Martin J. S. Rudwick

WORLDS *Before* ADAM

The Reconstruction of Geohistory in the Age of Reform

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INTRODUCTION

In February 1822, at three successive weekly meetings of the Royal Society in London, a large audience of its Fellows and their guests listened with fascination as William Buckland, the first reader in geology (and self-styled professor) at Oxford, described how he had reconstructed a den of large extinct hyenas, and their meals of mammoth steak, water rats, and other delicacies, in what had since become a quiet corner of rural Yorkshire. The Society's president, the chemist Humphry Davy, told Buckland he could not recall any paper that had aroused so much interest. Later in the year it was published in the Society's *Philosophical Transactions*, the world's oldest and most prestigious scientific periodical; and the Council decided to give Buckland the Copley Medal, the Society's highest award, in recognition of his paper's outstanding value and importance.

Buckland's "hyaena story" about Kirkdale Cave was used in my book *Bursting the Limits of Time* as the culmination of a narrative that spanned several previous decades of research in the sciences of the earth. Buckland's reconstruction of a vanished ecosystem in recent geohistory (to borrow useful terms from modern biologists and geologists respectively) was seen at the time as a sensational foretaste of what the great Parisian naturalist Georges Cuvier had eloquently set out, just ten years earlier, as a worthy and attainable goal for the new science of geology. "Would it not be glorious", Cuvier had asked rhetorically, for geologists to "burst the limits of time", just as astronomers had "burst the limits of space"? The allusion was not to the expansion of traditional conceptions of the magnitude of either time or space, but to the extension of reliable human knowledge in both dimensions, beyond the limits of direct human experience. Astronomers, although physically confined to one small planet, had already learned to calculate the motions of the whole solar system, and were even reaching beyond it to the stars in the inconceivable vastness of deep space. In the same way, geologists, although physically confined to the present moment, could hope to penetrate back into the inconceivable vastness of deep time, and to reconstruct the earth's own history—geohistory—with a similar degree of confidence and reliability. As portrayed in a celebrated caricature, Buckland, by crawling into Kirkdale Cave with the light of science in hand, had burst the temporal limits of recorded human history and penetrated back into the "antediluvial" world of the extinct cave hyenas (see figure opposite page 1). And this, as Davy recognized, was just a beginning: Buckland had shown by his example that geologists had now developed a conceptual time-machine, which could also be used to explore far earlier periods of geohistory.

The present book is a sequel to *Bursting the Limits of Time*, but it is self-contained and should be wholly intelligible to readers who have not seen the earlier volume. All the main characters carried over from the earlier narrative are introduced again, however briefly, for the sake of those who have not yet encountered them; so are the main empirical issues that were the stuff of the earlier debates. I have tried to make this book, like the earlier one, accessible both to readers who are unfamiliar with the historical period it covers, and to those who know little about geology. So I hope it will also be found intelligible by those who have no great background knowledge in either direction, but who are curious to know how the main outlines of the earth's own complex history were first reconstructed. And, as I emphasized before, no one should be put off by the small print of the footnotes: they give the detailed information that some readers will need, particularly on sources, and they add ancillary points that would disrupt the main text, but the book should be wholly comprehensible without looking at any of them.

In the earlier volume I traced the gradual development of the practice of geohistory within the sciences of the earth. In the late eighteenth century it was an infrequent and marginal feature of scientific research, but within a few decades it became a defining element of a newly named science of "geology". I argued that geology became the first truly *historical* natural science; and that it did so as a result of deliberately transposing methods and concepts from the human sciences of history itself. The earth's own immensely lengthy history, almost all of it apparently prehuman, then began to seem reliably knowable. By the time Buckland reconstructed his antediluvial hyena den, geohistorical ways of thinking were becoming so deeply embedded in the practice of geology that the explicit analogies with human history—the telling metaphors of *nature's* monuments and documents, *nature's* coins and inscriptions, *nature's* archives and chronologies—were beginning to drop out of scientific discourse, though they remained valuable as illustrative analogies whenever geologists sought to reach a wider audience.

The present volume takes as its starting point this sense that the earth's deep or prehuman geohistory could in principle be reconstructed almost as reliably as, say, the history of the ancient Greeks and Romans. The narrative takes a new tack, however, in that its focus is now on the character of the geohistory that this novel perspective disclosed; or, in other words, on what geologists discovered as they deployed their virtual time-machine. Of course, the research described in my earlier volume did often suggest what the course of geohistory had been like; but generally it did so either with a very broad brush, covering the whole globe in outline, or else in a detailed local vignette such as that of antediluvial Yorkshire. Furthermore, priority was quite properly given to establishing the sheer historical reality of the events of the deep past, shelving if necessary the problems of discovering their causal explanation. It seemed more important, for example, to establish that in recent geohistory there had indeed been some kind of geological "revolution"—which had apparently wiped out the cave hyenas and mammoths—and to determine its approximate date and physical character, rather than speculating how exactly it might have been caused. However, during the years covered in the present volume the geohistorical and the causal were increasingly brought together and integrated. By the end of this period—that is, well before the middle of the nineteenth century—geologists had reconstructed a consistent outline of geohistory with plausible causal explanations of many of its main features; and this geohistory was at least congruent with, and in some respects foreshadowed quite precisely, what is accepted as valid by geologists in the twenty-first century.

The narrative in this volume, then, covers a later period than its predecessor (with a little overlap to ensure continuity). It spans the quarter-century from about 1820 to about 1845. Put another way, it starts in the aftermath of the Napoleonic era in European history, and it extends into the earliest years of Britain's Victorian age and equivalent phases in the history of other nations. As a convenient label for this period, my subtitle borrows from political historians the phrase "the Age of Reform": the Great Reform Bill in Britain and the July Revolution in France, for instance, lie neatly near the middle of my chosen quarter-century. As in my previous volume, however, I do not intend this definition to imply that the political was necessarily the most important element in the context of the scientific work: the period covered by the present volume might also be defined—perhaps with no less relevance—as stretching from Schubert to early Verdi, from Scott to early Dickens, or as that phase of the Industrial Revolution that saw the coming of railways, steamships, and the electric telegraph. Although geology was already firmly established by the start of this quarter-century, it was a period marked by exceptionally intensive and innovative research, which was of outstanding importance for all the later history of the science. This justifies devoting a substantial volume to its tangled debates.

Apart from the period it covers, however, this book adopts much the same parameters as *Bursting the Limits of Time*, and they can be summarized here quite briefly. First, and somewhat negatively, I should emphasize again that I do not claim to offer a comprehensive history of geology, even within my chosen period. I make no attempt to describe or analyze the whole range of geological research; many important topics are mentioned only in passing or not at all, simply because they did not impinge directly or substantially on the reconstruction of geohistory. Even with that restriction, it would not be possible to cover all the relevant work, much of which—in ever increasing volume—was reported in a burgeoning range of scientific periodicals published throughout Europe (and a few beyond it, in Russia, the United States, and elsewhere). So my policy has once again been to trace and analyze those topics that were either *innovative* or *exemplary*, and to let them represent a far larger body of relevant research.

Second, I hope that this volume, like its predecessor, will help to correct an overwhelmingly anglocentric and anglophone bias in much of the historiography of geology. I try to replicate the highly international outlook and interactions of the leading scientific figures, by describing research that was being done in all the main scientific nations, which at this period meant primarily those in Europe (including Britain, of course, as a constituent part of Europe). It was France, however, that remained dominant in all the sciences, as in many other aspects of cultural life, despite the military defeat of its Napoleonic regime; and French remained the preeminent scientific language worldwide. France and the French language had, respectively, much the same positions as the United States and the English language in today's scientific world. But their primacy was just beginning to be challenged, not so much by Britain but rather by the still politically fragmented German-speaking lands; by the end of the century it was German rather than English that had overtaken French to become the dominant language for serious scientific research. Those who practiced any of the natural sciences outside Europe—for example, in Russia to the east or the United States to the west, let alone in still more remote parts of the world—were, and knew themselves to be, very much on the periphery; their work was valued primarily as factual evidence for the theoretical or interpretative debates that were taking place in Europe.

Third and last, as this implies, my focus once again is on the work and interactions of the leading scientific figures—those doing original research of international significance—rather than, say, amateur naturalists or the general reading public, let alone still wider classes of society. This book is, without apology, an elitist account of certain aspects of the science of geology at one of its most innovative periods; but this particular elite was based not on birth or wealth or social class, but primarily on intellectual effort and originality. Studies of popular science have their rightful place in scholarly work on the history of the sciences, but they are no substitute for the study of the original scientific research that gave the popularizers most of their raw material. Scientific popularization is no longer treated by historians simply as a story of diffusion *de haut en bas*: popularizers made creative use of what they found available, and refashioned it—sometimes in directions opposed to the original authors' intentions—for their own varied purposes. But in doing so their work was derivative from, and therefore secondary to, the original research that they sought to make accessible and meaningful to a wider audience.

There is therefore a strong case for giving as much historical attention to elite science as to popular science, if not more. For the topic of the present volume, as for that of its predecessor, this is an urgent necessity, because historical research on the earth sciences in the crucial period of the late eighteenth and early nineteenth centuries is still quite patchy and often seriously defective. This is in striking contrast to our historical understanding of other sciences in the same period. To mention just one example, scholars in the so-called "Darwin industry" have reconstructed in impressively thorough detail, and in its full intellectual and social context, the circumstances in which Darwin's evolutionary theory first took shape (also largely in the Age of Reform). This research has provided reliable foundations for valuable studies of the popular presentation, reception, and application of evolutionary ideas, both then and later in the nineteenth century, far beyond the circles of the scientific elite. There is much comparably fine research on the physical sciences in the same period. Geology, however, remains a Cinderella in the historical study of the sciences.

To mention Darwin and evolution in a context of the history of geology is to evoke, with seeming inevitability, images of "conflict" between geology and Genesis, or more generally between allegedly monolithic entities labeled "Science" and "Religion". In the introduction to *Bursting the Limits of Time* I mentioned briefly why this kind of historiography has long been abandoned by historians, although it remains popular in the modern media, and above all in the rhetoric of those self-appointed spokespersons for "Science" who are, in effect, atheistic fundamentalists. Here it is necessary only to emphasize that *all* the geologists with whom this book is concerned were convinced that geohistory had been played out on a timescale of humanly inconceivable magnitude (though they had as yet no means to put reliable figures to it). The many who were also religious believers saw no conflict between their geology and their understanding of the Creation stories in Genesis; they had long since learned that it was a *religious* mistake to treat biblical texts as if they were scientific sources, because an inappropriate literalism deflected attention away from religious meaning. It is true that some of these geologists, particularly in England, had to confront vocal critics—the self-styled "scriptural" writers—who relentlessly pursued a literalist line on matters of "geology and Genesis". But this, like the modern and peculiarly American phenomenon of creationism and other forms of religious fundamentalism, was a contingent feature of a particular time, place, and, above all, social location. In keeping with the focus adopted for this book, these issues will not be described or analyzed here, except when and where they impinged directly on the work of the scientific elite, rather than on its more general handling of its relations with the wider public; the latter is an important topic in its own right, but it is a different topic and it deserves separate treatment.

Toward the end of this book, Darwin himself comes on stage, but as a young and promising *geologist*, the role in which he first made his name and earned respect as a "man of science". As in *Bursting the Limits of Time*, I want to claim that the reconstruction of geohistory—within which the history of life or "biohistory" was just one major theme among several—was an outstanding intellectual achievement in its own right, and one that was only loosely linked to the search for a causal explanation of the diversity of life or of the origin of the human species. The establishment of a reliable geohistory was a part of the necessary infrastructure for any adequate evolutionary theory, but the latter was not its only outcome. All roads did not lead to Darwin. Appropriately—though without its having been my intention when first planning the book—my narrative in this volume reaches its culmination with a major phase of geological research in which Darwin's contribution was one that he himself later repudiated as "a great failure" and even as "one long gigantic blunder". My purpose in describing this episode is not to topple Darwin from his well-deserved historical pedestal, but simply to situate him in the scientific debates of his time. Like many outstanding scientists in the modern world, he did not always get everything right.

Darwin's failure when tackling one specific puzzle was in fact a minor episode within a much larger and more important (and international) story. This volume culminates in an account of research that vividly suggested how the earth's own history—no less than the human history that had once been its conceptual template—was intrinsically unpredictable (or, more correctly, unretrodictable), because it was ineluctably *contingent*. It became clear that at every turn, geohistory could conceivably have taken a different course, without impairing in any way the uniform action of the underlying "laws of nature". In consequence—and again as in human historiography—it could be reconstructed only bottom-up from a detailed study of surviving evidence of what had *in fact* happened, rather than top-down by the application of fixed laws of nature to determine what supposedly "must" or "should" have happened. As one of the most distinguished polymaths of the time recognized explicitly—and this forms the finale of the volume—geology had become the outstanding exemplar of a new *kind* of natural science, in which the historical dimension was central and constitutive. That *nature has had its own history* was a lesson already well learned by the young Darwin, when he transposed that insight from geology, his first love, to zoology and botany. Animals and plants, no less than mountains and volcanoes, glaciers and oceanic islands, could be fully understood only by taking into account the histories built into them. But Darwin's is another story.

To summarize: the scientific research described in my previous volume demonstrated that it was feasible in principle to gain reliable knowledge of the earth's history long before the earliest human records, and thereby to "burst the limits of time". The geologists whose research is described and analyzed in the present volume, spanning a subsequent quarter-century of exceptional fertility and importance for the future of the earth sciences, were able to take this approach for granted. They went on from there to reconstruct systematically and in detail what course geohistory had in fact taken, to reach the earth's present state. On a timescale that they agreed had been of inconceivable (though unquantifiable) magnitude, they plotted a sequence of distinctive periods and eras in geohistory, most strikingly distinct in the kinds of animals and plants that had flourished successively on earth. Many other long-term changes, for example in global geography and climate, were more problematic and controversial, as was the reality or otherwise of occasional episodes of rapid or even catastrophic change. However, what seemed a cumulatively reliable conclusion was that, in one way or another, the earth had had a highly eventful *history*, passing through many different and distinctive phases, long before the present world came into existence. And almost all this complex and eventful geohistory had preceded not only the earliest written records of human history but the human species itself. In terms of the traditional archetypal figure of *ha'adam*, The Man, it was a story of a long and complex sequence of Worlds before Adam.

The first half of *Bursting the Limits of Time* was devoted to a survey of the sciences of the earth as they were being practiced around the end of the Old Regime in Europe, or on the eve of the French Revolution; this acted as a baseline for the narrative in the second half of the book. That narrative is continued in the present volume, but is arranged this time in a larger number of much shorter chapters. As before, but to an even greater extent, the narrative has to sustain several subplots running in parallel, tracing the course of different loosely linked "focal problems" within what was defined by this time as the science of geology. But I hope I have provided sufficient flashbacks, recaps, and cross-references to enable the reader to follow the intricate interweaving of the various themes and their evolving interactions: classic Victorian novels such as Charles Dickens's *Bleak House* have been my inspiration and model, though I cannot begin to match their narrative flair.

The chapters are grouped loosely into four Parts, in chronological sequence though with some overlaps. Part One describes the first postwar years (that is, post-Waterloo and post-Napoleonic) and the early 1820s, when the great Georges Cuvier was still a dominant presence in geology. Part Two deals with the immensely fruitful period of the later 1820s and earliest 1830s, during which much (though not all) of the most innovative research was shared between France and England. Part Three is focused on the pivotal figure of Charles Lyell, and describes the gestation, publication, and immediate reception of his *Principles of Geology*, in the years around 1830. Finally, Part Four follows the development of geohistorical themes through the 1830s and into the early 1840s, partly (but not wholly) in response to Lyell's provocative synthesis. My substantial focus on Lyell will surprise no one familiar with the existing historiography of geology; but I try to show how his contemporaries were, at one and the same time, profoundly critical of some aspects of his work while being profoundly impressed by others.

The narrative as a whole traces the reconstruction—at first tentative, but gradually more confident—of an eventful geohistory, which in fact is congruent with what geologists in the twenty-first century accept as valid (at least in outline, and for the Phanerozoic or post-Precambrian portion of geohistory). More specifically, the story culminates in the formulation of the glacial theory, and the utterly unexpected inference of an exceptional and drastic "Ice Age" in the geologically recent past. It was this, more than any other single development, that forced geologists to recognize the contingent character of geohistory as a whole. The Concluding (Un)Scientific Postscript (with apologies to Kierkegaard), which lies outside this narrative, considers briefly some of the broader issues that the whole work has addressed.

I should here explain the relation between this volume (and its immediate predecessor) and my earlier work on the history of the earth sciences. My first historical book, *The Meaning of Fossils* (1972), set out a first sketch of some of the debates that I now see as central to the reconstruction of geohistory, but only insofar as they affected what came to be called paleontology (the science

I had been practicing professionally when that book was conceived). Much of the present volume is founded on my subsequent research on the early work of Charles Lyell, and that of his contemporaries and critics, centered on the meaning of the "uniformity" of nature and the legitimacy of "catastrophist" explanations in geology. This research was published in a string of papers, long and short, many of them now reprinted in *The New Science of Geology* (2004) and *Lyell and Darwin, Geologists* (2005). I make no apology for citing these papers rather fully in the present volume, because they contain far more detailed documentation than can be repeated here. Three other books are also relevant, more or less tangentially: *The Great Devonian Controversy* (1985) is primarily about stratigraphy, which was (and is) a major source of evidence for geohistory, but not coincident with it; *Scenes from Deep Time* (1992) deals primarily with the wider public's apprehension of the new geohistory, and it extends into later decades; conversely, *Georges Cuvier* (1997) focuses on the earlier work of the outstanding naturalist who provides the present volume with its starting point. However, I should emphasize that I have here used many new sources (new at least to me), and have re-studied the others; and I have interpreted them all within a largely new conceptual framework, namely the *reconstruction of geohistory* mentioned in my subtitle. So the present volume is much more than just a restatement or even a synthesis of my earlier publications.

As in *Bursting the Limits of Time*, readers who feel daunted by the scale and density of this narrative can get a brief overview of its argument by reading the concluding section of each chapter, which is in fact a summary of its contents; or by looking at the illustrations and their captions, which collectively embody much of the argument in visual form; or, paradoxically, by going first to the brief Postscript at the end of the volume.

I hope that the overall narrative framework I have adopted, in preference to any division of the material into separate topics, will convey the strong sense of unity of purpose and scientific progress that the participants experienced (albeit with plenty of false starts and dead ends). Contrary to what many modern scientists wrongly imagine—that the lives of their intellectual ancestors were altogether more leisurely than their own—early nineteenth-century geologists felt in fact that they were living in stirring times, and that the science to which they were contributing was changing and developing at almost breakneck speed. We in the modern world are the beneficiaries of what they first pieced together with such imaginative scientific skill.

CHAPTER 1

Cuvier's model for geohistory (1817–25)

1.1 CUVIER'S *FOSSIL BONES*

In the peacetime era after the fall of Napoleon, the Muséum d'Histoire Naturelle in Paris (hereafter just "Muséum") remained the world's most prominent institution for research in all the sciences—animal, vegetable, and mineral—that were grouped together as natural history. A quarter-century earlier, when the Muséum was founded during the Revolution (or rather, when it was "democratized" from the old royal museum and botanic garden), it had been the first institution anywhere to give formal recognition to what was then the newly named science of "*géologie*" (*BLT* §6.3). But in the event, the Muséum's greatest impact on the sciences of the earth had come not from Barthélemy Faujas de St Fond (1741–1819), its first and rather undistinguished professor of geology, but from the much younger naturalist who became its professor of comparative anatomy, Georges Cuvier (1769–1832), Napoleon's exact contemporary. In post-Napoleonic Europe, Cuvier was the Muséum's most powerful figure and one of the most famous savants in the world (Fig. 1.1).[1]

Back in 1812, while Napoleon, the self-styled Emperor of the French, held sway over most of mainland Europe, Cuvier had produced four volumes of *Researches*

1. Fig. 1.1 is reproduced from Bultingaire, "Iconographie de Cuvier" (1932), pl. 4, reproduced in turn from Cuvier, *Discours sur les révolutions* (1826), quarto issue, frontispiece, lithographed by Charles-Louis Constans after a painting by Nicolas Jacques. The Académie was the royalist successor of the natural-scientific "First Class" of the Institut de France set up during the Revolution, at which Cuvier had presented most of his earlier research: see Crosland, *Science under control* (1992). The word "*Muséum*", with its French accent, will here serve to distinguish the great Parisian institution from any other museum or *musée*. The word "*savant*", which at the time was widely used in English and almost invariably in French, denotes all who did original work in *any* of the sciences, natural or human; its use avoids the anachronistic connotations of the word "scientist", which was first coined during the 1830s (see §25.3) but failed to gain wide acceptance until the twentieth century.

on Fossil Bones. This massive work reprinted the many specialized papers he had published in still earlier years in the Muséum's in-house periodical, the *Annales du Muséum* (*BLT* §9.3). But it was prefaced by a new, long, and eloquent "Preliminary Discourse", adapted from some earlier lectures for the general educated public in Paris, which set out his ideas not only on fossil bones and but also more broadly on geology as a whole (*BLT* §10.3). It was in this celebrated essay that he had suggested that geologists could and should aspire to "burst the limits of time" by reconstructing in reliable detail what he was convinced was a vast expanse of *prehuman* geohistory, dwarfing the totality of subsequent recorded human history.[2]

The main outlines of Cuvier's ideas, as set out in his Discourse and substantiated in the rest of his *Fossil Bones*, will be recalled here quite briefly. First, his work was indeed geohistory. He presented himself as "a new species of antiquarian", a *historian* of the earth, who was using fossil bones instead of human artifacts to recover the distant past (*BLT* §7.2, §9.3). He repudiated a project that was still going strong among his contemporaries, that of devising a high-level causal theory that would explain all the major features of the earth: the genre of "theory of the earth" (or *geotheory*, as I have named it: *BLT* §3.1) was rejected as premature (*BLT* §8.4). In its place, Cuvier proposed more limited enquiries that had some hope of being resolved; in particular, he gave priority to work that might establish the geohistorical reality of specific events in the deep past, while deferring if necessary the more knotty problems of finding their causal explanation.

Like all other scientific savants at this time, Cuvier rejected emphatically the traditional *short timescale* for the earth, which had been derived from the purely textual evidence assembled by the venerable science of "*chronology*" (*BLT* §2.5); its most famous product, James Ussher's date of 4004 B.C. for the primal Creation, had been proposed more than a century and a half earlier and was now treated as utterly outdated. But Cuvier also rejected the unlimited time, indeed the *eternity*, imputed to the world by influential *philosophes* in the Enlightenment and by some of his own contemporaries. These positions—*both* of them profoundly unmodern—were being used to support political agendas, respectively religious and anti-religious in intent. In contrast, Cuvier adopted a third (and modern) alternative, arguing that the earth was of inconceivably vast antiquity *yet not eternal* (*BLT* §8.3). He claimed that it had truly had a *history*, a sequence of distinctive events and unrepeated eras, rather than the endless repetition or recycling of more or less similar physical states that was entailed by any kind of eternalism. But he insisted that this lengthy geohistory was not co-extensive with human history; on the contrary, almost all of it had been prehuman (*BLT* §10.3).

Cuvier, like almost all savants working actively in the sciences of the earth around this time, regarded this vastly extended but finite geohistory as one of gradual directional change towards the earth's present physical state. It was generally conceived as being marked by a progressive lowering of global sea level and a consequent gradual reduction in the extent of the world's oceans; this had long been geotheory's, and geohistory's, "*standard model*" (as I have termed it: *BLT* §3.5). But in the course of this directional change, long periods of calm conditions, recorded for example by thick beds of rock containing well-preserved shells and other marine fossils, seemed to have been punctuated by occasional episodes of rapid and perhaps violent change, recorded by broken and distorted strata or by thick beds of coarse gravel (often consolidated into "pudding-stone" or conglomerate). Like many other savants, Cuvier defined these episodes as the earth's natural "*revolutions*" (*BLT* §6.1); they were often treated as analogous to the traumatic political Revolution in France, which was still fresh in the collective memory of all Europeans.

The most recent of all these physical revolutions was of decisive importance in Cuvier's understanding of geohistory. Not only were its traces the clearest to see and the easiest to interpret, because the least effaced by the passage of time. It was also of unique significance because it seemed to separate the "present world" of human civilizations from the vastly more extended "ancient" or "former world" [*ancien monde*] before the first appearance of the human species. For by this time the few alleged finds of human bones or artifacts in ancient rocks were all regarded—with good reason—as spurious or at best dubious (*BLT* §5.4); and Cuvier, adopting the role of a textual critic, also rejected the historical records that were alleged to prove a vast antiquity for certain human cultures and were even taken as evidence for the eternity of the human species itself (*BLT* §10.1).

Cuvier claimed that the most important result of his detailed work on fossil bones was to show that a whole mammalian fauna had suffered a mass extinction. On the basis of his functional analysis of the anatomy of the extinct species, he argued that they had all been well adapted to particular modes of life. So their disappearance could be explained, in his view, only as the consequence of a sudden and overwhelming revolution, and a quite recent one at that. He remained uncertain about the physical character of this decisive event; unsurprisingly so, since he was an indoor museum naturalist with little firsthand experience of the relevant field evidence. At different times he provisionally adopted either of two current alternatives. Before the turn of the century the Parisian naturalist Déodat de Dolomieu (1750–1801) had suggested that the event might have been, as it were, a "*mega-tsunami*", a huge transient wave analogous to the humanly catastrophic tsunamis that often accompany submarine earthquakes, but on a far larger scale (*BLT* §6.3). An alternative explanation, suggested by the Anglo-Genevan naturalist Jean-André de Luc (1727–1817) in publications spread over many years of his long life, was that it might have been due to the sudden collapse of parts of the earth's crust, such that the continents of "the former world" had sunk below sea level, while the former ocean floors had been left high and dry to form the present continents: in effect, a massive interchange between continents and oceans (*BLT* §3.3, §6.2). However, Cuvier's uncertainty on this point was evidently tolerable to him, because he regarded it as even more important to establish the sheer geohistorical reality of the event, one that had been catastrophic enough to wipe out a whole fauna of apparently well-adapted animal species.[3]

2. Cuvier, *Ossemens fossiles* (1812) 1, "Discours préliminaire", translated in Rudwick, *Georges Cuvier* (1997), 165–252.

3. Gaudant, *Dolomieu* (2005), which was published just too late to be cited in *BLT*, does not include among its otherwise valuable essays any assessment of Dolomieu's influential mega-tsunami theory.

Still less was Cuvier concerned to determine the physical cause of this event, though he took it for granted that it must have a natural explanation of some kind. But he rejected the idea put forward by some of his contemporaries, that there had never been any such revolution or special event, and that everything could be explained by the gradual action of ordinary processes observably at work at the present day (*BLT* §6.1, §8.3). On the contrary, he agreed with de Luc that while these processes—which de Luc had termed "*actual causes*"—were real enough in themselves, they were utterly inadequate to explain the observable features, most of all the mass extinction for which Cuvier himself had presented so much new evidence based on fossil bones (*BLT* §10.3). Here he was simply following the prescriptive rules of the great Isaac Newton: any causes invoked as explanations should be proportionate to their observed effects.[4]

So the physical character and cause of the earth's most recent major revolution remained enigmatic. But its date was another matter. Cuvier argued that it could be dated reliably, albeit approximately, by collating the earliest *human* records. Although in his opinion these were all more or less garbled and often shrouded in myth and legend, when analyzed critically they provided multicultural evidence for a global catastrophe. This had apparently been a huge aqueous "deluge" of some kind, at or near the dawn of human history; Cuvier was no biblical literalist, and he treated the Flood story in Genesis on a par with similar stories from other ancient cultures, extending as far away as China. So the venerable science of chronology, when pursued in this multicultural fashion with the latest tools of critical textual analysis, did after all have a place in geohistorical practice. Cuvier argued that the last revolution could be dated, not to the very year (as Ussher and other chronologers had claimed long before, for Noah's Flood), but at least approximately, to no more than a few millennia in the past. In effect, therefore, the last revolution was the unique boundary event that tied human history back into geohistory, because the evidence for its historical reality came both from human records, however obscure, and from natural evidence such as that of fossil bones.

Cuvier's "Preliminary Discourse" was not confined to his analysis of the earth's last revolution; that event was unique only in its date, and hence in its link to human history. As already mentioned, he argued that it was just the most recent in a long succession of physically similar natural events, separated by lengthy periods of tranquil conditions.

Cuvier's best evidence for this picture of geohistory had come from his joint fieldwork with his near-contemporary the mineralogist Alexandre Brongniart (1770–1841), the director of the state porcelain factory at Sèvres just outside Paris. Together they had surveyed what they termed the "Paris Basin"—it was almost the only geological fieldwork that Cuvier ever did—and had described a complex sequence of rock formations, some of them rich in fossil shells. Their methods had been somewhat similar to what the English surveyor William Smith (1769–1839) was doing around the same time (*BLT* §8.2); and Brongniart may have heard about Smith's work while he was visiting London during the brief Peace of Amiens. But he and Cuvier had radically transformed what Smith later called the "stratigraphical" use of fossils (*BLT* §9.5). The Frenchmen had treated fossils not just as empirically "characteristic" of particular formations, but as diagnostic of specific environmental conditions. They had interpreted the pile of formations in the region around Paris in geohistorical terms: they claimed that tranquil seas had alternated with periods of equally tranquil freshwater lakes, lagoons, or marshes. Occasional sudden changes in the environment were then held responsible for the occasional abrupt changes in the observable rocks and fossils (*BLT* §9.1). In his Discourse, Cuvier had cited this work with Brongniart as the best exemplar of how geohistory could be reconstructed, reliably and in detail. He reprinted their joint monograph in his own work; indeed he had it bound into his first volume, following his introductory essay and preceding any of his detailed studies of fossil bones.

Cuvier and Brongniart had recognized that their research on the Paris Basin could also play a crucial role in the reconstruction of the whole sweep of global geohistory. The rock formations around Paris were clearly older than the "*Superficial*" deposits, such as the river gravels that contained the bones of most of Cuvier's extinct mammals; for the solid rocks had evidently been excavated to form the valleys in which the gravels lay. But these rocks in turn overlay the highly distinctive and widely distributed Chalk formation, which rose to the surface around the Paris region. The Chalk had previously been regarded as the uppermost (and therefore youngest) of all the thick and varied "*Secondary*" formations, those that often contained abundant fossils. Far lower in the pile, and therefore far older still, were the so-called "*Transition*" rocks, mostly slates and "greywacke" with only a few obscure traces of life. Lowest of all were the enigmatic "*Primary*" rocks such as schist, gneiss, and granite; having no trace of fossils of any kind, these were generally regarded as dating from the very earliest phases of geohistory, probably before the origin of life itself (*BLT* §2.3, §4.4). So the formations in the Paris Basin and others of the same age elsewhere—which were soon being distinguished as "*Tertiary*"—could act as the link or cognitive gateway, as it were, between the present world and the even stranger worlds of the still deeper past. One could use these formations as the first stage, and the least unfamiliar, on the way towards deciphering the more obscure periods of even earlier geohistory. Cuvier therefore urged geologists to make the close study of these youngest or Tertiary formations their highest priority (*BLT* §9.3).[5]

4. De Luc's actual causes [*causes actuelles*] were "actual" not in the modern anglophone sense of real and not imaginary, but in the older sense still retained in other European languages, meaning current or of the present day (the news bulletins on French television, for example, are the day's *actualités*). Hence the analytical term *actualism*, applied to the earth sciences, denotes the methodological strategy of using a comparison with observable present features, processes, or phenomena as the basis for inferences about the unobservable deep past: in epigrammatic form, "the present is the key to the past". As the following chapters will indicate, the heuristic value of this strategy was taken for granted by *all* the geologists with whom this book is concerned: it was *not*—as modern historical myth would have it—first proposed by Charles Lyell in 1830. The arguments were about its *adequacy* for causal explanation, not about its validity or its value.

5. In modern terms the Superficial deposits were roughly equivalent to the Quaternary, and the "regular" or Secondary formations to the rest of the Phanerozoic (where not altered by metamorphism). However, soon after Cuvier's work was published the younger Secondary formations (those lying above the Chalk, in the Paris Basin and elsewhere) began to be distinguished as Tertiary—a term still used by modern geologists to denote all the Cenozoic apart from the Quaternary—so that the word "Secondary"

In much of this, Cuvier was simply borrowing from the work of others in the well-established science of *geognosy*, the science of rock structures and rock formations (*BLT* §2.3), parts of which were changing into what would later be called "*stratigraphy*" (see §3.1 and Fig. 9.1). But his own work on fossil bones added a geohistorical gloss to the accepted geognostic picture. This will be clear from a summary of his evidence, plotted back in time from the present world. From the Superficial deposits he described a whole fauna of fossil mammals, many of spectacular size (in modern terms, the Pleistocene *megafauna*). He claimed that all of them were of species unknown alive, though most belonged to known genera: the mammoth, for example, belonged to the same genus as the living elephants but was distinct from either the Indian or the African species. He interpreted all the fossil species as truly extinct, the victims of the earth's most recent revolution. Moving back in time to the Tertiary formations around Paris, he described another mammalian fauna, much more distinct from that of the present world, consisting wholly of unknown genera (*BLT* §7.5). Still further back, in the Secondary rocks proper (the Chalk and the formations below it), he found no trace of any mammals, but instead a wide variety of reptiles. Some of these were relatively familiar, such as crocodiles and turtles, but others were extremely strange. For example he identified the already famous "Maastricht animal", found in the Chalk near the Dutch city, as a huge marine lizard. Sensationally, he interpreted a much smaller but equally striking fossil, from a well-known rock at Solnhofen in Bavaria, as a *flying* reptile, which he named the "*ptéro-dactyle*" or wing-fingered animal (*BLT* §9.3). So Cuvier suggested that there might have been an age of reptiles long before there were any mammals, let alone any humans. Although highly tentative, this reconstruction of the history of the "quadrupeds" (in modern terms, the mammals, reptiles, and amphibians) accentuated the directional character of geohistory as a whole.[6]

Cuvier could and did claim credit for much of this picture of geohistory, though for certain aspects he duly acknowledged his intellectual debts to other savants such as de Luc and Dolomieu, and above all to Brongniart. But his "Preliminary Discourse" was far more eloquent and readable than the published work of his colleagues, and it became widely known throughout the savant world and indeed among the educated public generally, in part through its translation into other European languages (*BLT* §9.3, §10.3). Together with the detailed studies that it served to introduce, it became in effect the baseline or starting point for the work of other and often younger savants, as they sought to take Cuvier's research in new directions. They might try to extend and confirm his inferences, or use new evidence to try to refute them, but in either case Cuvier could not be ignored.

1.2 THE *FOSSIL BONES* REVISED

Once Cuvier's *Fossil Bones* was in the public realm, he had resumed work on what, at the start of his career before the turn of the century, he had regarded as his main field of research. In 1817, two years after Napoleon's final defeat at Waterloo, Cuvier had published his great *Animal Kingdom*, also in four volumes, using rigorous comparative anatomy to set out a radically revised classification of the whole range of living animals. This work was recognized immediately as being of equally decisive importance in its own field. In effect, it invalidated the traditional "scale of beings" [*échelle des êtres*], which had supposedly linked all animals in a single linear chain or "series" from the simplest to the most complex. Therefore it also undermined the "*transformist*" (in modern terms, evolutionary) interpretation of that linearity, which had been proposed most forcefully by Cuvier's older colleague Jean-Baptiste de Lamarck (1744–1829), the professor of invertebrate animals at the Muséum (*BLT* §7.4, §8.3, §10.1).[7]

Cuvier the indefatigable workaholic then turned back to fossil bones, while also shouldering ever-increasing responsibilities in the educational administration of the restored Bourbon monarchy of Louis XVIII (who in 1820 awarded him the title of *baron*). His *Fossil Bones* had been in effect a massive progress report. He had hoped and intended that it would stimulate naturalists everywhere to study the bones found in their own areas and conserved in their cabinets and museums; and that they would send him further specimens, or at least accurate pictures of them, to supplement those he had already used, and thereby enable him to correct or extend the interpretations he had proposed (*BLT* §7.3, §7.5). His hopes had been amply fulfilled, for other naturalists were keen to be associated—with due acknowledgment, of course—in a work of such outstanding importance. Specimens, and *proxy* specimens in the form of accurate drawings and paintings, accompanied by manuscript letters and offprints of published articles, converged on Paris from around the world, in even greater abundance than in earlier years.[8]

In one important case, however, Mahomet went to the mountain. Cuvier visited England for the first time in 1818, with his wife and daughters and his

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then denoted, in modern terms, only the Mesozoic and the Paleozoic. The Transition rocks were mostly Paleozoic in age, but usually somewhat affected by metamorphism; the Primaries were, in modern terms, mostly "basement" rocks of igneous or highly metamorphic origin and Precambrian age (it was not yet recognized that in some regions they might be much more recent in origin).

6. Unlike the celebrated "Ohio animal", which Cuvier had named the *mastodon*, the "Maastricht animal" remained without a distinctive label until Conybeare (see §2.2) named it the *mosasaur*, or lizard of the Maas or Meuse, the river on which the Dutch city lies: see Parkinson, *Oryctology* (1822), 298, and Bardet and Jagt, "*Mosasaurus hoffmani*" (1996). Throughout the present volume, fossil animals and plants are referred to by the names given them at the time, not their modern equivalents; Cuvier's "*ptéro-dactyle*", for example, was in modern terms a pterosaur. And as was then customary, such names are printed here in their informal English style, without italics or initial capitals, unless there is reason to use their formal Latin names.

7. Cuvier, *Règne animal* (1817), like its brief trailer "Nouveau rapprochment" (1812), defined four "*embranchements*" of animals with sharply distinct basic anatomies; it was the origin of the modern concept of sharply distinct *phyla* such as the chordates (including all the vertebrates from fish to humans) and the arthropods (including insects, spiders, and crustaceans). See the classic accounts in Daudin, *Cuvier et Lamarck* (1926), and Coleman, *Georges Cuvier* (1964), chap. 4.

8. The flow of material to Paris can be assessed from Cuvier's massive research files in Paris-MHN and from his incoming correspondence in Paris-IF: the latter summarized chronologically in Dehérain, *Manuscrits du fonds Cuvier* 1 (1908). The term "proxy", first introduced in this context in Hineline, *Visual culture* (1993), denotes accurate—and sometimes strikingly trompe l'oeil—pictorial representations of particular specimens, which made them "mobile" across the international network of naturalists (*BLT* §2.1): see Rudwick, "Picturing nature" (2005). On the role of this "noble commerce", as Cuvier termed it, in the production of the first edition of *Ossemens fossiles*, see Rudwick, "Alliés internationaux" (1997) and "Cuvier's paper museum" (2000).

research assistant Charles Laurillard (1783–1853). As on his earlier wartime tours on the Continent, he traveled in an official capacity, this time representing the French universities and the Académie des Sciences; he was presented at court, watched the House of Commons in session, and was entertained by Sir Joseph Banks (1743–1820), the long-standing president of the Royal Society, and other leading savants. But he also found time to study fossil bones and other specimens in the major English museums, which had been frustratingly inaccessible to him during the years of war. In particular, he studied the outstanding collections at the Royal College of Surgeons, amassed in the previous century by John Hunter (1728–93). At the British Museum, he confirmed the opinion of Charles König (1774–1851), the German-born curator of its natural history collections, that a famous human skeleton from Guadaloupe in the West Indies was not truly fossilized and probably only a few centuries old, although it was embedded in solid (and therefore ancient-looking) limestone; so it gave no support to claims that the human species had existed far back in geohistory (*BLT* §10.3). He also visited Oxford to meet William Buckland (1784–1856), the university's most prominent geologist, and to inspect his museum collections (see §5.1). But Cuvier's overall opinion of the scientific scene in England was probably echoed faithfully in what his assistant reported to a friend after their return to France:

> The English anatomists, like the naturalists, are not strong in zoology or comparative anatomy, and do not even realize the value of their own riches [i.e., museum collections]. In general, the scientific institutions in England are almost nothing, the government favoring only the art of making money, which is brought to perfection in this country. Money is made on everything: art collections, natural history cabinets, seeing [historical] monuments; in England everything pays for itself, in effect, everything relates to money and money relates to everything.[9]

Cuvier's visit to England filled the last major gaps in his firsthand study of relevant specimens, and in 1821 a new edition of his *Fossil Bones* began to appear in print. Over the next four years the four original volumes were replaced by seven larger ones, even more fully illustrated with newly engraved pictures of a vast range of specimens.[10]

Cuvier's second edition opened with a revised version of his "Preliminary Discourse" (*BLT* §10.5). With one important exception, however, the revisions were slight. Cuvier was tacitly leaving to others, and particularly to Brongniart, the further development of his geological ideas. He himself was concentrating instead on the improvement of his evidence for the range and distinctiveness of the fossil species that he claimed had gone extinct. Only at one point was the text of his essay greatly enlarged with new material. Significantly, it concerned the relation of geohistory to *human* history. Cuvier cited massive further evidence from the textual records of ancient cultures, to refute the renewed claims being made at this time for a vast antiquity for early civilizations. His own view conceded that there must have been some kind of human presence even before the geologically recent "revolution": without it there could have been no later records of the event. But he insisted again that it was only after that event that humankind had developed literate civilizations, which had so far lasted no more than a few millennia. So nature's most recent revolution did still form, in effect, the boundary between the brief era of recorded human history and the vast spans of almost entirely prehuman geohistory.[11]

In the rest of the first volume and the whole of the next there were enlarged special studies of the fossil "pachyderms" (such as mammoths and mastodons, rhinoceros and hippopotamus), together with fossil horses, pigs, tapirs, and so on, all of them preserved in the Superficial deposits. These comprised much of the mammalian megafauna that Cuvier claimed had gone extinct in the earth's most recent major revolution (the roster was completed in later volumes with studies of ruminants, carnivores, rodents, and edentates from the same deposits).[12]

The following volume included a greatly enlarged version of his and Brongniart's study of the geology of the Paris Basin; the revisions were in fact mostly Brongniart's work. It was still further enlarged by Brongniart's account of similar rocks in other parts of western Europe, the fruits of his extensive fieldwork since the end of the wars (*BLT* §9.6). All this stratigraphical detail demonstrated the importance and wide distribution of these formations (above the Chalk and its equivalents), which other geologists were beginning to distinguish as "Tertiary". It was therefore becoming clear that the corresponding Tertiary era in geohistory could indeed act as a gateway leading from the familiar present world (and the still relatively familiar world of the extinct megafauna wiped out by the last revolution), back in deep time towards the much stranger worlds represented by the very thick Secondary formations that underlay and were therefore still older than the Tertiaries (see Chap. 10).[13]

Brongniart's work on the Tertiary formations now provided, even more firmly than before, a geohistorical context for Cuvier's detailed studies of the most important vertebrates of Tertiary age. These were the fossil animals from

9. Laurillard to Georges Louis Duvernoy, 30 September "1817" [printed in Mathiot and Duvernoy (M.), "Lettres inédits de Laurillard" (1940), 10–11, and in Duvernoy, "Sophie Duvaucel" (1939), 54]; the year must have been transcribed or printed in error, for there seems to be no other evidence that Cuvier visited England in 1817 rather than 1818. On his clan-like research team, see Outram, "Le Muséum après 1793" (1997). His stepdaughter Sophie Duvaucel (1789–1867) and his natural daughter Clémentine (at this point only a thirteen-year-old) were both intelligent, well educated, and fluent in English. This made them valuable to Cuvier, who spoke little English: see Orr, "Cuvier's daughters" (2007). Taquet, "Reptiles marins anglais" (2003), reproduces some of the drawings of fossil bones that Cuvier made at London-RCS in 1818, and later (in 1824) annotated as having been those of the plesiosaur (see §2.3).

10. Cuvier, *Ossemens fossiles*, 2nd ed. (1821–24), 5 vols. in 7.

11. Cuvier, *Ossemens fossiles*, 2nd ed., 1 (1821), Discours (i–clxiv); the thirty-six pages (lxxix–cxv) on ancient human records—over a fifth of the whole essay—were enlarged from twelve pages (in larger print) in the first edition. Those whom Cuvier was criticizing were claiming—speculatively—an antiquity for *literate* civilizations of, in some cases, more than a hundred thousand years. Cuvier's own dating was of course much closer to that assigned to the same kind of evidence by modern archaeological research.

12. The pachyderms are in Cuvier, *Ossemens fossiles*, 2nd ed., 1 (1821) and 2(1) (1822); the other mammals, including Buckland's cave hyenas (*BLT* §10.6), are in *ibid.* 4 and 5(1) (1823).

13. Cuvier, *Ossemens fossiles*, 2nd ed., 3 (1822). The term "Secondary" will be used henceforth in its then newly restricted sense, i.e., excluding the Tertiaries and therefore roughly equivalent, in modern terms, to the Mesozoic and Paleozoic combined.

the Gypsum formation that outcropped widely around Paris (where it was quarried to make "plaster of Paris"). Cuvier's analysis of them occupied the whole of the next volume. His earlier descriptions of several species of the mammals that he called "palaeotherium" and "anoplotherium" (*BLT* §7.5)—anatomically much stranger than anything in the Superficial deposits—as well as fossil birds and other less important forms, were greatly enlarged, utilizing the many further specimens that had been found by quarrymen in the intervening years or newly identified in older collections.[14]

Finally, two years later, the last volume of Cuvier's great work presented his revised and enlarged studies of fossil reptiles. He dealt with those of all geological ages, among them the celebrated specimen from a Tertiary formation at Oeningen near Konstanz—first found a century earlier and named at that time the "man a witness of the deluge"—which in the first edition Cuvier had famously debunked as being in fact a giant salamander (*BLT* §9.3). But by far the most important were the fossils from the Secondary formations, on which he had based his hunch that an age of reptiles might have preceded the age of mammals. As before, they included not only crocodiles and turtles, but also the huge marine lizard from Maastricht and the bizarre flying pterodactyl from Solnhofen. However, some sensational new discoveries, of an even wider range of peculiar fossil reptiles, were just in time to be included; but they were so important in their own right that they will be described separately, later in this narrative (see Chaps. 2, 5).[15]

1.3 CUVIER'S SECULAR RESURRECTION

In Cuvier's massively impressive new edition of *Fossil Bones*, only one other new feature need be noted here. In his earlier research on the Tertiary fossils found in the Gypsum formation around Paris, he had used hundreds of disarticulated bones (and, very rarely, more complete assemblages) to make careful reconstructions of the skeletons of the strange mammals; and he had published his drawings of these skeletons in lively and lifelike poses (*BLT* §7.5). His generation would not have missed the biblical overtones of his dramatic claim that his work was "almost a resurrection in miniature, and I did not have the almighty trumpet at my disposal . . . [but] at the voice of comparative anatomy each bone, each fragment of bone, took its place again".[16]

However, Cuvier had kept to himself his astonishing pictorial reconstructions of their whole bodies—the skeletons reclothed in muscles and skin, with ears, eyes, and all—which would have made these long-extinct animals as vividly real as the living ones in the Muséum's *ménagerie* or zoo just round the corner from his house (*BLT* §7.5). He may have feared that such pictures would be criticized as merely fanciful, and thereby detract from the scientific authority of his research. Whatever the reason, in his new edition he did publish some pictorial reconstructions, though they were far inferior to his private ones. It may be significant that he delegated to Laurillard the task of drawing this new set, as if to keep himself a little aloof from them. Laurillard's drawings were much less lively than Cuvier's, and showed only the external form rather than the internal anatomy. Nonethe-

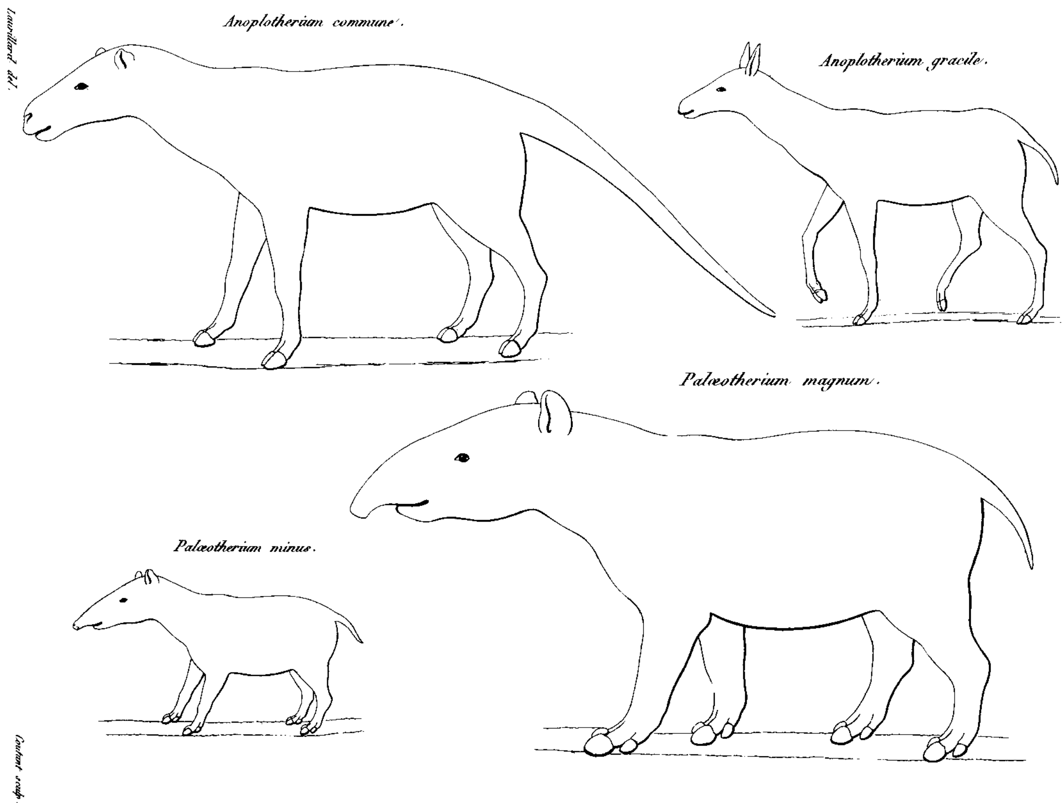

Fig. 1.2 Reconstructions of the body outlines of four of the strange extinct Tertiary mammals from the Gypsum formation around Paris, as published in 1822 in the second edition of Cuvier's *Fossil Bones.* The drawings were not by Cuvier himself but by his assistant Charles Laurillard. Their curiously stilted style, with rigorously lateral profiles, recalled the ancient Egyptian friezes that were attracting intense antiquarian interest at this time.

less, for readers (or rather, viewers) of the published work they did enhance the sense that Cuvier had successfully brought these extinct mammals back to life, at least in the mind's eye (Fig. 1.2).[17]

This represented a significant further step towards turning mere fossil bones into geohistory. Cuvier took yet another step when he described not only what these animals might have looked like but also how they might have lived in their environment. More fully than before, the valley of dry bones was becoming a

14. Cuvier, *Ossemens fossiles*, 2nd ed., 3 (1822).

15. Cuvier, *Ossemens fossiles*, 2nd ed., 5(2) (1824); the nominal fifth and final volume may have been split in two, and this its second half postponed, in order to allow these most recent discoveries to be included. At this time the class Reptilia was so defined as to include the amphibians (and among them the salamanders) as a subclass.

16. Cuvier, *Ossemens fossiles* (1812) 3, Introduction: 3; alluding to the prophetic vision in Ezekiel 37:1–10 and the eschatological one in 1 Corinthians 15:52. Contrary to later myths about him, Cuvier did not claim to be able to *reconstruct* a fossil animal on the basis of a single bone, but only (in favorable cases) to *identify* the kind of animal from which it had come.

17. Fig. 1.2 is reproduced from Cuvier, *Ossemens fossiles*, 2nd ed., 3 (1822), pl. 66, engraved by Jean Louis Denis Coutant. Laurillard, who was not unskillful as a scientific artist, also made many of the new drawings of specific bones for the second edition.

scene from deep time. The example of *Anoplotherium commune* (Fig. 1.2, top left) will make the point:

> What distinguished it most was its long tail. This gave it something of the appearance of an otter, and it is very probable that like that carnivore it was often on or under the water, above all in marshy places; but this was certainly not in order to fish there. Like the water rat, the hippopotamus, and all kinds of boar and rhinoceros, our Anoplotherium was a herbivore; so it went in search of the succulent roots and stems of aquatic plants. With its habits as a swimmer and diver, it would have the smooth skin of the otter.[18]

The second edition of Cuvier's *Fossil Bones*, including these reconstructions, completed his survey of fossil quadrupeds, but not the demand for it. In 1825 he reissued all the volumes as a third edition, little changed from the second. Then, with the work securely in print in its definitive form, he had its famous "Preliminary Discourse" reprinted as a separate small volume. As was common practice at this time, it was decorated with a portrait of the author, to enable a wider public to see what manner of man had achieved this celebrated resurrection of a "former world" of animal life (Fig. 1.1).[19]

Cuvier's essay had in fact been available in this form from the start, but only in English. When *Fossil Bones* first appeared, Robert Jameson (1774–1854), the professor of natural history at Edinburgh, had promptly commissioned a translation. But he had entitled it an *Essay on the Theory of the Earth*; and successive editions of this work, to which Jameson added more and more material of his own, had reinforced the impression among anglophone readers that Cuvier was contributing to the genre of geotheory (*BLT* §10.3). Significantly, Cuvier himself gave his text a quite different title: it was a "Discourse on the revolutions at the earth's surface, and on the changes that they have produced in the animal kingdom". The work was not on geotheory but on *geohistory*, and with the implication that the history of life was causally connected with the history of its physical environment. In this new form Cuvier's ideas became even more widely known, for his *Discourse* was soon translated into German, Italian, and Swedish.[20]

1.4 CONCLUSION

Cuvier's *Researches on Fossil Bones* was a seminal work: in the years that followed its first publication, it provided the baseline and suggested a starting point for many separate lines of research by other savants. Whether or not they agreed with his conclusions, his work could not be ignored.

Cuvier presented a forceful and eloquent case for treating geology as a *historical* science, and for hitching the short span of recorded human history on to the tail end of an inconceivably longer span of prehuman geohistory. Penetrating geohistory backwards from the known present—"bursting the limits of time"—Cuvier claimed, first, that around the dawn of human history there had been the most recent of the earth's physical "revolutions"; these, he argued, were natural events that had occasionally interrupted far longer periods of relative tranquility. A watery catastrophe of some kind was obscurely recorded in several ancient literate cultures (the biblical story of Noah's Flood being just one of them); but it was also recorded more clearly, in his opinion, in the apparent mass extinction of the diverse mammalian megafauna that had been revealed by his own careful analysis of fossil bones. Second, his joint research with Brongniart on the rocks of the Paris Basin showed that, long before that last revolution, there had been a succession of similar sudden events, which had several times altered the environment abruptly from marine to freshwater and back again. These Tertiary rocks (as they were soon being called) contained another mammalian fauna, but one much less like the present fauna of living species. Third, the underlying Secondary rocks recorded an even earlier era in geohistory, which seemed to have been an age of reptiles, with no mammals at all. Fourth and last, the Transition rocks, with very few fossils of any kind, were a transition to the Primary rocks, which formed a basement to the whole geognostic (or stratigraphical) pile; the Primaries were evidently the oldest, and they contained no fossils at all and were assumed to be likely to date from before the origin of life itself.

This picture of a broadly directional geohistory—on a vast timescale, but not an eternity—was far from being original to Cuvier. But he provided it with a striking new dimension, by analyzing fossil bones and interpreting them in terms of a *history* of quadruped life. In the particular case of the Tertiary mammals from around Paris, he showed by example how a vanished fauna could be brought back to life, at least in the mind's eye, in a feat of secular resurrection: the valley of dry bones could become a scene from deep time.

Even as Cuvier was revising his great work for its enlarged second edition, soon reissued as its third, other naturalists were taking up various aspects of the agenda he had proposed, either to reinforce his conclusions or to try to refute them. Some of these diverse lines of research will be described in the rest of Part One, in narratives that run in parallel over much the same years.

18. Cuvier, *Ossemens fossiles*, 2nd ed., 3 (1822), 247–48; all the verbal reconstructions are translated in Rudwick, *Scenes from deep time* (1992), 34–36. It should be obvious that Cuvier's paleoecology, no less than his functional anatomy, was underlain by the standard actualistic method: in both cases he was using living animals as the key to their extinct analogues.

19. Cuvier, *Ossemens fossiles*, 3rd ed. (1825). The 4th ed. (1834–36) was posthumous.

20. It is just possible that Cuvier considered issuing the second edition of his essay with *Jameson*'s title, and then thought better of it. A version entitled "Discours sur la théorie de la terre" and dated 1821 is so rare that it was probably only a trial printing: Smith (J. C.), *Georges Cuvier* (1993), no. 665, records a copy in Washington-SI, and there is another in Paris-MHN [Ch. 334]; apart from the title page it appears to be identical to the text in *Ossemens fossiles*, 2nd ed., 1 (1821). Smith also lists the early translations (nos. 662, 664, 688).