

Perilous Planet Earth

CATASTROPHES AND
CATASTROPHISM
THROUGH THE AGES

TREVOR PALMER



CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011-4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa
<http://www.cambridge.org>

© Trevor Palmer 2003

This book is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 2003

Printed in the United Kingdom at the University Press, Cambridge

Typeface Quadraat 10/14 pt System L^AT_EX 2_ε [TB]

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data

Palmer, Trevor, 1944–

Perilous planet earth : catastrophes and catastrophism through the ages / Trevor Palmer.

p. cm.

Includes bibliographical references and index.

ISBN 0 521 81928 8

1. Asteroids – Collisions with Earth. 2. Catastrophes (Geology) 3. Evolution. I. Title.

QE506 .P35 2003

551.3'97–dc21 2002035183

ISBN 0 521 81928 8 hardback

Contents

Acknowledgments	page ix
Introduction	i
Part I Catastrophism: the story of its decline and fall . . . and resurrection	
Section A From prehistory to 1899: catastrophism dominates for centuries, but then gives way to gradualism	5
1 Mythology, religion and catastrophism	5
2 Hutton: fact and fiction about the origins of modern gradualism	16
3 Cuvier and Lamarck: choosing between extinction and evolution	23
4 Natural theology and Noah's Flood: the high-water mark of catastrophism	36
5 Catastrophism, uniformitarianism and idealist philosophy	42
6 Lyell triumphant: gradualism dominates geology	55
7 Darwin and evolution	60
8 After the <i>Origin</i> : the triumph of evolutionary gradualism	72
Section B From 1900 to 1979: gradualism reigns supreme	85
9 Neo-Darwinism: the Modern Synthesis	85
10 Phyletic gradualism	94
11 Gradualist perceptions of human evolution	105
12 Heretical catastrophists	114
13 Atlantis: rational and irrational theories of a 'lost' civilisation	125
14 Evolutionary mass extinctions and neocatastrophism	133
15 Punctuated equilibrium: a new evolutionary perspective	149
16 Human evolution: gradual or punctuational?	161
Section C From 1980 to the present day: catastrophism strikes back	167
17 Evolution evolving	167
18 Into the new millennium: evolution today	180
19 Chaos in the Solar System	188
20 Catastrophes on Earth	197

Contents

21	The death of the dinosaurs: iridium and the K–T extinctions	215
22	The continuing K–T debate	228
23	Mass extinctions and the course of evolution	244
Part II <i>Catastrophes and the history of life on Earth</i>		
24	Extinctions large and small	255
25	Cyclic processes and mass extinctions	274
26	The uncertain origins of humankind	287
27	Ice Ages in the Pleistocene Epoch	302
28	Modern views of Atlantis	316
29	Natural catastrophes and the rise and fall of civilisations	336
30	Conclusions	363
	Notes	373
	Index	503

Section A

From prehistory to 1899: catastrophism dominates for centuries, but then gives way to gradualism

I Mythology, religion and catastrophism

Ancient beliefs

In the ancient world, deities were generally believed to intervene in human history, often in a very major way. So, for example, according to the book of *Genesis*, in the Jewish and Christian traditions, God created the world. Then, six days later, after spending the intervening time filling it with fish, birds and land animals, he breathed life into Adam and Eve, the first man and woman. Just nine generations later, corruption had become so widespread that God brought about the Flood, when ‘the waters prevailed upon the earth an hundred and fifty days’, and ‘all the high hills, that were under the whole heaven, were covered’. However, Noah, who was an exception to the general rule of wickedness, had been given a warning about the coming deluge. That enabled his family to build a large boat, the Ark, on which to sail on the waters. In this way, they survived the Flood, supposedly the only humans to do so.¹

These events were all believed to have taken place within the past six thousand years. Using genealogies and information about time-intervals taken from the Bible, James Ussher (1581–1656), the protestant archbishop of Armagh, and an authority on Semitic languages, argued in his book *Annales veteris testamenti* (‘Annals of the Old Testament’), published in 1650, that the Earth must have been created in 4004 B.C. For that he has become a figure of ridicule, but in fact he was only following a long tradition, using a well-established methodology. The Jewish calendar introduced by the Palestinian patriarch, Hillel II, in 359 A.D., and still widely used today, starts when the world supposedly began, at a date equivalent to 3761 B.C. Similarly, the Venerable Bede estimated in the eighth century of the Christian era that the Creation took place in 3952 B.C. Returning to the seventeenth century, the great polymath, Sir Isaac Newton, who included the chronology of the ancient world amongst his many areas of interest, agreed with the conclusions of Ussher. Indeed, a 4004 B.C. Creation became generally

accepted in Britain and, for the next two centuries, dates from Ussher's chronology were often inserted in the margins of the Bible. One such date was that for the Flood, which was believed to have taken place in 2349 B.C.²

However, the legend of Noah does not stand in isolation. Indeed, it is just one of several hundred flood myths from around the world, many of which similarly involve a man and a woman escaping by boat. Amongst these is the one told in the Babylonian epic of Gilgamesh, where the hero, Uta-Napishtim, was warned by Ea, God of the Waters, about the coming deluge. Others include a Greek myth, where the survivors were Deucalion and his wife, Pyrrha, and one from the Aztecs of Mexico, where the equivalent figures were Coxcoxtli and Xochiquetzal.³

As well as legends of a catastrophic flood, there are other widespread myths where the Earth suffered near destruction by fire. According to the Aztecs, the present age (or 'sun') had been preceded by four others, each of which ended in catastrophic fashion. One of the transitions between world-ages involved (needless to say) a deluge, whereas another was brought about by fiery rain falling from the sky. Conflagrations were also a feature of the Greek tales of the battles fought by the Olympian gods against the Titans, the Giants, and the monstrous Typhoeus (or Typhon), when thunderbolts and molten rocks were hurled around as weapons. The fact that Zeus clashed with Typhoeus near Mount Vesuvius and finally trapped him under Mount Etna has suggested to some that these stories were inspired by a series of volcanic eruptions, involving an outburst of molten lava and ash from within the Earth, a process known alternatively as 'vulcanism' or 'volcanism'. These various terms were derived from the name of Vulcan, the Roman God of Fire, who was associated in legend with Vulcano, one of the Aeolian Islands off the northern coast of Sicily, between Vesuvius and Etna, and part of the same volcanically active region. Vulcano itself experienced major eruptions in 424 and 360 B.C. (and more recently in 1786 and 1888 A.D.).⁴

In Norse mythology, Odin and his fellow gods of Valhalla fought against the monstrous wolf Fenrir and the poisonous serpent Jormangard at the time of *Ragnarok* (or *Götterdämmerung*), when the world-order changed, accompanied by earthquakes, tidal waves, and episodes of fire and frost. Other legends where conflicts between heroic gods and evil monsters led to environmental convulsions on a massive scale include the battles involving Marduk and Tiamat in Babylonian mythology, Feridun and Zohak in stories from Persia, and Huitzilopochtli and Coyolxauhqui in Aztec tradition. Even where there were no such clashes between supernatural rivals, the human race could sometimes be threatened with mass destruction, as in the Greek myth where Phaeton tried to drive the Sun-chariot of his father, Helios, but lost control and came too close to the Earth. People were in danger of being burned alive until Zeus cast one of his thunderbolts, diverting the chariot and causing Phaeton to fall to his death.⁵

According to the philosopher Plato (c. 429–347 B.C.), writing in the *Timaeus*, his distant ancestor Solon had been told by an Egyptian priest at Sais, in the Nile delta, that the Phaeton myth owed its origin to one of a series of cosmic disturbances which

produced periodic catastrophes on Earth. The priest claimed, 'That story, as it is told, is in the style of a legend, but the truth of it lies in the shifting of the heavenly bodies which move around the Earth, and a destruction of many things on the Earth by fierce fire, which recurs after long intervals'.⁶

Naturally, we are under no compulsion to accept this as a statement of fact. According to the *Timaeus* and another of Plato's works, the unfinished *Critias*, a separate and more detailed story told to Solon on the same occasion concerned the destruction of the island civilisation of Atlantis by a catastrophic flood, but this is generally regarded with considerable scepticism. Even if the two books were intended as strictly historical accounts, which is by no means certain, Plato might have been misinformed. By his own admission, Plato's source, Critias, was an old man of failing memory, who had learned the entire story at the age of ten from his ninety-year-old grandfather, whose father had been told it by Solon. Critias did, however, claim that he had some of Solon's original writings in his possession.⁷ But even if the transmission of the story had been accurate, it might not have been so firmly based on knowledge as the Egyptian priest supposed.

How the ancient myths and legends came into being is far from clear, and the stimulus may have been quite different from one to the next. It is likely that some myths are dramas based on the replacement of one cult by another in a particular region, whereas others could be stories associated with rituals whose purpose was to induce fertility, the succession of seasons, or a hoped-for life after death.⁸ It is also possible that some legends may, to a greater or lesser extent, have been inspired by actual happenings. It will probably never be known whether any of the specific characters mentioned in Homer's *Iliad* and *Odyssey* ever lived, or whether the events took place as described, but archaeologists such as Heinrich Schliemann, Wilhelm Dörpfeld, Sir Arthur Evans and Carl Blegan found abundant traces of pre-classical civilisations at sites located from details in these stories.⁹ As to the flood and fire myths, they seem to indicate at the very least that ancient societies believed in the possibility of cataclysmic events, regardless of whether they themselves had actually experienced any.

In most ancient traditions, catastrophes were associated with divine displeasure. In the book of *Genesis*, as we have seen, God caused Noah's Flood because of the increasingly wicked behaviour of humankind. Shortly afterwards, the twin cities of the Dead Sea plain were destroyed for similar reasons. As related in *Genesis*, 'the Lord rained upon Sodom and upon Gomorrah brimstone and fire . . . out of Heaven', because not even ten righteous people could be found within them.¹⁰ Prophecies of further punishment for evil abound. According to *Psalms* 11, 'Upon the wicked he shall rain snares, fire and brimstone, and an horrible tempest';¹¹ whilst *Malachi* warns, 'For behold, the day cometh, that shall burn as an oven; and all the proud, yea, and all that do wickedly, shall be stubble; and the day that cometh shall burn them up, saith the Lord'.¹²

In an Egyptian myth, the sun-god, Ra, began to lose the respect of humankind as he grew older, so he loosed his 'eye' upon the Earth, causing great slaughter.¹³ Similarly,

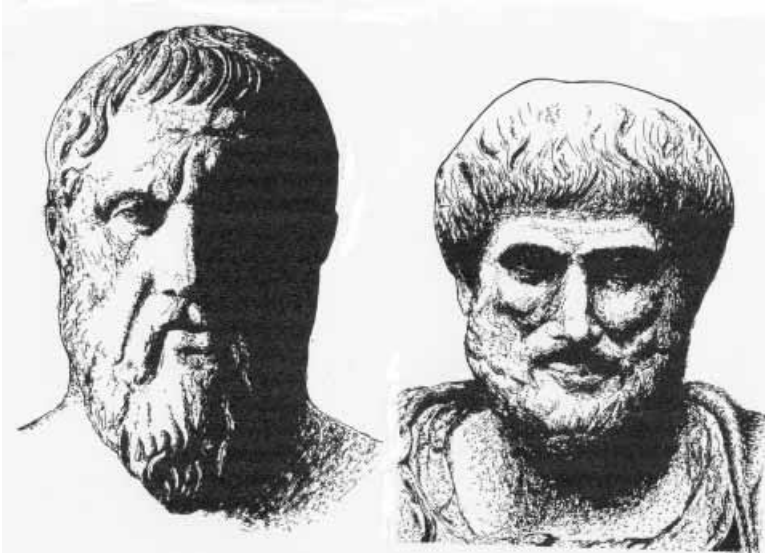


Figure 1.1 Left: Plato, based on a bust in the Fitzwilliam Museum, Cambridge, a first century A.D. Roman copy of a bronze by Silanion, probably made during Plato's lifetime. Right: Aristotle, based on a bust in the Kunsthistorisches Museum, Vienna, a Roman copy of a Greek original dating from the fourth century B.C.

in Greek mythology, Zeus often indicated his displeasure by casting thunderbolts, as in the story of Phaeton, whilst Poseidon was inclined to cause floods or storms when annoyed. So, for example, when the Trojan king Laomedon broke a promise to him, Poseidon flooded the nearby coastal plain and, for good measure, sent a sea-monster to terrorise the people.¹⁴

Such floods had undoubtedly occurred. By the time of Aristotle (384–322 B.C.), a pupil of Plato (figure 1.1), the evidence of marine fossils in outcrops of rock made it clear that at least part of what was now land had once been covered by sea. In his *Meteorologica*, Aristotle wrote that there were periodic transpositions of land and sea, but generally those occurred too slowly and over too long a time interval for anyone to notice them happening. Nevertheless, on rare occasions a great winter could occur, bringing protracted heavy rainfall and causing devastating floods, such as that of Deucalion.¹⁵ Similarly, there could be a very lengthy arid period, a great summer. The Greek word for the great winter flood, *kataklysmos*, is the origin of the modern word cataclysm.

Aristotle had views very different from those of his teacher Plato who, as we have seen, accepted that sudden and violent events could take place in the heavens, with serious consequences for the people below. According to Aristotle, writing in his *De Caelo*, the stars and planets occupied a series of concentric spheres and, unlike the corrupt

Earth, which was located at the centre, the heavens were perfect and unchanging.¹⁶ Comets and shooting stars, as he explained in another book, the *Meteorologica*, were purely terrestrial phenomena, caused by changes of temperature, coupled with friction between the Earth's atmosphere and the innermost sphere.¹⁷

Many of Aristotle's ideas, including his concept of a stable Universe, with the heavens segregated from the Earth, were taken up by the Christian philosopher Thomas Aquinas in the thirteenth century, and remained influential amongst scholars for many centuries afterwards.¹⁸ At the same time, the Church maintained a belief that the world would come to an end in catastrophic fashion. As prophesied in the *New Testament*, 'the day of the Lord will come as a thief in the night; in which the heavens shall pass away with a great noise, and the elements shall melt with fervent heat, the earth also and the works that are therein shall be burned up'.¹⁹ There was not seen to be any contradiction here: cosmic catastrophes could be brought about by the intervention of God, but not by any natural process.

The appearance of a comet in the sky was generally viewed with alarm, as it was thought to signal some coming disaster.²⁰ For example, the Venerable Bede, in his *Ecclesiastical History of the English People*, wrote, 'In the year of the incarnation of Our Lord 729, two comets appeared about the Sun, to the great terror of the beholders'.²¹ The very word 'disaster' was derived from the Latin words 'dis' and 'astrum', together meaning 'evil star'. The disaster could be to the population as a whole, or to an important individual. So, in William Shakespeare's play *Julius Caesar*, written in 1599, Caesar's wife, Calpurnia, is concerned by unusual features in the sky, and warns her husband, on the night before his assassination, 'When beggars die there are no comets seen; The heavens themselves blaze forth the death of princes'.²²

Cosmogonists: blending belief and observation

In the seventeenth and eighteenth centuries, various theories of the formation and development of the Earth were put forward by the so-called cosmogonists. Their interest was the origins of stars and planets, whereas the main concern of a different group, the cosmologists, was the nature of the Universe as it actually existed at the time. Posterity has consistently admired cosmologists such as Galileo Galilei (1564–1642) and Sir Isaac Newton (1642–1727), who followed the example of Nicolaus Copernicus (1473–1543) in rejecting Aristotle's geocentric Universe in favour of the modern system in which the Earth and planets orbit the Sun, according to natural laws. In contrast, for reasons we shall come to later, twentieth century geologists generally believed that the cosmogonists who lived around the same time as Galileo and Newton had been extremely poor scientists.

The cosmogonists were catastrophists, i.e. they believed that 'the history of the Earth has to be explained by events radically different from anything going on at the present day', which is the definition of catastrophism given in the *Cambridge Encyclopedia*.

Other reference books define catastrophism as the theory that the Earth's geological features have been fashioned by 'sudden, short-lived, worldwide events' (the McGraw-Hill *Dictionary of Scientific and Technical Terms*), by 'sudden, violent and unusual events' (the *Oxford English Reference Dictionary*) or by 'infrequent violent events' (the *Chambers Dictionary of Science and Technology*).²³

Whichever of these precise definitions is used, it is clear that geological catastrophism, in itself, is a perfectly rational notion, regardless of whether or not it is correct. However, it has generally been supposed that a characteristic feature of seventeenth, eighteenth and nineteenth century catastrophism was an association with supernatural forces, particularly as an explanation of the replacement of one set of fossil forms by another during the course of the Earth's history. So, for example, in 1982, the University of Guelph science historian Michael Ruse wrote of the catastrophists in his book, *Darwinism Defended*: 'They argued flatly that new species of organism, including God's final creation, man, were produced miraculously by God. God wants no nonsense about unbroken laws coming between them and his handiwork. He intervenes personally.'²⁴ Similarly, a few years later, the Oxford University zoologist Richard Dawkins claimed in his book *The Blind Watchmaker* 'Catastrophism was an eighteenth – and nineteenth – century attempt to reconcile some form of creationism with the uncomfortable facts of the fossil record'.²⁵ Again, the Johns Hopkins University palaeontologist Steven Stanley wrote in *Earth and Life Through Time*, published in 1986, that, up until the early nineteenth century, many natural scientists were catastrophists who believed that 'floods caused by supernatural forces formed most of the rocks visible at the Earth's surface'.²⁶

As we shall see, such statements present a false picture of the catastrophists of the seventeenth to nineteenth centuries. Whilst it is true that they were unable to separate science from religion, the same was true of all their contemporaries. There seems no justification for making critical judgements on, say, cosmogonists, by the strict application of twenty-first century standards, whilst ignoring some of the strange views of cosmologists. We have to consider both groups in the context of the times in which they were living, including the fact that they were sometimes forced to adopt orthodox views (as Galileo was compelled by Pope Urban VIII to recant his belief that the Earth moved around the Sun), or risk sharing the fate of the philosopher Giordano Bruno who was burned to death as a heretic in 1600.²⁷ If cosmogonists and cosmologists are looked at together, it can be seen that they had much in common, operating within the complex intellectual climate of their day.²⁸ Even Newton, who is justly given great credit for formulating the mathematical laws of gravity, could never accept that gravitational forces were purely materialistic phenomena. Rather, he considered them to be an expression of God's will.

That comes over clearly in an exchange of letters between Newton and Richard Bentley, Chaplain to the Bishop of Worcester, following a series of sermons on the 'evidences for Christianity' preached by Bentley at St Martins-in-the-Fields, London,

in 1682. At the end of that year, Bentley wrote to Newton, 'It is inconceivable that inanimate brute matter should (without a divine impression) operate upon and affect other matter without mutual contact'. Newton replied that he agreed wholeheartedly, echoing Bentley's words and adding, 'That gravity should be innate, inherent, and essential to matter, so that one body may act upon another, at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it'.²⁹

It should not be forgotten that, for many centuries, the Church had maintained and controlled scholarship in Christian countries, everything having to be considered within a spiritual context.³⁰ Without question, the most reliable source of information was believed to be the Bible, which testified that the Earth was only a few thousand years old, and that there had been a single major cataclysm, the Flood in the time of Noah. Anyone who thought differently was in a difficult position, because to have said so would have incurred the wrath of the Church, and the risk of being condemned as a heretic. That continued to apply even after the Reformation in the early sixteenth century. The leading Protestants, including Martin Luther and John Calvin, emphasised the role of *The Bible* in determining 'true' doctrine. Similarly, for the Catholic Church, the Council of Trent, which met at Trento, in northern Italy, between 1545 and 1563, confirmed the belief that the Latin Vulgate Bible represented the authentic word of God.³¹

At that time, it was still generally accepted that all marine fossils found inland had been carried there by Noah's Flood, although Leonardo da Vinci (1452–1519), Girolamo Fracastoro (1483–1553) and a few others had argued that this was impossible, because the thickness of beds containing such fossils was incompatible with the short time-scale. Instead, the land must have risen in places, changing the shoreline in significant fashion, just as Aristotle had suggested.³²

In 1669, the Danish naturalist Niels Stenson, better known as Nicolaus Steno (1638–1686), produced a theory to explain the landscape of Tuscany in which the Flood played a prominent but far from unique role. Other features included the elevation of land in some locations because of precipitation of sediments from the waters, and lowering of the land elsewhere as a consequence of the collapse of caverns under the ground. Steno appreciated that not all rocks had been formed at the same time and so, since rock formation most likely involved the deposition of sediment on existing rock, each stratum in a formation must be younger than the one below. Some rocks would have been formed from sediments precipitated from the waters of Noah's Flood, whereas earlier ones must have been part of the land which emerged from the original worldwide ocean, as described in the *Genesis* account.³³

Later, following a similar methodology, several English cosmogonists put forward models that tried to reconcile observations of the natural world with the teachings

of the Church. Thomas Burnet (1635–1715), an Anglican clergyman who became chaplain to King William III, proposed a system which had some features in common with that of Steno. However, instead of relying on rain and subsidence to cause the Flood, Burnet suggested that wide cracks appeared in the Earth's surface, allowing water to be forced upwards from underground stores. He believed this sudden release of water might have caused the Earth's axis to tilt.

Considered against the attitudes of his time, Burnet was undoubtedly a rationalist. He wrote to Newton early in 1681 to explain why he could not accept a literal interpretation of *Genesis*, which maintained that the Earth had been created in just six days. His major work was the four-volume book, *The Sacred Theory of the Earth*, published during the 1680s. As was inevitable in the seventeenth century, he started with the assumption that the Biblical record was essentially true, even if not accurate in every detail, and then sought natural explanations for the events described. Newton, as we have seen, thought that gravitational forces must be supernatural in origin, yet operated in an unchanging fashion according to physical laws. Similarly, Burnet, having little time for those who invoked miraculous interventions as an explanation for observed phenomena, believed that God had set natural laws in motion at the time of Creation. He pointed out, 'We think him a better artist that makes a clock that strikes regularly at every hour from the springs and wheels which he puts in the work, than he that hath so made his clock that he must put his finger to it every hour to make it strike'.³⁴

Burnet was not prepared to accept that the waters causing the Flood had been created miraculously by God. However, they must have come from somewhere, so the interior of the Earth seemed the most likely possibility. That suggestion was strongly opposed by those who viewed with displeasure any departure from the traditional interpretation. On the other hand, whatever the cause of Noah's Flood, Robert Hooke (1635–1703), a founder-member of the Royal Society of London, was unconvinced that it could have lasted long enough to account for all the world's fossil-bearing strata. Instead, the evidence seemed to suggest that earthquakes had occasionally caused significant rearrangements of land and sea.³⁵

Nevertheless, cosmogonists continued to propose systems in which Noah's Flood played a major role. In the model of John Woodward (1665–1728), a geologist based at Gresham College, London, who was a pioneer of fieldwork and a Fellow of the Royal Society, the Flood arose much as Burnet had suggested. Then, in some way, it dissipated all the rocks previously in existence. Afterwards, materials carried by or released from the waters of the Flood sedimented according to their specific gravities to form horizontal strata. These were later dislocated by depressions and elevations of unspecified origin to form the patterns which were so apparent to observers.³⁶

William Whiston (1666–1753), who succeeded Isaac Newton in the chair of mathematics at Cambridge University, was another who thought that some of the

waters of the Flood might have been released from the interior of the Earth, but he considered that the major proportion had fallen as rain derived from the vapours in the tail of a passing comet. He also believed that the passage of the comet brought about the diurnal rotation of the Earth and changed its orbit from a perfect circle to an ellipse. These ideas were presented in his book, *A New Theory of the Earth, from its Original, to the Consummation of all Things*, which was published in 1696.³⁷ Long before this, in 1577, detailed observations by the Danish astronomer Tycho de Brahe had demonstrated that, contrary to the teachings of Aristotle, comets travelled in regions far beyond the Earth's atmosphere. Whiston was also aware, from observations of the great comet of 1680 made by John Flamsteed, the Astronomer Royal, that comets moved between the region of the Sun and the outer Solar System in highly elongated orbits. Furthermore, Edmond Halley had calculated that the comet of 1682 (which subsequently took his name) had the same orbit as those of 1531 and 1607, and predicted, correctly as it turned out, that it would return in 1758. He was not so close to the mark when he deduced (quite incorrectly) that the 1680 comet was the same as the great comet of 1106, thus having a periodicity of 575 years, but this led Whiston to believe that it could have made an earlier visitation in 2342 B.C., around the time the Flood was thought to have occurred.³⁸

Whiston was eventually dismissed from his post for expressing various views which gave rise to theological concern. Amongst these was his belief that global catastrophes, past and future, might be caused by natural phenomena. Halley had similar thoughts about this subject, but showed more caution about letting them become generally known. In 1694, in a lecture entitled 'Some considerations about the Universal Deluge', he had suggested to the Royal Society that the story of Noah's flood might be an account of a cometary impact, the projectile splashing into the Caspian Sea, with devastating consequences for the surrounding lands. Precisely what happened after the lecture is uncertain, but Halley went back to the Royal Society a few days later to tell the members that he had been mistaken, and his paper was not published for another 30 years.³⁹

By this time it was clearly established that comets were neither atmospheric phenomena nor signs of divine displeasure. Instead, as conclusively demonstrated in Newton's *Principia Mathematica* of 1687, they were objects obeying the same laws of motion as all cosmic bodies. However, even here, in his greatest scientific work, Newton emphasised his belief that these laws had been established by a benign God. Hence, comets obeying them were far more likely to have beneficial effects than to bring disaster to the planet. Near the end of Book 3 of the *Principia*, he suggested that they formed part of some divine plan to maintain life on Earth by replenishing the planet's stores of water during a close passage, writing that 'comets seem to be required, so that from the condensation of their exhalations and vapors, there can be a continual supply and renewal of whatever liquid is consumed by vegetation and putrefaction and converted into dry earth'.⁴⁰

Eighteenth century cosmogony and Neptunism

On the continent of Europe, Newton's laws of planetary motion were slow to become accepted, largely because of the influence of the theories of the French mathematician and philosopher René Descartes (1596–1650). In 1644, in his *Principia Philosophiae*, Descartes argued that space was full of matter which, in the beginning, had been stirred into movement by God, as part of a carefully formulated plan, and then left alone for the system to develop in purely mechanical fashion. Vortices were produced, in which the Sun and planets were able to form by condensation, the planets being whirled around the Sun by the continuing action of the vortices.⁴¹ In Germany, another mathematician and philosopher, Baron Gottfried von Leibniz (1646–1716), accepted Descartes' view that the newly condensed Earth would have been very hot, and hence in a fluid-like state. He developed the notion that, as it cooled, a crust formed which later cracked on occasions to release flood water from within the Earth, each time depositing a layer of sediment.⁴²

Around the middle of the eighteenth century, the French naturalist Georges-Louis Leclerc, Comte de Buffon (1708–1788), suggested that the 'days' of creation in *Genesis* were not meant to be taken literally. It made more sense, he thought, to regard them as periods of unspecified but great length. Buffon calculated that if, as he personally supposed, the Earth had been formed by a collision between the Sun and a comet, it could have cooled down sufficiently within 35,000 years to allow condensation of atmospheric water vapour to form a universal ocean. Further cooling over many tens of thousands of years caused cavities to appear in the Earth's surface, through which sea water drained until it reached its present level. As volcanoes began to erupt, the continents appeared and valleys were gouged out by ocean currents. More cooling took place and there was gradual erosion of the mountains, until the Earth assumed its present form.⁴³

Buffon's fellow-countryman Benoît de Maillet (1656–1738) believed that erosion of the earliest mountains by the action of the ocean over a time-scale of millions of years was an important factor in producing sediment from which new mountains could be made. These ideas were expressed in a book entitled *Telliamed* (a reversal of the author's name), published in 1748 but written over thirty years earlier. In an attempt to avoid offending the Church, *Telliamed* was presented as a work of fiction, de Maillet's speculations about the history of the world being put into the mouth of an Indian philosopher. As well as having heretical views about geology, de Maillet also believed that every species alive today had originated in the primaeval ocean as a result of the natural germination of seeds which pervaded the Universe, each developing separately into modern forms as conditions changed.⁴⁴

Theories that a universal ocean once contained in solution all the material that later formed the Earth's crust were generally labelled as 'Neptunist' (after Neptune, the Roman God of the sea). The most influential advocate of Neptunist views was

Abraham Gottlob Werner (1749–1817), a German mineralogist and geologist associated with the Freiburg Mining Academy, who developed the ideas of his fellow countrymen Johann Gottlob Lehman and George Christian Füchsel. In Werner's theory, precipitation of dissolved material took place over long periods of time, first forming primitive rocks such as granite, and then, as erosion of these began to contribute to the process, deposits such as limestones and slates. Later, when mechanical deposition became more significant than chemical precipitation, came the laying down of chalk and other fossil-rich rocks, together with basalt. Whilst all this was going on there were occasional episodes when powerful currents, associated with sudden drops in water-level, cut deep channels through the sediments. Localised uplift of rock also occurred, generally linked to volcanic activity.⁴⁵

Werner's ideas were most certainly not determined by religion. He believed that the Earth was far older than a few thousand years, and refused to speculate, because of a lack of scientific evidence on which to do so, about where the universal ocean might have come from, and where the water went when the sea-levels fell. However, the British supporters of Neptunism, such as Robert Jameson in Scotland and Richard Kirwan in Ireland, tried to find, and then emphasise, links with the scriptures. Similarly, Jean André de Luc, who was Swiss by birth, but spent most of his working life in England, presented a Neptunist theory which was explicitly in line with the *Genesis* account. De Luc claimed that there had been a universal flood in relatively recent times, and six periods of deposition, which corresponded to the six days of creation.⁴⁶

He was not alone. At around the same time, the second half of the eighteenth century, others in Britain such as Alexander Catcott, Patrick Cockburn, John Whitehurst and John Williams were still maintaining the old traditions, producing cosmogonies which attempted to be consistent with accumulating field evidence, whilst retaining a place for Noah's Flood. Often, these were variants of earlier models. So, for example, Whitehurst agreed with Woodward that materials had precipitated from the waters of the Flood, settling according to their densities, but differed from him by thinking that this process had been uneven, because of the gravitation effects of the Moon. However, by the end of the century it was becoming increasingly clear that, even if the Flood had occurred, it could only have been one of many factors responsible for the formation of features at the Earth's surface.⁴⁷