Evolutionary Catastrophes

Why did the dinosaurs and two-thirds of all living species vanish from the face of the Earth sixty-five million years ago? Throughout the history of life, a small number of catastrophic events have caused mass extinction and changed the path of evolution forever.

Two main theories have emerged to account for these dramatic events: asteroid impact and massive volcanic eruptions, both leading to nuclear-like winter. In recent years, the impact hypothesis has gained precedence, but Vincent Courtillot suggests that cataclysmic volcanic activity can be linked not only to the K–T mass extinction but also to most of the main mass extinction events in the history of the Earth. Courtillot's book explodes some of the myths surrounding one of the most controversial arguments in science. It shows among other things that the impact and volcanic scenarios may not be mutually exclusive. This story will fascinate everyone interested in the history of life and death on our planet.

Vincent Courtillot is a graduate of the Paris School of Mines, Stanford University, and University of Paris. He is Professor of Geophysics at the University of Paris (Denis Diderot) and heads a research group at Institut de Physique du Globe. His work has focused on time variations of the Earth's magnetic field, plate tectonics (continental rifting and collision), magnetic reversals, and flood basalts and their possible relation to mass extinctions. He has published 150 papers in professional journals, and a book entitled *La Vie en Catastrophes* (Fayard, Paris, France, 1995). This volume is a translation and update of this book. Courtillot is past-director of graduate studies and funding of academic research of the French Ministry of National Education (1989–93), past-director of the Institut de Physique du Globe (1996–98), and past-president of the European Union of Geosciences (1995–97). He has been a consultant for the French Geological Survey (BRGM). He is a Fellow of the American Geophysical Union, Member of Academia Europaea, and Associate of the Royal Astronomical Society and he won the Silver Medal of the French Science Foundation (CNRS) in 1993. He has lectured at Stanford University, the University of California at Santa Barbara, Caltech (Fairchild Distinguished Scholar), and the University of Minnesota (Gerald Stanton Ford Lecturer) and is a senior member of Institut Universitaire de France. In June 1997, he became special advisor to the Minister of National Education, Research and Technology, in charge of higher education and research and in December 1998, the Director in charge of research for the Ministry. Vincent Courtillot is a Chevalier de l'ordre national du Mérite and Chevalier de la légion d'honneur.

For Michèle, Carine and Raphaël

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The Science of Mass Extinction

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Not even the most tempting probability is a protection against error; even if all the parts of a problem seem to fit together like the pieces of a jig-saw puzzle, one must reflect that what is probable is not necessarily the truth and that the truth is not always probable.

Sigmund Freud

Moses and Monotheism (1939)[1]

1 From *The Standard Edition of the Complete Psychological Works of Sigmund Freud*, Vol. XXIII, translated from the German under the general editorship of James Strachey, in collaboration with Anna Freud, London, The Hogarth Press and the Institute of Psycho-Analysis, 1964.

Preface

I would like to tell a story here, or rather a fragment of the story of the natural history of our planet and the beings that populate it. With Darwin, the evolution of species became part of our collective awareness. People more or less recall glimpsing the trilobites or dinosaurs, sea lilies or mastodons in those superb dioramas of which our mid-century museums were so proud. People know that a vague link of ancestry ties us to these fantastic animals, which belong to the 99% of all species that once lived on Earth and have now departed from it forever. Why are most of these animals no longer around us? Do paleontologists, whose profession it is to discover and describe fossil species, know the reason for these extinctions? Do they occur rarely, or often? Did they come about suddenly, or gradually and regularly over the course of geological time?

Well – both. Species disappear every year. And this has been so since the dawn of Life. But there are a small number of periods during which the extinctions of ancient species and the appearances of new ones attain an astonishing concentration within a rather brief time. What then are the causes of these profound breaks in the line of species, those very breaks that led nineteenth century science to define the great geological eras? The answer began to come to light less than two decades ago. Several times in the course of the history of our globe there occurred catastrophes, undoubtedly difficult to imagine, that caused vast slaughter and resulted in a mass extinction of living species. Though of major importance, this notion of extinction has generally been neglected by biologists. Since the early 1980s it has fallen to geologists to prove that convulsive phases of extinction have indeed occurred repeatedly over geological time – for the record has been preserved in fossils.

The model we inherited from the nineteenth century represents geological and biological processes as unfolding in gradual and regular harmony. To Lyell and Darwin it was simply the immensity of

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time and the incomplete record of this time preserved in rock that might at times give the impression of abrupt change. This scheme seemed to have been swept away when, in 1980, a team led by the American physicist Luis Alvarez and his geologist son Walter announced that the disappearance of the dinosaurs 65 million years ago was the result of an asteroid impact. Almost immediately, without denying the catastrophic aspect of the changes the world has witnessed since the end of the Mesozoic, another hypothesis followed: the last great mass extinction may have been initiated by extraordinary volcanic eruptions, in which a vast portion of the Deccan region of India was covered with lava.

This was the resurgence of the century-old debate between the "gradualists," for whom nothing special happened at the boundaries between geological eras, and the "catastrophists." This debate goes back to Lamarck and Cuvier in the late eighteenth century. And over it is superimposed a second controversy: if there was indeed a catastrophe, did death come from the sky, or from the bowels of the Earth?

In order to find an answer, geochemists and geophysicists journeyed to the ends of the Earth to sample and analyze the rare surviving archives of the time of the catastrophe. They investigated metals and rare minerals, iridium and shocked quartz (whose odd names will soon become familiar to the reader), isotopes, remnant magnetization in rocks – and, of course, fossils. Have all these potential sources of evidence preserved the memory of the last great crisis the Blue Planet had suffered? Would we be able to measure the age of such ancient objects and events with enough precision to distinguish between the mere seconds' duration of an impact and the millennia that an eruptive volcanic phase might last? How many other catastrophes had marked the history of Earth and changed the course of species' evolution in a jagged line? Was the end of the trilobites and stegocephalians, which accompanied the lowering of the curtain on the Paleozoic Era 250 million years ago, caused by the same forces as the end of the dinosaurs and ammonites?

The quest for answers to these questions has been a great scientific adventure. Retelling this adventure is also an occasion, as we pass through a review less austere than some scholarly manuals might impose, to describe the great discoveries in earth science in the last quarter of the twentieth century. The attraction of these discoveries is attested by the recent appearance of Paul Preuss's novel *Core*. In this new *Voyage to the Center of the Earth*, a physicist father and his geologist son are unwitting competitors in drilling through the Earth's mantle. It says something about what a thorough dusting-off geophysics has enjoyed when, duly spiced up with a dash of added greed and love interest, it can now compete with Michael Crichton's *Jurassic Park*.

We will need to adjust to a different way of perceiving the measurement of time and discover just how dynamic the inanimate world can be. Modern chaos theory finds superb illustrations here on an unwonted scale: sudden reversals of the earth's magnetic field, and the more majestic formation of those enormous instabilities known as mantle plumes.

It is, in fact, the inanimate world that caused the great fits and starts in the evolution of Life. The Moon is deeply marked by the great impacts that sculpted its surface down through its history. On the Earth, most of these impacts have been erased by erosion and the incessant drift of the continents. But have they played no role in the history of species?

In 1783, an eruption – quite a modest one, really – devastated Iceland and upset the climate of the entire Northern Hemisphere. Yet this eruption was a hundred thousand times less than the great basaltic outpourings that surged ten times across the Earth's surface over the past 300 million years. Wouldn't these have thrown the climate out of balance beyond all imagining? So, impact or volcanism: which is the answer?

Dust and darkness, noxious gases and acid rain, persistent cold followed by suffocating heat: the scenarios of these ecological catastrophes, whether their sources lie beyond the Earth or deep within it, inspired the terrible concept of the "nuclear winter". And, as has never before happened in geological time, a species – ours – is by itself able to alter the atmosphere to the same extent as the great natural disturbances, and far more rapidly. Deciphering past catastrophes may perhaps be the only way of predicting the future effects of human activity on this planet's climate.

This history is also meant to bear witness to the exciting world of scientific research, to an adventure that is both individual and collective. The accidents, setbacks, changes of approach, and successes that punctuate a researcher's career are not unlike those that episodically alter the course of evolution. And so we will be transported to lovely Umbria in Italy, to the roof of the world in Tibet, then to the Deccan Plateau in India, and the tip of the Yucatán Peninsula in Mexico. We will seem to change subjects, goals, and methods. We will encounter failure at times – but fortunately only temporarily.

Scientists' quarrels are frequently sharp, sometimes unpleasant, often fascinating, and always rife with new knowledge. They parallel the sometimes chaotic evolution of ideas. They make it possible to understand how a hypothesis is built, why a researcher hesitates, how long "truth" can search for evidence only to find it unexpectedly all at once and surge ahead. In the course of this narrative I hope to help the reader share some enthusiasms and, perhaps, even inspire a vocation. My purpose is in determined opposition to the aim of the great Swiss mathematician Leonhardt Euler: someone once asked him why the published demonstration of his theorems had been so extensively rewritten that it was impossible to understand how he had conceived his ideas. He haughtily replied that the architect never leaves his scaffolding behind.

Impact or volcanism? Or both together? The reader will certainly not neglect to look critically at the new catastrophic models that appear in this study. The metaphor of the puzzle that Freud evokes in the epigraph to this book applies particularly well to the geological sciences, where the record of far-off times is so very fragmentary. Karl Popper echoes him:[1] "A theory may be true though nobody believes it, and even though we have no reason for accepting it or for believing that it is true." As for me, I see Freud's metaphor as a reminder that from time to time one has to know how to throw caution to the winds: this is often the price of decisive advances.

A new conception of the erratic march of evolution is emerging and has been well described by Stephen Jay Gould. The tree often used to represent the genealogy of species bears little resemblance any more to a grand old oak. Instead, it is espaliered: the first

1 In Karl R. Popper, *Conjectures and R efutations: The Growth of Scientific Knowledge*, New York, Basic Books, 1962.

branches emerge low down, at right angles to the trunk, only to branch again immediately and rather often, again taking the vertical. As though the gardener had gone berserk with the pruning shears, from time to time most of the branches are lopped off, even many that are perfectly healthy. Those that remain were just lucky.

In "normal" times – in other words, most of the time – the process of evolution is governed by necessity. But the role of chance, during the rare and brief moments when it strikes, is so great that one almost wonders whether it does not play the main role after all. Humans would probably not exist and our environment would be unrecognizable if the nature of certain improbable catastrophes, and the order in which they occurred, had not left an indelible mark on the living world.

I would also like to express my heartfelt thanks to those who were kind enough to be the first readers of this book and help me to improve it by their observations: José Achache, Guy Aubert, Michèle Consolo, Emmanuel Courtillot, Jean-Pierre Courtillot, Yves Gallet, Jean-Jacques Jaeger, Claude Jaupart, Marc Javoy, Jean-Paul Poirier, and Albert Tarantola. Françoise Heulin and Claude Allègre provided me with crucial advice about the overall organization. Joël Dyon provided the illustrations. The French part of the research reported in this work was financed by several universities, the Institut de physique du globe de Paris, and the Institut national des sciences de l'univers (CNRS).

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Preface to the English edition

Four years have elapsed since the original French version of this book came out. It is my feeling that much of the research that has appeared in print during this time has further vindicated the views I held back in 1995. I would like to thank Joe McClinton for what appears to me as an excellent and faithful job in translating the French original version of this book into English. This translation has given me a number of opportunities for updates, for example on the age of the Permo–Triassic sections from China, the eruption of the Emeishan Traps, the confirmation of the presence of anomalous iridium in the Deccan Traps (in the district of Kutch), our recent work on the Ethiopian Traps, the strong link between flood basalts and continental rifting, and the further suggestion that catastrophes (whether volcanic or of some other kind) are a prerequisite for any major shift in evolution. I hope English-language readers will enjoy this unconventional account of the causes of mass extinctions and reflect on the potential of modern Earth Sciences in helping us to use the past to make the future more understandable, though perhaps not predictable.

At the end of the book a Glossary, essentially produced by Stuart Gilder, to whom I am particularly grateful, defines many of the terms used within the text.

Paris, 1999

Foreword

The dinosaurs are the most famous of all fossils. From gigantic *Diplodocus* to terrifying *Tyrannosaurus rex*, through the waystations of the pterodactyl or *Triceratops*, they have all haunted our childhood fantasies. For more than a century, these strange fossils have posed a daunting riddle for scientists. They had reigned unchallenged for 200 million years on land, in the sea, and in the air; they were superbly adapted to their environment; they never ceased to grow larger and larger; yet all at once they vanished from the face of the Earth some 65 million years ago. Why?

In 1980 the physicist Luis Alvarez and his son Walter, a geologist, proposed an answer to the riddle: a gigantic meteorite struck the Earth, plunging it into dark and cold for several years. They thus revived the old hypothesis of Georges Cuvier, which linked changes in fossil flora and fauna to natural catastrophes. Was Darwin wrong in his theory of the continuous evolution of species?

The Alvarezes' work exploded like a bombshell in the serene skies of paleontology, sparking an extraordinary degree of scientific activity focused on their hypothesis and its consequences, and rapidly pitting supporters against dissenters. After a decade of space research, was it not natural to appeal to a cosmic influence in the evolution of species? On the other hand, was it acceptable that two scientists – themselves not even paleontologists – should call into question the 'certainties' of an entire profession? The exchange of arguments was vigorous, if not always rigorous.

It is this extraordinary scientific adventure that Vincent Courtillot recounts for us. But this is not the narrative of a spectator, however committed. It is an account from one of the active, creative, and incisive participants in this adventure, a participant who defends a thesis with talent and precision, but who also accepts arguments from others, provided they can pass the muster of his implacable logic.

This book reads like a novel, and the end takes an unexpected twist – incredible yet probable, a conclusion that shatters probabilistic beliefs, the well-known refuge of those who dwell among certainties.

I will leave to the reader the pleasure of following the episodes of this saga, which will remain one of the major scientific polemics of the current turn of the century.

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