The Age of the Earth

Robert S White

'We find no vestige of a beginning,– no prospect of an end', Hutton 1788[1]

'I am the Alpha and the Omega, the First and the Last, the Beginning and the End.' Rev. 22:13

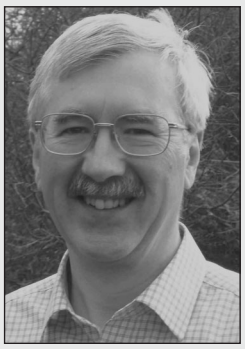
Summary

The best estimate for the age of the material which forms the Earth is 4,566 million years, which is accurate to within a few million years. The universe is three times older, at 13,700 million years. Modern humans extend back only a few thousandths of one per cent of the age of the Earth, although living organisms have been present on Earth throughout most of its history. I discuss the scientific basis of geological dating, historical and recent views on the age of the Earth, and some theological implications that follow from the biblical and scientific evidence.

It might seem odd to need a paper on the age of the Earth at the beginning of the twenty-first century. The understanding of 'deep time' which started in the Reformation and was widely accepted amongst educated people by the 1850s marked a major change in perception of the place of humans in the universe.[2] Not only were humans a tiny speck in a vast universe, but they now occupied only the tiniest part of an almost unimaginably long history, for almost all of which they were not even present. The seemingly never-ending cyclicity of many geological processes highlighted in the quotation from Hutton at the head of this paper also seemed at first sight to contradict the one-way progress of history that is characteristic of the Bible accounts. Although these new views were accommodated easily at the time in the religious understanding of people with a wide spectrum of beliefs, there have been attempts by some Christians and Muslims since the latter part of the twentieth century to reverse the clock and espouse a very young age for the Earth despite the overwhelming scientific evidence to the contrary.

Scientific Perspectives on the History of the Earth

The Earth, and indeed the entire solar system, was formed from a massive collision of meteoritic material which collected into discrete planetary bodies. The most basic method of geological dating is to use the layering of a rock sequence to define the order in which they were formed, known as their stratigraphy. This is conceptually straightforward: younger rocks usually lie above older rocks, especially if they are sedimentary in origin, unless subsequently they have been disturbed. An important extension to this ordering is that rock units of the same age can be correlated around the world, provided they carry some unique identifier which changes through time. Fossils are an excellent example of such a marker: they can be used to 'tag' the age of that rock to be the same as all others around the world which carry the same fossils. This dating is improved if assemblages of different fossils are used rather than just single species, because different species survived for different intervals of the geological history. Importantly, this only tells us the *relative* age of a rock layer in the global sequence, and not its absolute age. Dating by fossils is only useful for the last 10% of the Earth's history (see Table).



About the Author

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The simplest method of calculating the *absolute* age of a rock is to use known cyclic changes, such as annual tree ring growth or predictable variations in the Earth's orbit that affect some characteristic of the rock layers that are laid down, and then to count these cycles back in time starting from the present. Individual tree ring widths vary according to local climate changes. If all the trees in one region exhibit the same climate-controlled patterns, tree rings can be counted back beyond the lifespan of individual trees by finding older timber with sufficient overlap to correlate the distinctive tree-ring pattern from the younger to the older. A unique tree-ring chronology has been built from trees in central Germany extending back beyond 8400 BC and similar chronologies have been developed elsewhere.

Annual layers are also found in coral growth rings, in lake sediments and in snow layers accumulated in continental interiors, such as the Greenland and the Antarctic icecaps. In Greenland, deep coring has penetrated ice more than 200,000 years old, while in the Antarctic a 3190 metre (10,500 feet) core has reached ice 740,000 years old.[3] Counting annual layers in the uppermost ice is unam-

1 Hutton, J. 'Theory of the Earth', *Transactions of the Royal Society of Edinburgh* (1788) 1, 209–305.

2 See Roberts, M. B. 'Genesis Chapter One and Geological Time from Hugo Grotius and Marin Mersenne to William Conybeare and Thomas Chalmers (1620 to 1825)', In *Myth and Geology,* Geological Society of London Special Publication (2007) and Gould, S. J. *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time*, Harvard University Press, Cambridge, Massachusetts (1987), 222pp.

3 North Greenland Ice Core Project Members 'High-resolution record of northern hemisphere climate extending into the last interglacial period', *Nature* (2004) 431, 147–151 (reports ages back to 123,000); EPICA Community Members 'Eight glacial cycles from an Antarctic ice core', *Nature* (2004) 429, 623–628 (reports ice 740,000 years old sampled at the base of an Antarctic ice core).

biguous, but at greater depths, as layers become compacted, it is possible that some annual layers may be overlooked, or that near the base of the ice sheet remelting or folding has distorted the annual layering. Conservative estimates of the errors in counting annual layers increase from about 2% at 11,000 years to 10% at 150,000 years ago.

Perhaps more surprisingly, changes in the Earth's orbit cause long-term cyclicity in climate patterns, known as Milankovitch cycles. Eccentricity of the Earth's orbit round the sun produces 100,000 and 413,000 year cycles, tilt of the Earth's axis generates 40,000 year cyclicity, and precession of the Earth's axis of rotation creates cycles at approximately 19,000 and 23,000 years. Identification of these cycles by their rhythmic climatic effect on ancient sediments allows precision dating back to 30 million years.[4]

A final example of irregular cyclic changes that can be used to date rocks is their magnetic polarity. Fluid motions in the Earth's liquid outer core create a dynamo which generates a global dipole magnetic field roughly aligned with the Earth's axis of rotation. The magnetic field reverses its polarity on average 2–3 times per million years. Since rocks bearing magnetised minerals record the direction of the magnetic field at the time they were deposited, the polarity reversals can be recognised and used to date the volcanic basement of the seafloor back 170 million years. This technique was the basis of recognising seafloor spreading, leading quickly to the plate tectonics theory which in the 1960s revolutionised geological interpretation of the Earth's history.

Radiometric dating remains the most useful method for dating the older rocks found on Earth, and indeed the age of the Earth itself. It relies on the fact that many atoms that occur in nature have unstable nuclei (the 'parent' nuclides) that decay spontaneously to a lower energy state (the 'daughter' nuclides): because this radioactive decay involves only the nucleus of an atom, the rate of decay is independent of physical and chemical conditions such as pressure, temperature and chemical binding forces. This makes them ideal chronometers.[5]

In its simplest form, radiometric dating involves measuring the daughter/parent ratio of an isotopic system with a known decay rate. This involves two main assumptions: first that no atoms of the daughter nuclide were present when the rock was formed, or at least that the initial ratio is known; and secondly that no parent or daughter atoms have been lost preferentially from the rock since its formation. In general, the daughter atoms are less well adjusted to the crystal lattice than are the parent atoms, and so tend to escape preferentially when the rock is heated or otherwise disturbed. So if dates are inaccurate they tend to err in a 'young' direction because some of the daughter atoms have escaped. The best way to protect against untrustworthy dates is to use two or more different decay systems on the same rock, or to use decay systems of three different isotopes which allow checks to be made for internal consistency.

Well over forty different radiometric isotopic systems are in current use for dating rocks. Half-lives of commonly used isotopic systems cover a wide span: examples include 106,000 million years for samarium-147 to neodymium-143; 18,800 million years for rubidium-87 to strontium-87; 1,260 million years for potassium-40 to argon-40; and 700 million years for uranium-235 to lead-207. Shorter time periods are best investigated using cosmogenic isotopes generated in the atmosphere, such as 1.52 million years for beryllium-10; 300,000 years for chlorine-36; and 5715 years for the well-known carbon-14. In most cases decay rates are known to within 2%, and uncertainties in the dates derived from radiometric decay are of a similar magnitude of a few per cent.

The span of half-lives makes it possible to date rocks of differing ages by choosing an appropriate isotopic decay system, although the precision of the measurement limits reliable ages to a maximum of 5–6 half-lives. The best-known technique using carbon-14 is useful for archaeological and recent geological studies, but is of no use for dating the demise of the dinosaurs (60 million years), or the age of the Earth. The most accurate methods in current use for dating geological rocks are uranium-lead and argon-40/argon-39 methods. These both rely on two different decay systems, which enables internal consistency checks to be made that no isotopes have been gained or lost.

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The age of the Earth has been determined as 4,566 ± 2 million years using the uranium-lead decay system, which has a suitably long half-life. On its own, knowledge of the present daughter/parent ratios in lead ores found on Earth only tells you the age since they separated from the parent mantle of the Earth. The trick in using them to date the Earth itself is to measure the uranium-lead ratios found in meteoritic material which has recently fallen to earth and to compare the present ratios with those. Because such meteorites have remained isolated as they travelled through space since the formation of the solar system, they record the pristine isotopic ratios of the material which initially accreted to form the Earth. Strictly therefore the age of the Earth we measure is the age of formation of the material which formed the solar system.

The oldest reliably dated, *in-situ* continental crustal rocks that are geographically contiguous over a large area occur in western Greenland, and date from 3,806 ± 2 million years: they show evidence of deposition in water, so oceans already existed at this early stage of the Earth's history shortly after the end of the main period of meteorite bombardment about 3,900 million years ago. There is more debated evidence of 4,031 ± 3 million year old crustal rocks from Canada. Zircon grains, which are resilient to erosion, found in Western Australia are 4,408 ± 8 million years old, close to the age of the Earth itself.[6] The oldest putative biogenic material, inferred from carbon-13 depleted graphite, is 3,850 million years old, and undoubted microfossil remains occur in 3,500 million year old rocks.

So far I have discussed only dating material we can sample, such as rocks on Earth. How do we date astronomical events during the first two-thirds of the history of the universe, before the Earth was formed? The answer is to use the normal scientific technique of investigating physical processes we can observe today and extrapolating them to the wider sphere of the universe. For example, by assuming that the speed of light is constant and that the universe is expanding, the doppler shift of light coming from distant parts of the universe (the 'red shift') can be used to calculate how far it has travelled, and therefore how old it is. The best currently determined age of 13,700 million years for the origin of the universe comes from observing the intensity of the microwave background radiation that permeates space.

Historical Perspectives on the History of the Earth

Attempts to date the Earth in the pre-Christian era range from Zoroaster's sixth century BC belief in an age of the world of more than 12,000 years, through dates of hundreds of thousands of years

4 Hinnov, L. A. 'Earth's orbital parameters and cycle stratigraphy', In Gradstein, F., Ogg, J., and Smith, A., (eds.) *A Geologic Time Scale 2004*, Cambridge University Press (2004), pp. 55–62.

5 For a good introduction to radiometric dating see Wiens, Roger C. *Radiometric Dating: A Christian Perspective,* available at www.asa3.org/ASA/resources/Wiens.html

6 Wilde et al. 'Evidence from detrital zircons for the existence of continental crust and oceans on the earth 4.4 Gyr ago', *Nature* (2001) 409, 175–178.

based on the supposed longevity of major ancient civilisations, to the beliefs of the priesthood of Chaldea reported by the Roman writer Cicero that the Earth emerged from chaos two million years ago.[7]

Throughout most of the Christian era, educated people have looked to the Bible as the source of credible information on the age of the Earth. For example, in 1600 AD Shakespeare had Rosalind say in *'As You Like It'* that 'The poor world is almost six thousand years old'. One of the first people to make serious calculations using biblical data was Theophilus of Antioch, who in 169 AD used biblical chronologies to calculate an age of 5529 BC for the creation of the universe. He was the first of many. Bishop Ussher's (1581–1656) date of 4004 BC for Adam is only one of many similar calculations, although its influence has been exaggerated by later writers: only a handful of theologians in the seventeenth and eighteenth centuries adopted a strict twenty-four hour day chronology for Genesis 1.

By 1778 Buffon published an age for the Earth of 74,000 years with an unpublished estimate of 2 million years. So, right from the beginning of Geology as a science, it is clear that extremely long time periods on the Earth were envisaged by its new practitioners, far longer than those recorded by human history. Between 1770–1800 the main controversy was not whether the Earth was 6–8,000 years old, but whether it was around 100,000 or many millions of years.[8] By the time Darwin wrote '*On the Origin of Species'* in 1859,[9] the idea that the Earth was millions of years old (Darwin calculated the age of the Weald as 300 million) was well established, not least by the clerical geologists such as Buckland and Sedgwick who dominated geology at Oxford and Cambridge. For example, in 1860 John Phillips, the Professor of Geology at Oxford University, used data from the sediments in the Ganges Basin to estimate the rate of sedimentation, and deduced an age for the Earth's crust of 96 million years. There were many other similar calculations. The conservative Anglican view of the 1860s is well expressed by the Rev Richard Main: 'Some school-books still teach to the ignorant that the earth is 6,000 years old… No well-educated person of the present day shares that delusion.'

The next main player in calculating the age of the Earth was Lord Kelvin (1824–1907), the leading physicist of his day and, incidentally, a Christian who was firm in his belief in the existence of design or divine order. From arguments about heat production by the Sun he deduced that it was probably less than 100 million years old,[10] and subsequently from arguments about the heat loss from Earth derived an estimate for the Earth's age of 98 million years, with a range from 20–400 million years.[11] His arguments were mathematically sound, and seemingly superior to the geological estimates by Darwin, Phillips and others. They shook Darwin sufficiently for him to reduce his estimate of the age of the Weald by a factor of 2–3 in his second edition of the '*Origin of Species'*, and he removed his calculation entirely from the third edition. But other geologists still felt certain that Kelvin's calculations, however clever, simply did not provide sufficient time to produce the geological strata they walked over and hammered.

The resolution of this impasse was provided by the discovery by Henri Becquerel in 1896 of radioactivity, and its recognition in 1903 by Pierre Curie as a heat source in radium. Kelvin had known nothing of radioactive processes, which is why his estimates based on cooling of the Earth and the Sun were more than an order of magnitude too small. Once the heating caused by the decay of radioactive elements was included, the age of the Earth required to explain its present temperature increased immensely. Rutherford quickly became a leader in the new field of radioactivity, and it is striking that very early in this new research area, in 1904, he suggested that the decay of helium trapped in minerals might provide a way of calculating geological ages. From then on it was just a matter of improving the estimates as better rock samples were examined and, chiefly, as better instrumentation became available. By 1953, Patterson found an age for the Earth of 4,550 million years, which has scarcely been improved on since.[12]

Although the Earth has been widely accepted as many millions of years old since the early 1800s, with increasingly accurate measures of its age derived through the first half of the twentieth century, a reversion amongst some fundamentalist Christians to belief in an Earth only 6,000–10,000 years old developed in the latter part of the twentieth century. Popularisation of this belief can be traced to publication in 1961 of *The Genesis Flood* by Whitcomb and Morris.[13] They maintained that there was a worldwide flood that in a single year laid down most of the geological strata, and that the whole universe was created in six literal days of twenty-four hours each. Their stance was based on a belief in the inerrancy of the Bible coupled with unwavering confidence in their own interpretation of the early chapters of Genesis.

Arguments over the age of the Earth were often conflated with a desire to repudiate the theory of evolution, giving rise to the Young Earth Creationist (YEC) movement. In 1963 the Creation Research Society was founded, followed in 1972 by the Institute for Creation Research, and a host of smaller creationist organisations. They were strongest in the USA, where they sought to normalise YEC beliefs into mainstream education, particularly in public (i.e. State) schools. In this aim they were generally unsuccessful, with a series of legal judgments up to the present day ruling that creationist beliefs, and their successors in the Intelligent Design movement, were religious rather than scientific in nature.[14] However, they were effective both in causing the publishers of lucrative school textbooks to become more circumspect in their teaching of biological evolution, and in creating a climate where there is now widespread acceptance amongst the US populace of YEC views.

'life existed on Earth almost as soon as the environmental conditions made it possible to do so.'

Despite the surprisingly strong popular acceptance of YEC views, the creationist movement has published little in the peer-reviewed scientific literature, and there is no acceptance of YEC views amongst professional geologists. The response of the scientific community to YEC claims was first to ignore them, since by and large scientists were incredulous that such views could be maintained in the light of scientific evidence to the contrary. However, as the strength of YEC rhetoric increased, the secular scientific world responded by setting up not-for-profit organisations such as the National Center for Science Education to defend the teaching of evolution in public schools in the USA. There is not space here to discuss the reasons why each of the myriad YEC claims for a young Earth lack credibility, but well argued secular[15]

7 See Lewis, C.L.E. & Knell, S.J. (eds.) *The Age of the Earth: from 4004 BC to AD 2002*, Geological Society of London (2001), Special Publication No. 190, 288pp. for an excellent collection of articles on historical attitudes to dating the earth.

8 M. J. S. Rudwick *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution,* U. Chicago Press (2005), 840pp.

9 Darwin, C. *On the Origin of Species*, London: Murray (1859) p. 282.

10 Kelvin, Lord *Macmillans Magazine vol.* 5 (1862), p. 288.

11 Thomson, William (Lord Kelvin) 'On the secular cooling of the earth', *Philosophical Magazine* (1863) (series 4) 25, no. 165, 1–14.

12 For further details on dating the Earth see Dalrymple, G. B. *The Age of the Earth*, Stanford University Press (1991), 474 pp.

13 Whitcomb, J.C. & Morris, H.M. *The Genesis Flood: The Biblical Record and its Scientific Implications*, Philadelphia: Presbyterian & Reformed (1961).

14 See www.natcenscied.org

15 See the index to creationist claims on the Talk Origins web site at www.talkorigins.org/indexcc/ for a secular view of YEC claims, although responses are of variable quality due to the open nature of the postings.

and Christian[16] point-by-point rebuttals are widely available.

Theological Perspectives on the Age of the Earth

Two striking things stand out from the list of significant dates in the Table.[17] First, life existed on Earth almost as soon as the environmental conditions made it possible to do so. And ever since then, through thousands of millions of years, the conditions on Earth have remained favourable for life to continue, despite the Sun's power having increased by about 30%, and the rate of the Earth's rotation having slowed by a factor of 4–5.[18] This is remarkable, because life requires a relatively narrow band of environmental conditions to survive. If the temperature of the Earth's surface were to increase to more than 100ºC, all the water would boil off and that would be the end of life as we know it. At the other extreme, if it were not for the greenhouse effect of carbon dioxide in the atmosphere, the Earth's surface would be more than 30°C colder and would be a barren, icy waste. We can take this either as an amazing coincidence or, from a Christian standpoint, as an example of God's providence in continually upholding and sustaining the world as a place fit for life (Heb. 1:3).

The other striking point is that, despite living organisms having existed on Earth since soon after its formation, humans have only been present for a tiny portion of its most recent history. To put this into perspective, if the history of the Earth were to be compressed into one year, modern *Homo sapiens* would have been present for only the last fifteen minutes before midnight on New Year's Eve. Does this have any theological significance? Not in itself, since it is just the way things are. But taken in conjunction with the understanding that has emerged over recent years that the conditions in the universe are finely tuned to make it possible for life to exist on Earth – the anthropic principle – it does give reason for atheists to pause for thought[19] and for Christians to rejoice in the creativity and sovereignty of the Creator God. It also provides a humbling perspective on the position of humankind in the time frame of the universe and adds striking significance to the Bible's assertion that humans are of especial importance to God (e.g., Gen. 1:26–31; Ps. 8).

The problem with reconciling the scientific age of the Earth and the biblical account is not in the period since Genesis chapter 2 onwards, which is easily accommodated within 10,000 years or so, but in the assumption that the six days described in Genesis account for the entire history of the universe in six twenty-four hour days. One approach has been to treat the six days not as literal twenty-four hour periods, but as long periods of time stretching to billions of years.[20] Another is to assert that the Earth only *appears* to be much older.[21] Although science cannot address such a suggestion, it raises immense theological problems, because if true it would mean that God purposefully designed a universe to deceive us. That does not square with everything else God tells us about himself in the Bible.

Table: Significant Dates in the History of the Universe

	Years before Present
Origin of the Universe	13,700 million
Origin of the solar system (= origin of Earth)	4,566 ± 2 million
Oldest known minerals on Earth (zircons)	4,408 ± 8 million
Oldest known rock on Earth	4,031 ± 3 million
Earliest evidence of life on Earth (carbon-13 depleted graphite)	3,850 million
Earliest microbial fossils on Earth	3,500 million
First cyanobacteria	2,000 million
First multicellular red algae	1,200 million
Oldest multicellular animal	575 million
First placental mammals.	135 million
Earliest hominid (Australopithecus)	c. 5 million
Early modern Homo sapiens	c. 200,000
Adam & Eve (Garden of Eden, Neolithic agriculture)	c. 12,000 – 10,000
First man on the Moon	1969 AD

The most fruitful approaches take seriously the literary genre of the Genesis passages dealing with the six days of creation. Since specialised scientific writing did not emerge as a literary genre until the founding of the first scientific journals in the seventeenth century, it is anachronistic to press scientific meanings on to Genesis, and in any case Augustine, Origen and other early Church Fathers were already interpreting Genesis figuratively in the early centuries AD.[22] The central aim of the Genesis text is theological: to explain God's purposes in his creation and his own relationship to it. The theological narratives of early Genesis proclaim that the universe was created by a loving, personal God, in an orderly fashion, that he was pleased with it, and that one of his main objectives was to make it a place in which humans could live fruitful lives and have loving relationships with himself. The biblical evidence of a purposely created universe, taken together with the scientific evidence for its evolution over billions of years into a place fit for human habitation, reinforce the message that humankind is not the accidental product of a meaningless universe.

16 See, for example the article by Roger Wiens in note 5 and the comprehensive web site www.answersincreation.org.

17 Table is adapted from references given in Alexander, D. & White, R. S. *Beyond Belief: Science, Faith and Ethical Challenges*, Oxford: Lion (2004),219 pp. and from Carroll, S. B. 'Chance and necessity: the evolution of morphological complexity and diversity', *Nature* (2001) 409, 1102–1109

18 Direct measurements of tidal effects on ancient sediments shows that 900 million years ago (i.e. 20% of the Earth's history), there were 420 days in a year, and each day lasted less than 21 hours. The Earth's rotation has been slowing since then due to the effect of tidal friction (see Willams, G. E. 'Precambrian tidal and glacial clastic deposits: implications for Precambrian Earth–Moon dynamics and palaeoclimate', *Sedimentary Geology* (1998) 120, 55–74). Estimates of rotation rates of the early Earth are based on models of the Earth–Moon interaction, and suggest that one day lasted only 5–6 hours in the very early history of the Earth.

19 See for example the move from atheism to deism by the philosopher Antony Flew and the reasons he gives for this based on scientific knowledge from big cosmology, fine tuning and design arguments at www.biola.edu/antonyflew/

20 This is the approach taken by Ross, H. *A Matter of Days*, Navpress (2004), 303 pp. He argues for an old Earth, but is also critical of macro-evolution.

21 This was argued as long ago as 1857 by P. Gosse, with his famous suggestion that God created Adam with a navel.

22 For discussion of the interpretation of origins in Genesis and the evidence from science see Kidner, D. *Genesis,* Tyndale Old Testament Commentaries, Leicester: Inter-Varsity Press (1967); Lucas, E. *Can we Believe Genesis Today?*, Leicester: Inter-Varsity Press (2001); Wilkinson, D. *The Message of Creation*, Leicester: Inter-Varsity Press (2002), 296pp.; Alexander, D. R. *Rebuilding the Matrix*, Oxford: Lion (2001).

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