An illustration of the problems faced by geologists in unraveling Tertiary stratigraphy. Tertiary rocks of Europe tend to occur in small and isolated basins (as in d above), making correlation difficult. (From first edition of Lyell's *Principles*.)

rather than sheets, then we cannot unravel them by superposition. (Many Tertiary strata are, for example, impersistent stream channels rather than broad sheets of shallow oceanic sediments so common in the Mesozoic.) And if strata are confined to isolated local basins, then we cannot correlate them easily from place to place.

Since Tertiary times had been marked by increasing continentality in Europe (recall Lyell's second substantive argument; see pages 139–141), marine sediments were deposited in shifting, isolated embayments, not as favored broad sheets. Thus, Tertiary strata were a challenge to the stratigraphic program, not its premier example, as logic (without history's peculiarities) might have dictated. They were also something of an embarrassment, since a good technique should snare its potentially easiest reward without difficulty. Lyell therefore decided to bag the Tertiary with a different method, based on his distinctive vision of time's cycle. Success would crown his abstract vision as weighed in the empirical balance and found triumphant.

In the face of such difficult stratigraphy, fossil remains would unlock the Tertiary sequence. The stratigraphic research program had congealed about the paleontological criterion of temporal ordering. A chronometer of history has one, and only one, rigid requirement—something must be found that changes in a recognizable and irreversible way through time, so that each historical moment bears a distinctive signature. Geologists had long appreciated this principle in the abstract, but had not found a workable criterion. Werner and the Neptunians had tried to use rocks themselves, arguing that a distinctive suite "of compositions and densities had precipitated in temporal sequence from a universal ocean. This idea was sound in logic, but didn't work in practice because the earth's strata were not deposited in order of density from one ocean in one great era of precipitation. Moreover, rocks are simple physical objects formed by chemical laws and, as such, do not bear distinctive temporal signatures. Quartz is quartz—conjoined tetrahedra with a silicon ion in the center, surrounded by four oxygen ions, each shared with a neighboring tetrahedron. So it was in the beginning, and is now, and ever shall be so long as nature's laws prevail. Cambrian quartz is no different from Pleistocene quartz.

But life is complex enough to change through a series of unrepeated states. Today we attribute this irreversible sequence to the workings of evolution, but the fact of uniqueness may stand prior to any theory invoked to resolve it. The fossil criterion became the Rosetta stone for the stratigraphic research program, but few early consumers accepted evolution as the reason behind distinctive temporal stages of the fossil record. In Lyell's time, the fact of temporal distinction stood as an unexplained but crucial tool. Lyell himself had always professed agnosticism about the reasons, stating that he simply did not know whether new species arose by God's direct will, or by the operation of unknown secondary causes—though he did profess confidence that they arose in perfect balance with their environments.

In Lyell's time, the problem of unresolved Tertiary stratigraphy centered upon a proper use of fossils to "zone" strata—that is, to establish a worldwide sequence of temporally ordered stages within this long and previously undivided segment of the earth's history. In 1830, most stratigraphers were progressionists. They believed that life had improved throughout the Tertiary and that, as a rough guide at least, we might judge the relative age of Tertiary strata by the level of development displayed in their fossils. All paleontologists understood that progress was neither sufficiently linear nor unambiguous enough to employ as an actual measuring rod. In practice, a progressionist might use similarity to living forms, rather than some unattainable measure of relative perfection in biomechanical design. Moreover, he would search for a series of guide fossils—easily identifiable creatures of short and distinct geological range—to zone the Tertiary. And he would focus more upon their uniqueness and restriction to a small stretch of time than upon their supposed levels of relative complexity. Still, however far practice diverged from theory, a commitment to progressionism still channeled the actual work of stratigraphy into a search for temporal sequences of guide fossils arrayed as a ladder of improvement.

Lyell's world view did not permit him to work by the usual methods of his profession. Life participated fully in the dynamic steady state of time's cycle. The fossil record displayed no vector of progress, and its sequence of species could not be ordered by any criterion of advance. To put it as baldly as possible, life (as a totality) was always just about the same—with balance maintained both in number of species and relative proportions of different groups. How, then, could a Lyellian find any paleontological criterion for dating rocks—and, if not, how could he participate in the central and guiding concern of his profession?

Had Lyell been a strict Huttonian, he would have found no exit from this dilemma. He would have been mired in an ahistorical outlook that viewed each event as so similar to its corresponding stage in the previous cycle that no criterion of history could be established. But Lyell, as a premier practicing geologist of his day, was a committed historian. He accepted the uniqueness of events, and used this principle to extract a mark of history from time's cycle.

To borrow Lyell's own favored technique of metaphorical illustration, we may depict all the earth's species at any one time as a fixed number of beans in a bag—for species are particles in Lyell's vision. We begin a five-day experiment. The bag contains a thousand beans, and it will always hold this number. New beans are entering at a fixed and constant schedule, say one every two minutes. But the bag can only hold a thousand beans, so each time a new one enters, the beanmaster reaches in and pulls an old one out at random.

One more crucial step completes the isomorphism with Lyell's view of life. The beans are not identical; each is a distinct historical object. Let us say that each bears a unique brand in its lower right-hand corner (if beans may be construed as possessing such a thing). We can tell unambiguously which bean is which—but, and here's the rub, these distinct brands include *absolutely no signature of time whatever*. The beans are not color-coded by day of entry into the bag, or marked with the geometry of their time of origin. In other words, we can recognize each bean as an distinctive object, but we have no clue (from form or color) about its age or time of entry into the bag.

This system corresponds point for point with Lyell's vision of the fossil record in a world of time's stately cycle. The five days are the broad eras of geological time (few in number); the brands are marks of historical uniqueness, but (please note) not of progress, for each bean is distinct and all are equivalent in merit. The entrance of a bean every two minutes marks the stately uniformity of rate; the random removal of an old bean at each entrance maintains the steady state of diversity.

The grand beanmaster now sets us a problem. He took an x-ray of the bag every six hours during the last day, but he forgot to mark the times on his negatives, and he wants us to arrange the four photos (for midnight, six A.M., noon, and six P.M.) in proper temporal order. He is also willing to give us the bag as now constituted at day's end. How can we proceed?

Lyell and his student Simplicio consider the problem. Simplicio, ever in search of the easy way, suggests that they look for a crucial bean in each photo. But Lyell responds that no such object can exist. The uniqueness of each bean is, perversely, absolutely no guide to its age. Lyell castigates Simplicio for laziness, and argues that the problem can only be approached statistically.

Fortunately, the wily beanmaster has provided one criterion that can resolve this dilemma of history under time's cycle—he has given us the bag in its present state. Consider, Lyell advises, how the beanmaster proceeded on the last day. Every two minutes, or 720 times during the day, he put in a new bean and removed one from the bag at random. We now open the bag. It is dominated, we reason, by beans added during the last day—not all 720, of course, because some have been removed by luck of the (with) draw. But, Simplicio complains as he begins to catch on, we can't tell from the signatures which beans represent the last day's additions, for a signature contains no information *in se* about time.

Lyell then proposes his statistical criterion. We cannot know when any particular bean entered the bag, but we can make a list of all signatures in the bag as now constituted. We can then study the beanmaster's four photos and tabulate the 1000 signatures in each. The longer any bean is in the bag, the greater its chance of removal (since beans are pulled out at random as new ones enter). Thus, the more recently any bean entered, the greater the chance that it still resides in the bag. Lyell exclaims triumphantly that we need only tabulate, for each photo of the bag at a previous time, the percentage of beans that remain in the bag at day's end. The higher the proportion of current beans, the younger the photo.

What other criterion could we use? No bean betrays its age, but we do have the present bag, and can tell time by a gradual and continuous approach to current composition. The present bag is not better or more distinctive than any other; it only possesses the virtue of precise location in time—and we may therefore compare the similarity of other bags with it.

Lyell dated the Tertiary (last "day" of just a few) in this manner precisely. He proposed a statistical measure based on the relative percentage of living species of mollusks. (He used mollusks because they are numerous and distinct in Tertiary strata, and because he could pay his French colleague Deshayes to compile faunal lists for all major sections of the European Tertiary, based on the consistent criterion of Deshayes's personal taxonomic expertise.) Such a statistical criterion cannot yield overly fine distinctions, since several random factors operate (not just in removal, as in our bean experiment, but also, for the complexities of reality, because species don't arise at equally spaced intervals, and because total numbers of species are not truly constant). Thus, Lyell split the Tertiary into four subdivisions (as the beanmaster took four photos)—named, in order, Eocene. Miocene, older Pliocene, and newer Pliocene (Figures 4.8 and 4.9), and defined as bearing about 3 percent of living species (Eocene), about 20 percent (Miocene), more than a third and often more than a half (older Pliocene), and about 90 percent (newer Pliocene). (Readers who have been forced to memorize the geological time scale will recognize that our modern system retains LyelTs names, with a few additions in the same mold—Paleocene,

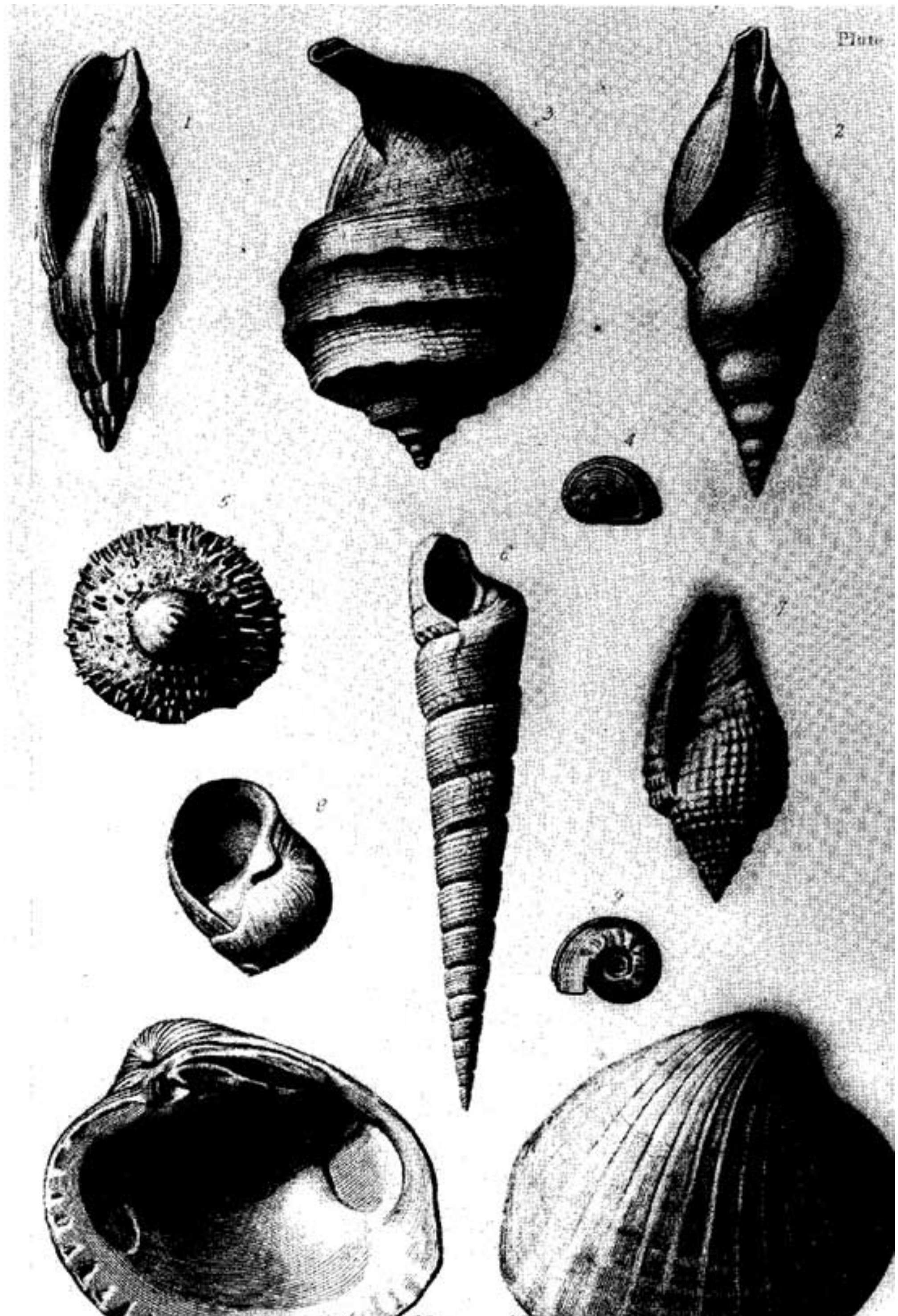


Figure 4.8

Eocene mollusk fossils used by Lyell in his statistical method for zoning the Tertiary. (Plate 3, volume 3 of the first edition of Lyell's *Principles.*}

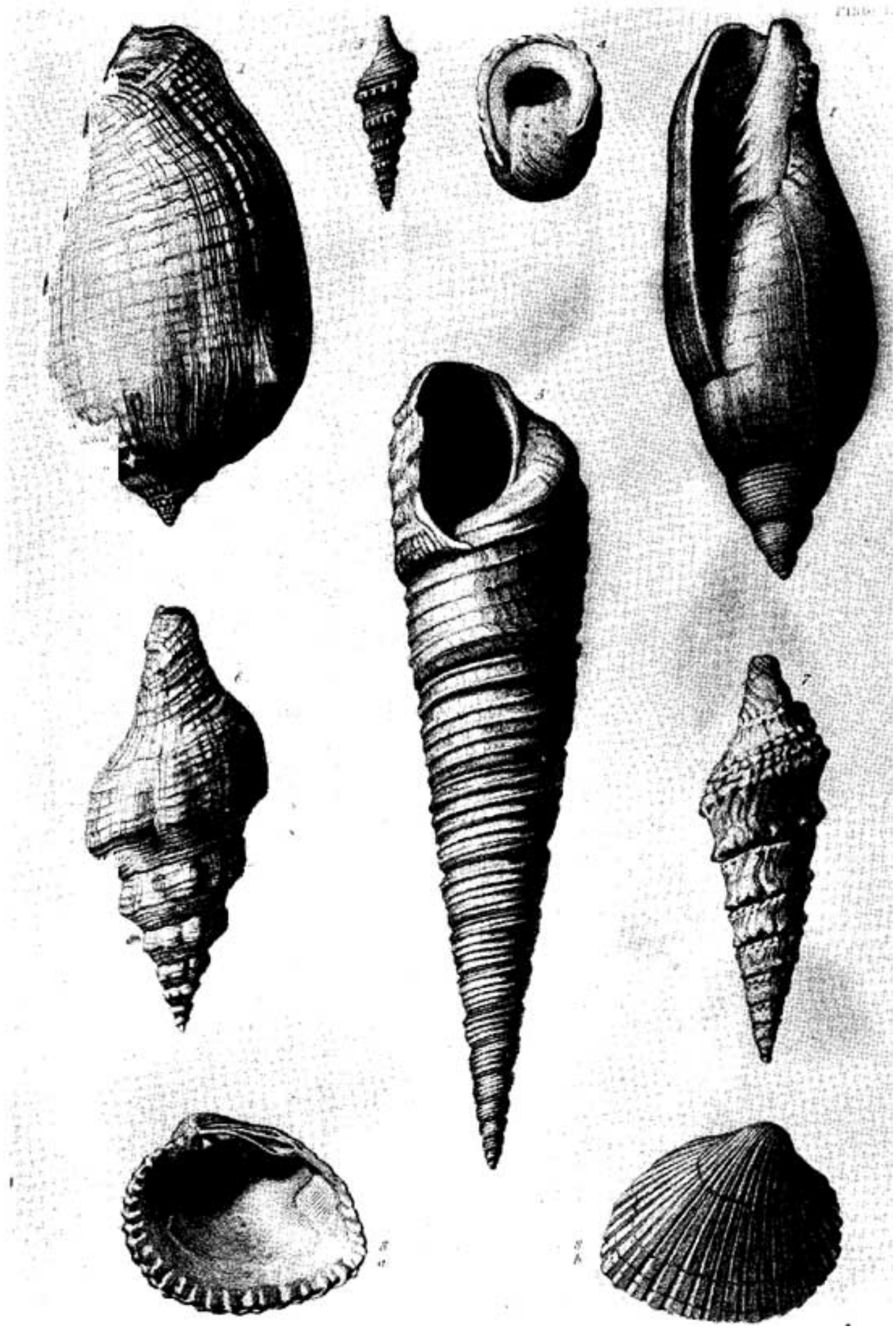


Figure 4.9

Miocene mollusk fossils used by Lyell to zone the Tertiary. (Plate 2, volume 3 of Lyell's Principles.) Note, by comparing figures 4.8 and 4.9, the key precepts of Lyell's method, based on the assumption of time's stately cycle. The later Miocene fossils are in no way "better" versions of their forebears. They are simply different as signs of history's passage.

Oligocene, and Pleistocene-to express the finer divisions permitted by increasing knowledge.) Lyell writes, citing a metaphor strictly comparable with our beanbag:

This increase of existing species, and gradual disappearance of the extinct, as we trace the series of formations from the older to the newer, is strictly analogous, as we before observed, to the fluctuations of a population such as might be recorded at successive periods, from the time when the oldest of the individuals now living was born to the present moment.

This simple description of Lyell's method cannot capture the brilliance and radical character of his concept. Consider just three points:

First, Lyell proposed this numerical method based on a sophisticated model of random processes at a time when such statistical thinking was in its infancy. Most of us still need metaphors to grasp it today, after a century of success for this powerful procedure.

Second, Lyell's method flies in the face of all paleontological convention during his time. Most stratigraphers denied both substantive uniformities of rate and state—and each denial led to a method abjured by Lyell. I have already discussed how progressionism (nonuniformity of state) led most stratigraphers to search for key fossils that might mark time by their anatomical complexity—a method contrary to Lyell's statistical approach toward entire faunas.

Lyell's opponents also rejected uniformity of rate by viewing the fossil record as punctuated by mass extinctions and rapid subsequent radiations of new species. This concept of life's history led to a different practice in dating—the search for distinctive suites of species to mark each epoch of time. Such a procedure makes no sense in Lyell's world. His species are independent particles evenly spaced in time; they do not enter and leave the geological scene in concert. Distinct epochs are an illusion of our imperfect record; we can only capture moments with statistical measures of a smooth and continuous flow:

We are apprehensive lest zoological periods in Geology, like artificial divisions in other branches of Natural History, should acquire too much importance, from being supposed to be founded on some great interruptions in the regular series of events in the organic world, whereas, like the genera and orders in zoology and botany, we ought to regard them as invented for the convenience of systematic arrangement, always expecting to discover intermediate gradations between the boundary lines that we have first drawn. (III, 57)

Third—and this is harder to put in words—Lyell's method is quirky and fascinating. It makes you think. It stands against all traditions of the field, from his day to our own. Paleontologists are devoted to specifics. Professionals become experts on particular groups at particular times; we receive advanced training by apprenticeship to authorities, and we spend years learning the taxonomic details of our chosen group. We expect to resolve stratigraphic problems by using this expertise-to identify this stretch of time because Joe the brachiopod lives there, and that interval because Jill the bryozoan inhabits its strata.

"Charles Lyell's dream of a statistical paleontology" (the apt title of Rudwick's fine analysis, 1978) stands against this tradition of particulars. It applies to the quirky world of history the generality of an abstract process, regular as the ticking of a clock (albeit with random fluctuations). Such marriages of dissimilar partners (methods of one domain with alien particulars of another) are often among the most fruitful of intellectual unions.

This understanding of Lyell's ingenious method for dating the Tertiary also permits us to grasp the rationale and organization behind the last two volumes of the Principles of Geology, for both are centered upon Lyell's attempt to apply time's cycle as a working method of history. We may view volume II, with some simplification, as a long defense of "species as particles" in a world of time's stately cycle-setting up, if you will, the metaphor of the beanbag. With this key, we understand Lyell's true design and do not misread him as an old fuddy-duddy castigating evolution even before Darwin tried to make the idea popular.

Chapters 1–4 of volume II, Lyell's attack on Lamarck and the entire concept of evolution, argue that species are particles, not tendencies or arbitrary segments of a continuous flux. Species are beans in nature's bag. In the closing words of chapter 4: "It appears that species have a real existence in nature, and that each was endowed, at the time of its creation, with the attributes and organization by which it is now distinguished" (II, 65).

Chapters 5–8, on geographic distribution, claim that species arise at particular places, in foci of origin. Again, they are not general tendencies, but particular things-beans that enter the bag as unique items at definable moments. Lyell writes that "single stocks only of each animal and plant are originally created, and that individuals of new species do not suddenly start up in many different places at once" (II, 80).

Chapters 9–10 then discuss the principle of perfect fit to prevailing environment, the branding of each bean with its distinctive[8] signature: "the fluctuations of the animate and inanimate creation should be in perfect harmony with each other" (II, 159). Finally, chapter 11 argues that introduction of new species compensates for gradual loss of old forms-the beanbag remains in dynamic balance, always full but changing in composition: "the hypothesis of the gradual extinction of certain animals and plants and the successive introduction of new species" (III, 30).

Volume III is an excursion through geological time—an application of Lyell's methodology to the earth's actual history. But

8. Lest this claim seem inconsistent with Lyell's reverie about returning ichthyosaurs, I note that he chose his words with consummate care. The famous passage, caricatured by De la Beche, states: "then might those genera of animals return," not "then might those species . . ." The difference is crucial, not trivial. Genera, to Lyell, are arbitrary names for anatomical designs; species are unique particulars. The returning summer of the great year might inspire the origin of a creature sufficiently like Jurassic ichthyosaurs that taxonomists would place it in the same genus. But the returning ichthyosaur would be a new bean, with distinctive characters marking it as a unique species.

nineteen of its twenty-six chapters chronicle the Tertiary and most others discuss Tertiary problems prominently. The volume ends with a sixty-page appendix, reproducing *in toto* Deshayes's charts for the duration of Tertiary mollusks and the percentage of living species in each stratigraphic unit. We have no trouble detecting Lyell's main interest; for this is no impartial text, allotting space in proportion to time or preserved strata.

Most working geologists could tell you that Lyell named the epochs of the Tertiary. They know this as a curious little fact, proving that the apostle of uniformitarianism also did some field- work. If we could only learn to grasp the intimate—indeed necessary—connection of this achievement with his vision of time's cycle, then we would understand the power of Lyell's system. Lyell broke through the sterility of Hutton's ahistorical view, and showed that the vision of time's stately cycle could serve as a research tool for geology's basic activity, the ordering of events in time. Lyell's system works because we inhabit a world of history—by the primal criterion of uniqueness, based on temporal context, for each phenomenon. Charles Lyell was the *historian* of time's cycle.

The Partial Unraveling of Lyell's World View

Retreating from the Uniformity of State, or Why Lyell Became an Evolutionist

Mountains arise and erode through time—"the seas go in and the seas go out," as the old geologists' motto proclaims. Uniformity of state might well describe physical history. But Lyell's extension of time's cycle to the history of life had always seemed implausible to most colleagues—especially in the light of human origins at the very summit of time's mountain. Lyell had provided a rationale for nonprogressionism in life's history (see pages 137–142), but his arguments were shaky on both theoretical and empirical grounds. Thus, when Lyell, late in his career, finally surrendered his uncompromising commitment to time's cycle, he capitulated by admitting, albeit with great reluctance, that apparent progress in life's history was also a reality after all.

Lyell held firm for more than twenty years, from the first edition of the *Principles* in 1830 to his last defense of nonprogression in an anniversary address as president of the Geological Society of London in 1851. But twenty years of exploration had uncovered no Paleozoic mammals, and his old argument—that we had no right to expect any while our knowledge of Paleozoic times rested upon just a few oceanic sediments of limited geographic extent—became less and less defensible as studies of Paleozoic geology spread into eastern Europe and North America. Lyell began to waver, and eventually, during a painful process extending through the 1850s, he surrendered.

While Lyell believed that no human remains, or even artifacts, graced the geological record, he could view *Homo sapiens* as God's addition of the last moment. But as undoubted artifacts were unearthed from the youngest strata, Lyell could no longer deny that human origin had been an event in the ordinary course of nature. How could he then deny progress as a guiding principle? Thus, when Lyell gathered his material on human history into a separate volume in 1862 (*On the Geological Evidences of the Antiquity of Man*), he wrote that progress in life's history was "an indispensable hypothesis . . . [which] will never be overthrown."

As for the Principles, Lyell had published his ninth edition in 1853, last to defend the strict version of time's cycle. He then waited thirteen years, far longer than the time to any previous revision, to bring forth the tenth edition in 1866—the first to announce his retreat. I have no doubt that this long interval records his growing doubt and confusion, his unwillingness to commit himself once again in print until he had resolved this crucial dilemma. The eleventh edition, last of Lyell's lifetime, appeared in 1872, with only minor revisions from his key capitulation in 1866.

Chapter 9 of this last edition still treats the same subject—"theory of the progressive development of organic life"—ut this time Lyell assents. In the summary of his closing paragraph, Lyell finally untangles the conflation of methodological and substantive uniformities that had fueled his rhetoric for forty years—and admits that a scientist can accept progression in life's history while holding firm to the uniformities of law and process:

But his reliance need not be shaken in the unvarying constancy of the laws of nature [uniformity of law], or in his power of reasoning from the present to the past in regard to the changes of the terrestrial system [uniformity of process], whether in the organic or inorganic world, provided that he does not deny, in the organic world at least, the possibility of a law of evolution and progress. (1872, I, 171)

Lyell tries to mitigate the meaning of his conversion, depicting it as a minor shift imposed by evidence, and characterizing his former denial of progress as simple skepticism based on insufficient data, but we can scarcely credit this minimization of change. For, by admitting progress in life's history, Lyell surrendered both his vision and all its sequelae, including his dream of a statistical paleontology.

The dates of the successive appearance of certain classes, orders, and genera, those of higher organization always characterizing rocks newer in the series, have often been mis-stated, and the detection of chronological errors has engendered doubts as to the soundness of the theory of progression. In these doubts I myself indulged freely in former editions of this work. But after numerous corrections have been made as to the date of the earliest signs of life on the globe, and the periods when more highly organized beings, whether animal or vegetable, first entered on the stage, the original theory [progressionism, not uniformity of state] may be defended in a form but slightly modified. (1872, I, 145)

I believe that Lyell's retreat and surrender usually receive a backward interpretation—another unfortunate result of our anachronistic tendency to impose Darwin's theory of natural selection upon older debates and then to interpret them as part of a great dichotomy between evolution and creation. This reading holds that evolution provoked Lyell's reconsideration—and that his personal linkage of transmutation with progress[9] forced his reassessment once Darwin had convinced him to accept evolution. Lyell was, of course, one of Darwin's principal friends and confidants, a party to the "delicate arrangement" that printed Wallace's separate discovery of natural selection along with an earlier unpublished manuscript of Darwin's, thus affirming Darwin's priority. Charles Darwin was instrumental in provoking Lyell's assent to evolution, and this reversal also enters the 1866 revision of *Principles.*

But a remarkable series of documents—seven private journals "on the species question" compiled by Lyell between 1855 and 1861 and first published by L. G. Wilson in 1970—forces us to reverse this conventional argument toward a new interpretation that makes more sense in terms of human psychology, as usually expressed.

The notebooks record that Darwin first broached his theory to Lyell during a visit at Down in April 1856. (Lyell knew, of course, that Darwin had been working on "the species problem," and that he accepted the common heresy of evolution, but Darwin had not previously revealed his mechanism of natural selection to Lyell.) The journals also show that Lyell was already obsessed with doubt about his linchpin of nonprogressionism in life's history. All accumulating evidence tended to refute his conviction, particularly the discovery of human artifacts in young sediments. He had already, before Darwin's revelation, come to the most reluctant conclusion

9. This, in itself, underscores a curious point. No logical necessity can extract an implication of progress from the fact of evolution. Darwin himself had maintained a very ambiguous attitude toward the idea of progress, accepting it provisionally as a feature of parts of the fossil record, but denying that the theory of natural selection—a statement about adaptation to shifting local environments— required organic advance. Nonetheless, many evolutionists have always viewed the concepts of progress and transmutation as necessarily connected, and Lyell, for whatever reason, certainly adopted this view. Therefore, for him, a decision to embrace evolution also entailed progress as a fact: "The progression theory, which accounts for man being improved out of an anthropomorphous species, is natural the moment we embrace the Lamarckian view" (in Wilson, 1970, 59).

of his professional life—that he would probably have to abandon this anchor of his central vision.

What does a man do in die face of such sadness? I suggest diat he usually attempts to cut his losses and to beat a minimal retreat. Evolution served Lyell as touchstone for this minimal retreat. Lyell didn't accept evolution because Darwin persuaded him, or because he found the theory of natural selection so powerful; he finally embraced transmutation because it permitted him to preserve all other meanings of uniformity, once accumulating evidence had reluctantly forced him to accept the fact of progress in life's history.

If Darwin impressed Lyell with natural selection, the notebooks record no hint. These private jottings are distinguished by Lyell's nearly total lack of interest in mechanisms of evolutionary change— a decidedly peculiar attitude if Lyell wavered because Darwin's theory had convinced him. The entries record a few passages of criticism, for Lyell never accepted natural selection, much to Darwin's disappointment. I particularly like Lyell's Hindu metaphor, so well expressing the classical objection that natural selection may act as an executioner of the unfit, but cannot create the fit: "If we take the three attributes of the deity of the Hindoo Triad, the Creator, Brahma, the preserver or sustainer, Vishnu, and the destroyer, Siva, Natural Selection will be a combination of the two last but without the first, or the creative power, we cannot conceive the others having any function" (in Wilson, 1970, 369).

The notebooks instead, with almost obsessive repetitiveness, record Lyell's struggle about progress in life's history—particularly his supreme reluctance to place human origins into nature's ordinary course. Yet, when finally forced to admit both the fact of progress and the inclusion of humans in life's standard sequence, what strategies could Lyell adopt to explain his retreat? He imagined only two alternatives—he could either accept the progressionist creed *in toto,* and admit both extraneous laws of progress and (most distasteful of all) perhaps even periods of mass extinction with subsequent recreation at higher levels of complexity; or he could explain the same phenomenon of progress as a consequence of evolution. A key passage reveals that Lyell's distress centered on the fact of progress, and that he viewed evolution as a more acceptable explanation for life's advance than old-fashioned progressionism in its unvarnished form:

There is but little difference between the out and out progressionist and Lamarck, for in the one case some unknown *modus* operandi called creation is introduced and admitted to be governed by a law causing progressive development and by the other an extension or multiplication by Time of the variety-making power is adopted instead of the unknown process called Creation. It is the theory of a regular series of progressively improved beings ending with Man as part of the same, which is the truly startling conclusion destined, if established, to overturn and subvert received theological dogmas and philosophical reveries quite as much as Transmutation . . . There seems less to choose between the rival hypotheses [evolution and progressionism] than is usually imagined, (in Wilson, 1970, 222–223)

I regard this last statement (repeated with little variation many times throughout the journals) as the key to Lyell's conversion. He does not accept evolution because facts proclaim it—for he finds little to choose between evolution and progressionism as an explanation for the phenomenon of improvement, now reluctantly admitted. Why, then, prefer evolution?

Lyell's answer seems clear in the journals: evolution is the fallback position of minimal retreat from the rest of uniformity, once life's progress be admitted. If progressionism be embraced, the uniformity of rate will be threatened as well because mass extinction had long been the foundation of progressionist mechanics. Even the uniformity of law might be challenged, if an essentially mysterious process of creation be advocated as the cause of origin (remember that Lyell had never been a creationist, but agnostic about modes of origin for new species). And what about the uniformity of process? Since the creative power operates intermittently and has never been observed on our planet, how can we learn about it by actualist procedures?

But with evolution, Lyell could shore up his defenses and relinquish only one of the uniformities—his beloved time's cycle to be sure, but better one room than the entire edifice. With evolution, he could hold firm to uniformity of rate, especially with Darwin's congenial commitment to such a strict form of *natum non facit saltum* (nature does not make leaps). He could also continue to embrace both the uniformity of law, for evolution "has the advantage of introducing a known general Law, instead of a perpetual intervention of the First Cause" (in Wilson, 1970, 106)— and actualism, for Darwin insisted that small-scale changes produced by breeders and planters were, by extension, the stuff of all evolutionary change.

In short, Lyell accepted evolution in order to preserve his other three uniformities, thereby to retain as much of his uniformitarian vision as possible, when facts of the fossil record finally compelled his reluctant allegiance to progression in life's history. Although I interpret Lyell's embrace of evolution as the most conservative intellectual option available to him, we must not diminish the pain and trouble of mind that it provoked. Consider this remarkable passage, with its resplendent affirmation of both human intellect and basic honesty before the world's complexity:

Species are abstractions, not realities—are like genera. Individuals are the only realities. Nature neither makes nor breaks molds— all is plastic, unfixed, transitional, progressive, or retrograde. There is only one great resource to fall back upon, a reliance that all is for the best, trust in God, a belief that truth is the highes aim, that if it destroys some idols it is better that they should disappear, that the intelligent ruler of the universe has given us this great volume as a privilege, that its interpretation is elevating, (in Wilson, 1970, 121)

The Uniformity of Rate

Since Lyell finally abandoned time's cycle for life's history, this linchpin of his original vision has dropped from sight; few practicing geologists are aware that Lyell ever espoused uniformity of state, and they do not understand the theory of their founding father because they do not recognize its keystone.

But gradualism, or uniformity of rate, experienced a different fate. If anything, Lyell strengthened his commitment to this other substantive uniformity by accepting evolution in Darwin's gradualistic version. Uniformity of rate has therefore persisted to our present day, not always embraced by geologists, but understood as Lyell's vision. Unfortunately, Lyell's trope of rhetoric has also descended in unmodified form—his conflation of method and substance. For more than a century, many geologists have been stifled— the range of their hypotheses falsely channeled and restricted—by a belief that proper method includes an a priori commitment to gradual change, and by a preference for explaining phenomena of large scale as the concatenation of innumerable tiny changes.

Lyell's own attempts to base a research program on uniformity of rate failed when his statistical method for zoning the Tertiary foundered upon inconsistent criteria among experts for the designation of species (Rudwick, 1978) and, especially, when he could not extend his method beyond the Tertiary to formulate a general practice rooted in time's stately cycle. If uniformity of rate really applied to the introduction of species—if life's beanmaster introduced and removed these basic units at a stochastically constant rate—then Lyell could have extended his method to the abyss of time. Few modern species could be found in Eocene rocks (defined as 3 percent of modern forms), and none in earlier strata. But, in principle, new baselines could be established to push Lyell's method further back—one might, for example, tabulate the list of Eocene species and then zone the Secondary strata by percentage of species still living in the Eocene.

Lyell did envision just such a procedure. With courage, he designated a difficult, and potentially disconfirming, case as a potential test for his statistical paleontology based on time's stately cycle. He noted a disabling impediment for any scheme of dating Secondary strata by percentage of species still living in Eocene times (first division of the Tertiary). He studied the Maastricht beds, top units of the Secondary, and noted that they contained not a single species also found in Eocene strata. But what could produce such a discordance, for Eocene rocks lay directly atop the Maastricht? In Lyell's world of gradualism, this peculiar circumstance could bear only one interpretation—an immense period of nondeposition, longer than the entire Tertiary, must separate Maastricht and Eocene beds. The beanmaster's cycle had run an entire course during this interval of no preserved evidence:

There appears, then, to be a greater chasm between the organic remains of the Eocene and Maastricht beds, than between the Eocene and Recent strata; for there are some living shells in the Eocene formations, while there are no Eocene fossils in the newest secondary group. It is not improbable that a greater interval of time may be indicated by this greater dissimilarity in fossil remains . . . We may, perhaps, hereafter detect an equal, or even greater series, intermediate between the Maastricht beds and the Eocene strata [than between Eocene and Recent]. (III, 328)

A gutsy prediction required by time's stately cycle, but wrong as we now know. Lyell's catastrophist opponents had long advocated an obvious alternative: no huge gap in time separates Maastricht and Eocene beds; rather, a catastrophic episode of mass extinction marked the end of Secondary times—and this great dying, rather than an immensity of interpolated time based on no evidence, explains the discordance of faunas. We now know that the catastrophists were right. The Cretaceous-Tertiary transition (as we now call it) stands among the five great episodes of mass extinction that have punctuated the history of life. It removed the dinosaurs and their kin, along with some 50 percent of all marine species.

Lyell's gradualism has acted as a set of blinders, channeling hypotheses in one direction among a wide range of plausible alternatives. Its restrictive effects have been particularly severe for those geologists who succumb to Lyell's rhetorical device and believe that gradual change is preferable (or even required) a *priori* because different meanings of uniformity are necessary postulates of method. Again and again in the history of geology after Lyell, we note reasonable hypotheses of catastrophic change, rejected out of hand by a false logic that brands them unscientific in principle. Thus, J Harlen Bretz's correct hypothesis for the formation of Washington's channeled scablands by catastrophic flooding was long dismissed by uniformitarians, who sought more time and many smaller rivers on little basis beyond a stated repugnance for catastrophes (several detractors at the famous 1927 confrontation between Bretz and scientists of the U.S. Geological Survey admitted that they had never visited the area, but were quite willing to propose gradualist alternatives as preferable *a priori*—see Baker and Nummedal, 1978; Gould, 1980). And the *New York Times,* in its editorial pages no less, has proclaimed that extraterrestrial impact as a catastrophic cause of the Cretaceous-Tertiary extinction has no place in science: "Terrestrial events, like volcanic activity or change in climate or sea level, are the most immediate possible cause of mass extinctions. Astronomers should leave to astrologers the task of seeking the causes of earthly events in the stars" (April 2, 1985).

Yet the Alvarez hypothesis of asteroidal or cometary impact is a powerful and plausible idea rooted in unexpected evidence of a worldwide iridium layer at the Cretaceous-Tertiary boundary, not developed from an anti-Lyellian armchair. It must be tested in the field, not dismissed a priori. In this light, and as a final example of how Lyell's rhetorical confusion might stifle legitimate research, I note Lyell's harsh dismissal of the seventeenth-century scientist William Whiston, because he dared to promote comets, and not earthly agents alone, as sources of geological change. Comets, I note, are now a favored mechanism for mass extinction under the Alvarez hypothesis: "He [Whiston] retarded the progress of truth, diverting men from the investigation of the laws of sublunary nature, and inducing them to waste time in speculations on die power of comets to drag the waters of die ocean over the land—on the condensation of the vapors of their tails into water, and other matters equally edifying" (I, 39).

Most geologists, especially if they believe the textbook cardboard they read as students, think that Lyell was the founder of modern practice in our profession. I do not deny that Principles of Geology was the most important, the most influential, and surely the most beautifully crafted work of nineteenth-century geology. Yet if we ask how LyelPs controlling vision has influenced modern geology, we must admit that current views represent a pretty evenly shuffled deck between attitudes held by Lyell and the catastrophists. We do adhere to Lyell's two methodological uniformities as a foundation of proper scientific practice, and we continue to praise Lyell for his ingenious and forceful defense. But uniformities of law and process were a common property of Lyell and his catastrophist opponents— and our current allegiance does not mark Lyell's particular triumph.

As for substantive uniformities of rate and state, our complex and multifarious world says yes and no to bits of both. Lyell himself abandoned uniformity of state for life's history, while a primary thrust of modern research into Precambrian strata (the first five- sixths of our earth's history!) tries to identify how die early earth differed—in sedimentary consequences of an atmosphere devoid of oxygen, for example—from the current order of nature. The great geologist Paul Krynine once called "uniformitarianism" (but meaning only uniformity of state) "a dangerous doctrine" because it led us to deny or underplay these early differences (Krynine, 1956). Even uniformity of rate, Lyell's stronger and more persistent argument, has suffered increasing attack as a generality. In the history of life, for example, alternative punctuational styles of change have been advocated at all levels—from the origin of species (punctuated equilibrium) to the overturn of entire faunas (catastrophic hypotheses of mass extinction).

Lyell, by the power of his intellect and the strength of his vision, deserves his status as the greatest of all geologists. But our modern understanding is not his, either unvarnished or even predominantly, but rather an inextricable and even mixture of uniformitarianism and catastrophism. Lyell won a rhetorical war, and cast his opponents into a limbo of antiscience, but we have been compelled to balance his dichotomy—because time's arrow and time's cycle both capture important aspects of reality.

Epilogue

Most working scientists are notorious for their lack of interest in history. In many fields, journals more than a decade old are removed from library shelves and relegated to microfiche, to unheated attics, or even to the junkpile.

During the summer of 1972, I met in Woods Hole with three of the best young-Turk paleontologists and ecologists of our day— Dave Raup, Tom Schopf, and Dan Simberloff. We were trying, immodestly to be sure and with limited success as it happened, to find a new approach to the study of life's history. We wanted to break away from a paleontological tradition that we found stultifying—a training that made professionals into experts about particular groups at particular times in particular places, and seemed to discourage any development of general theories that might be expressed in testable and quantitative terms. We decided to work with random models of origin and extinction, treating species as particles with no special properties linked to their taxonomic status or time of flourishing. As we proceeded, we realized that our models bore remarkable similarity in concept to Lyell's method for dating the Tertiary. Indeed, we recognized that his vision of time's stately cycle had become the ground of our proposal. And so, for several hours, four young scientists out to change the world sat around a table and talked about Charles Lyell.

My colleague Ed Lurie, distinguished scholar of Louis Agassiz, once told me that he had tried to escape Agassiz for years, and to branch into other areas of nineteenth-century American biology. But he couldn't, for Agassiz loomed so large that his shadow extended everywhere. Any exploration of any subfield in American biology became, at least in part, a study of Agassiz's influence.

I feel much the same way about Charles Lyell. I have made no active effort to avoid him, but neither do I court his presence. Still, I cannot escape him. If I recognize a baleful influence of his rhetoric, my quest for a different formulation still embraces another aspect of his vision. Thus, when Eldredge and I developed the theory of punctuated equilibrium, we tried, above all, to counteract both Lyell's bias of gradualism and his method of probing behind appearance to defend the uniformity of rate against evidence read literally—for punctuated equilibrium, as its essential statement, accepts the literal record of geologically abrupt appearance and subsequent stasis as a reality for most species, not an expression of true gradualism filtered through an imperfect fossil record. We felt mighty proud of ourselves for breaking what we saw as a conceptual lock placed by Lyell's vision upon the science of paleontology. But then, from another point of view, what is punctuated equilibrium but a nongradualist view of evolutionary theory applied to Lyell's *original* vision of species as discrete particles, arising at geological moments in space and time, and persisting unchanged until their extinction? Lyell had compromised this vision by embracing a gradualist account of evolution to salvage his uniformities, but we had been driven back to his original formulation. We had, it seemed, attacked Lyell in order to find him.

I could drown you in words—indeed I already have—about the power and importance of Lyell's vision. But any scientist will tell you that utility in practice is the only meaningful criterion of success. I can offer no greater homage to Charles Lyell than my personal testimony that he doth bestride my world of work like a colossus.