Introduction

To claim that it is true is nowadays the convention of every made-up story. Mine, however, *is* true.

JORGE LUIS BORGES, *THE BOOK OF SAND*

WHY DID THE DINOSAURS BECOME EXTINCT? Why did fishes evolve legs and learn to walk on land? How did birds become airborne? Is humanity the culmination of evolution? Apart from their perennial fascination, questions like these—evolutionary questions, about 'how' and 'why'—are united by an implication of a narrative in which causes and effects are linked: dinosaurs became extinct *because* of the after-effects of an asteroid impact, or *because* they were rendered obsolete by mammals. Chains of cause and effect may also be animated by purpose: fishes evolved legs *for* walking on land; birds evolved feathers *for* flight; human beings evolved from apelike ancestors *because* they had bigger brains, could make tools and use language.

Popular views of science assume that cause, effect, and purpose can be easily discerned: hardly a day goes by without reports of discoveries of genes *for* homosexuality, good motherhood, breast cancer or alcoholism; of the bones of ancestors and 'missing links'; of explanations of why the elephant evolved its trunk; or warnings that a certain food item *causes* a particular disease. Many of the assumptions we make about evolution, especially concerning the history of life as understood from the fossil record, are, however, baseless.

The reason for this lies with the fact of the scale of geological time that scientists are dealing with, which is so vast that it defies narrative. Fossils, such as the fossils of creatures we hail as our ancestors, constitute primary evidence for the history of life, but each fossil is an infinitesimal dot, lost in a fathomless sea of time, whose relationship with other fossils and organisms living in the present day is obscure. Any story we tell against the compass of geological time that links these fossils in sequences of cause and effect—or ancestry and descent—is, therefore, only ours to make. We *invent* these stories, after the fact, to justify the history of life according to our own prejudices. Nobody will ever know what caused the extinction of the dinosaurs, because we weren't there to watch it happen. All we have are two isolated observations—the apparent absence of dinosaurs 65 million years ago, and evidence for a catastrophic phenomenon, such as the impact of an asteroid, at around the same time. There can be no certain link between the two. Geological time admits no narrative in which causes can be linked with effects.

Fossils are never found with labels or certificates of authenticity. You can never know that the fossil bone you might dig up in Africa belonged to your direct ancestor, or anyone else's. The attribution of ancestry does not come from the fossil; it can only come from us. Fossils are mute: their silence gives us unlimited licence to tell their stories for them, which usually take the form of chains of ancestry and descent. These stories are like history, of events leading to other events; of succession and defeats; change and stability. Such tales are sustained more in our minds than in reality and are informed and conditioned by our own prejudices, which will tell us not what really happened, but what we think *ought* to have happened. If there are 'missing links', they exist only in our imaginations.

John McPhee, an eloquent writer on geology, coined the term 'Deep Time' to distinguish geological time from the scale of time that governs our everyday lives. McPhee meant the term to refer to the immense intervals, measured in millions of years, discussed as if they were days or weeks in the conversation of geologists: yet in reality, the intervals of geological time are too long to be readily comprehensible to minds used to thinking in terms of days, weeks and years—decades, at most.

Books on the history of life usually start with an appreciation of the vastness of Deep Time and try to use some analogy to make it comprehensible in everyday terms. Walter Alvarez, for example, suggests thinking of an interval of a million years as if it were a kind of geological 'year'. On this scale, the dinosaurs became extinct 65 years ago—a lifetime away, just before the outbreak of World War II. Fishes evolved legs and clambered ashore about 360 years ago, in the 1640s, around the time of the English Civil War, and animals with backbones appeared approximately 500 years ago, when the first conquistadors made landfall in the Americas. The first signs of life on Earth appeared more than 3,600 years ago, when Babylon was a major city, and Earth itself formed 4,500 years ago, around the time that the mythical hero Gilgamesh is supposed to have gone about his heroic business. On this scale, our own species, *Homo sapiens*, is a very recent arrival, having appeared only a year ago.

At this point, popular books will present a table outlining the formal divisions of geological time, calibrating their passage in millions of years from the present day. My own contribution can be found in figure 1. I present it because I mention technical names for several geological intervals throughout this book, and you might wish to refer to it.

After presenting a chart of geological time and impressing you with its scale, canonical accounts of the history of life consider that their duty towards Deep Time has been fulfilled and will move on to telling the story of life as if it were *Hamlet:* a drama that can be understood in human terms. We will learn of the origin and evolution of life; the rise of the fishes and the fall of the dinosaurs; the evolution of the birds and mammals, the primates, and finally Man. Each species will make its entry and exit like an actor on a stage, with Deep Time as the backdrop.

But apart from telling you that Deep Time is long, conventional ac-

Age (millions of years)	Period	Era	Eon
2	Quaternary	Cenozoic	Phanerozoic
65	Tertiary		
144	Cretaceous	Mesozoic	
213	Jurassic		
248	Triassic		
286	Permian	Palaeozoic	
360	Carboniferous		
408	Devonian		
438	Silurian		
505	Ordovician		
543	Cambrian		
1000		Neoproterozoic	Proterozoic
1600		Mesoproterozoic	
2500		Palaeoproterozoic	
4000			Archaean
~4500			Priscoan
(origin of the Earth)			

Figure 1. A chart of Deep Time.
(Compiled by the author from various sources and drawn by Majo Xeridat)

counts never consider the implications of the scale of Deep Time on the way we think about evolution. If, as McPhee says, Deep Time implies intervals more or less incomprehensible to humans, we are entitled to ask whether it is valid to tell stories about evolution according to the conventions of narrative or drama. If it is not, then every story we tell in which causes are linked with effects, and ancestors are linked with descendants, becomes questionable: we can no longer use Deep Time as a backdrop for the stories we tell ourselves about evolution, and how and why we came to be who we are.

Once we realize that Deep Time can never support narratives of evolution, we are forced to accept that virtually everything we thought

we knew about evolution is wrong. It is wrong because we want to think of the history of life as a story; but that is precisely what we cannot do. This tension—between Deep Time and the everyday scale of time—is the theme of this book. What we need is an antidote to the historical approach to the history of life—a kind of 'anti-history' that recognises the special properties of Deep Time.

If we can never know for certain that any fossil we unearth is our direct ancestor, it is similarly invalid to pluck a string of fossils from Deep Time, arrange these fossils in chronological order, and assert that this arrangement represents a sequence of evolutionary ancestry and descent. As Stephen Jay Gould has demonstrated, such misleading tales are part of popular iconography: everyone has seen pictures in which a sequence of fossil hominids—members of the human family of species—are arranged in an orderly procession from primitive forms up to modern Man. To complicate matters further, such sequences are justified after the fact by tales of inevitable, progressive improvement. For example, the evolution of Man is said to have been driven by improvements in posture, brain size, and the coordination between hand and eye, which led to technological achievements such as fire, the manufacture of tools, and the use of language. But such scenarios are subjective. They can never be tested by experiment, and so they are unscientific. They rely for their currency not on scientific test, but on assertion and the authority of their presentation.

Given the ubiquitous chatter of journalists and headline writers about the search for ancestors, and the discovery of missing links, it may come as a surprise to learn that most professional palaeontologists do not think of the history of life in terms of scenarios or narratives, and that they rejected the storytelling mode of evolutionary history as unscientific more than thirty years ago. Behind the scenes, in museums and universities, a quiet revolution has taken place.

The architects of this revolution sought ways to discover the pattern of the history of life that is free from subjective, untestable stories. If it is fair to assume that all life on Earth shares a common evolutionary origin, it follows that every organism that ever existed *must* be related to every other. We are all cousins. Every goanna and gourami is a cousin of every gecko and ginkgo that has ever lived, or will live in the future. This must be true, even though we can neither tell who was whose direct ancestor or justify any scenarios to support assertions about ancestry and descent.

Before we can understand the history of life, we need to find the order in which we are all cousins, the topology or branching order of the tree of life. This can be done without having to make any prior assumptions about cause and effect, or ancestry and descent. These branching diagrams, which look, misleadingly, like genealogies, are proper scientific hypotheses that can be tested by examining the strength or likelihood of alternative orders of branching—different orders of cousinhood—in the light of the anatomy of the organisms in whose relationships we are interested. As long ago as 1950, a German entomologist called Willi Hennig used these simple principles as a basis for a new way of looking at the living world. Hennig sought to understand creatures in terms of how they shared characteristics with one another, independently of time, rather than in terms of their histories of ancestry and descent. Hennig called his philosophy 'phylogenetic systematics', but it came to be known as 'cladistics' and its practitioners, inevitably, as 'cladists'. The branching diagrams cladists drew up to represent orders of cousinhood between organisms—patterns of relationship—became known as 'cladograms'.

Cladistics looks only at the pattern of the history of life, free from assumptions about the process of the unfolding of history. It resolves the conundrum of trying to comprehend Deep Time in terms of an unfolding drama. Because of this, cladistics is the best philosophy for the scientific understanding of the history of life as we unearth it from Deep Time. More than a set of techniques, but less than a science in its own right, cladistics is a way of 'seeing', of looking at the products of evolution as they are, and not how we would like them to be.

An important aspect of cladistics, as in all science, is testability. In cladistics, you are asked to find the most likely way in which a set of organisms is related to one another—to estimate, in other words, their relative degrees of cousinhood. This is done with a cladogram. As I show in chapter 1, if you have more than two organisms, you will find that there is more than one way of drawing a cladogram that links them up. What this means is choice: if there is more than one way in which organisms can be cousins, you are forced to consider the alternatives, and you must find a way of evaluating them all.

How can these alternatives be evaluated? The central test is as old as science—older: Occam's razor, or the Principle of Parsimony. That is, if you have to make a choice between explanations, you should choose the simplest. The simplest, or most 'parsimonious', cladogram is the one that assumes the smallest amount of evolutionary change. I'll discuss what that means for our understanding of evolution later in this book.

Conventional stories about evolution, about 'missing links', are not in themselves testable, because there is only one possible course of events—the one implied by the story. If your story is about how a group of fishes crawled onto land and evolved legs, you are forced to see this as a once-only event, because that's the way the story goes. You can either subscribe to the story, or not—there are no alternatives. In cladistics, you can put the story to the test, by studying the fossils and asking yourself how they might have been related to one another. A fossil fish you happen to find *might* have been your direct ancestor, but you will never be able to establish the case, one way or the other.

Such study might turn up some surprises. For example, your evidence might show that more than one group of fishes crawled ashore independently, or that other groups of fishes evolved legs, but stayed underwater. By offering choices, cladistics opens our eyes to surprising new discoveries and possibilities of evolution otherwise hidden from us. Conventional wisdom has fishes crawling ashore, evolving limbs, and progressing, inexorably, to amphibians, to reptiles, to mammals, and to Man. Cladistics suggests that things might have been otherwise.

Testability is a central feature of the activity we call science. Some have sought a kind of special dispensation for palaeontology as an 'historical' science, that it be admitted to the high table of science even though palaeontologists cannot, classically, do the kinds of experiments other scientists take for granted. You cannot go back in time to watch the dinosaurs become extinct or fishes crawl from the slime to become amphibians. More pointedly, you cannot, as Stephen Jay Gould discussed in his book *Wonderful Life*, go back in time to see what other things *might* have happened instead, had circumstances been slightly different. What if the asteroid missed Earth, sparing the dinosaurs? What would have happened if the fishes decided to stay underwater after all? In either case, would we be here? We cannot see what nature would have done had she been able to rerun the tape of evolution: were we able to witness such a re-run, would the outcome be different from what we see, as Gould argues, or very much the same? In strict, scientific terms, such questions are meaningless. The problem is that what we see before us is the result of a once-only experiment in history. Because it happened only once, it is not accessible to the reproducibility scientists usually require. This is not possible in palaeontology except in our imaginations.

However, palaeontology is either scientific, or it is not, and you may ask whether the particular problems that palaeontology has with its subject—Deep Time—should be allowed to mitigate its inability to reproduce experiments in the approved scientific manner. They should not. To see palaeontology as in any way 'historical' is a mistake in that it assumes that untestable stories have scientific value. But we already know that Deep Time does not support statements based on connected narrative, so to claim that palaeontology can be seen as an historical science is meaningless: if the dictates of Deep Time are followed, no science can ever be historical.

Palaeontology read as history is additionally unscientific because, without testable hypotheses, its statements rely for their justification on authority, as if its practitioners had privileged access to absolute truth—'truth which can be known', in the words of the late palaeontologist and cladist Donn Rosen (whose views I discuss in chapter 5). Whether you believe the conventional wisdom that our own species *Homo sapiens* descended in seamless continuity from the preexisting species *Homo erectus* depends not on the evidence (because the fossil evidence is moot) but on the deferment of your lack of knowledge to the authority of the presenter or whether the *presentation* of the evidence resonates with your prejudices. The assumption of authority is profoundly, mischievously, and dangerously unscientific. It conflicts with how we are taught science from our earliest years, that the scientific method should be rigorously democratic; that statements from authorities in a field should be as subject to scrutiny as those emanating from the most humble sources, even a beginning student. Nobody should be afraid to ask a silly question.

Cladistics has remained true to this simple view of science. When, as a student, I spent a summer working on fossil fishes at the Natural History Museum in London, my innocent views were accorded the same respect had they come from the head of the Fossil Fish Section, the late Colin Patterson, one of the world's most respected workers on fossil fishes, and one of the most influential advocates for cladistics. As I discuss in chapter 5, Patterson wished to replace the élitist, authoritarian presentation of old-fashioned museum displays with an approach to science that encouraged the participation of a wider audience, represented by the museum-going public. My opinion received equal value because Patterson, for all his eminence, had no special access to the truth that would be denied to me.

The story of human interaction with fossils represents an example of how experience and belief have a powerful effect on interpretation and demonstrates why scientific truths can only be temporary. Today, we see fossils as the remains of creatures that once lived. However, this nature is not inherent in the fossils. It is our immersion in a century and a half of Darwinian thought, not the fossils themselves, that gives us the capacity to see fossils as kin to things that were once as alive as you or I. If this were not the case, we would interpret fossils differently. In societies without science in the sense that we would understand it today, fossils were seen as signs of divine or diabolical action, as the bones of giants or the teeth of dragons, or as the bones of creatures that perished in Noah's flood. Observers innocent of science, ignorant of religious or cultural tradition, and incapable of imagination would no doubt see fossils only as rocks. All these views could be as valid to their respective beholders as the apprehension of fossils as the remains of living organisms is to us. We cannot be certain, therefore, that our current understanding of fossils is not as provisional as these earlier ones.

This line of reasoning appeals to contemporary philosophers and critics who regard with detachment the conventional claims of scientists to be rolling back the frontiers of ignorance, unveiling universal truths, and so on. Such critics suggest, instead, that what scientists find out is conditioned at least as much by their cultural heritage as by objective reality. It is hard to argue with this point of view, borne out, for example, by the way our approach to fossils has changed over the ages. Looking at science from this perspective, you might ask whether cladistics itself—in its embrace of patterns of relationships rather than lines of ancestry, and its insistence on truths that are relative and provisional rather than absolute and final—falls foul of these contemporary prejudices.

The answer must be no. Cladistics is, in truth, somewhat reactionary in that it embodies a purist attitude to science that seeks to establish traditional, scientific values such as the importance of objectivity, the testability of hypotheses, and the provisional nature of the results of such tests. A cladist might say that the *whole* of science ought to be similarly austere, in that those scientists who claim to unveil universal truths have no business making such claims in the name of science.

Without cladistics, palaeontology is no more of a science than the one that proclaimed that Earth was 6,000 years old and flat—and *then* had the effrontery to claim divine sanction for this view.

1.

Nothing Beside Remains

'My name is Ozymandias, king of kings;
Look on my works, ye Mighty, and despair!'
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away.

Percy Bysshe Shelley, 'Ozymandias'

I CLIMB TO THE TOP OF THE RIDGE to get a better look at the view. Mazes of badlands fall away before my gaze; dry gullies opening just a few feet away spread out, broaden, and meander into a yellow-green landscape. I am in East Africa, more precisely a part of northwestern Kenya, the valley of an ephemeral river called the Topernawi that drains—if such a word applies to a river of sand—into Lake Turkana, at a point some twenty kilometres southeast of where I stand.

Tussocks of grass punctuate the red-grey earth. The ground is patterned by small thorn bushes and dotted with acacias, all with the same flat tops, as if a glass sheet covers the scene just fifteen feet from the ground. In the distance, the acacias seem to get smaller and closer together as they converge on the dense, grey-green line of the riverbank. Further away still, beyond the river, the acacias, now too small to make out individually, thin out into a piebald jumble of hills. Silence surrounds me.