

## APPENDIX 3

# THE EVOLUTION OF LIFE

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## LIFE ON EARTH

Air-breathing life cannot exist without oxygen, which was not part of earth's original atmosphere. However, life in the form of primeval bacteria and algae evolved without this element; these life forms consumed carbon dioxide and nitrogen from the original atmosphere and emitted oxygen as a waste. In addition to adding oxygen to the atmosphere, this process also formed the ozone layer.

The first life forms evolved in the seas. As indicated in Table A3.1, there is evidence of life forms as early as 3.5 billion years ago (BYA), of an ozone layer 2.5 BYA, and of a breathable oxygenated atmosphere 1.7 BYA. Such early life forms were not affected by the absence of an ozone layer because they lived below the water's surface. Oxygen-breathing life, initially single- and later multicelled, appeared following the creation of a suitable atmosphere. Soft-bodied animals, comparable to jellyfish, evolved 650 million years ago (MYA) and shelled animals about 70 million years later.

About 400 MYA, fishes diversified considerably and some gradually moved into areas of shallow water that were subject to drying up. Amphibious species appeared shortly thereafter, moving onto land already occupied by plants and insects, especially close to water. Much of the earth at this time comprised swamp environments, which were well-suited to plant growth and provided food for amphibians. One group of amphibians evolved into reptiles, animals with waterproof skins capable of remaining out of the water indefinitely. These reptiles were able to move away from water and soon colonized large areas, dominating much of the earth

for about 135 million years. Mammals and birds appeared during this period; when the reptiles vanished 65 MYA, the mammals and birds remained. The cause of the reptiles' extinction remains uncertain, although recent evidence suggests that the most likely explanation is an asteroid that struck the Yucatan Peninsula in Mexico, causing earthquakes, tsunamis, and a long global winter.

With the absence of reptilian competition, mammals and birds flourished, expanding, diversifying, and filling the ecological gaps left by the dinosaurs. Among the new evolutionary lines that began at this time were the primates; today, humans are 1 of about 200 species of living primates. Apes, a new group of primates, evolved about 25 MYA. Some 10 MYA, mammals reached their greatest diversity. Most available evidence suggests that the human evolutionary line separated from that of the apes about seven MYA.

Four factors need to be highlighted in this account of the emergence and spread of life on earth. First, the planet was a changing environment in this period. Climatic change, especially a series of glacial periods, was ongoing. Second, the land masses were moving. The most recent movements began with the initial breakup of Pangaea (see Figure A2.2) some 225 MYA. The spread of life has been greatly affected by both of these factors, as land routes around the world have changed. Third, the relationship between the physical earth and the emergence and evolution of life is not fully understood (a topic discussed in Box 4.4). Fourth, even a very basic understanding of life on earth helps us understand that our human species is just one among millions, probably tens of millions, of species.

**TABLE A 3.1 | Basic chronology of life on earth**

Time	Event
<i>Physical Origins</i>	
10–20 BYA(?)	Creation of universe
5 BYA	Solar system forms
4.5 BYA	Earth forms
<i>Origins of Life</i>	
3.5 BYA	Oldest life forms
3.2 BYA	Oxygen-creating bacteria
2.5 BYA	Ozone shield forms
2.2 BYA	Oxygen in atmosphere
1.7 BYA	Atmosphere breathable
<i>Origins and Evolution of Life Forms</i>	
1.4 BYA	Oxygen-using animals
800 MYA	Multicellular life
650 MYA	Soft-bodied animals
580 MYA	Shelled animals
500 MYA	First fishes
430 MYA	First land plants
360 MYA	First insects
350 MYA	First amphibians
280 MYA	First reptiles
225 MYA	Breakup of Pangaea
220 MYA	First mammals
200 MYA	Reptiles dominant for next 135 million years
190 MYA	First birds
65 MYA	Dinosaurs extinct; birds and mammals diversify; first primates
25 MYA	Grasslands become widespread; first apes
10 MYA	Maximum diversity of mammals
6 MYA	Emergence of earliest human ancestors

## HUMAN ORIGINS

Although our knowledge continues to increase, there is still much that we do not know about human origins and early history (Table A3.2). Current evidence suggests that the large apes evolved as one primate line in Africa about 25 MYA and then split into several relatively distinct evolutionary lines. One of these in turn split into two further lines, chimpanzees and humans. The most compelling evidence of a common origin is that humans and chimpanzees differ in only about 1 per cent of their genes; this means that our two species could not have been evolving separately for much more than about seven million years. It is generally accepted—using a combination of

fossil, geological, and genetic evidence—that this is when human ancestors diverged from the ape line. Supporting evidence for this approximate date includes the 2001 discovery of a skull in Chad, known as *Sahelanthropus*. But some recent genetic research suggests that the split occurred more recently, perhaps between 6.3 and 5.4 MYA and that this split was followed by some interbreeding between humans and chimpanzees.

### Our Earliest Ancestors: *Australopithecus*

What was it that distinguished the earliest human ancestors from other primates? Unlike all earlier primates, they were bipedal (i.e. they walked upright). This was a critical adaptation

**TABLE A 3.2 | Basic chronology of human evolution**

6 MYA	Probable earliest date for evolution of first hominids, the bipedal primate <i>Australopithecus</i> , in Africa
3.5 MYA	First fossil evidence of <i>Australopithecus afarensis</i> in East Africa
3 MYA	Probable appearance of <i>Homo habilis</i> in East Africa; evidence of first tools
1.8 MYA	First appearance of <i>Homo erectus</i> in East Africa
1.5 MYA	Evidence of <i>Homo erectus</i> in Europe; evidence of chipped-stone tools in Africa; beginning of Pleistocene
700,000 BP	First evidence of chipped-stone tools in Europe
400,000 BP	<i>Homo erectus</i> uses fire; develops strategies for hunting large game; first appearance of archaic <i>Homo sapiens</i>
195,000–150,000 BP	Appearance of <i>Homo sapiens sapiens</i> (in Africa only, according to favoured replacement hypothesis)
80,000 BP	Beginnings of most recent glacial period
50,000 BP	Arrival of humans in Australia
25,000–15,000 BP	Arrival of humans in America
12,000 BP	First permanent settlements
10,000 BP	End of most recent glacial period; beginning of Holocene period

Note: BP = years before present.

that permitted early humans to move over great distances while carrying objects; fossil evidence has been found throughout eastern and southern Africa. The first known **hominid** group is called *Australopithecus*. Currently, most authorities agree that the common ancestor of all hominids was *Australopithecus afarensis*; fossil evidence of this species, discovered in East Africa, has been dated to more than 3.5 MYA. *A. afarensis* had a small brain of about 440 ml (modern human brains average 1,450 ml).

## Towards Modern Humans: *Homo Habilis*

The next critical evolutionary event in human lineage occurred about three MYA, when the hominid line split into two types, one of which became extinct and one of which evolved into modern humans. The first representative of the line leading to modern humans appears to be the species *Homo habilis*. Both *Australopithecus* and *Homo habilis* were probably—though not certainly—restricted to Africa, notably the East and South African savanna areas, where they lived by hunting small animals and gathering plants. But *Homo habilis* had a larger brain (about 680 ml), which made possible the development of an important new cultural behaviour and a major technological

advance: the fabrication of stone tools. Brain size distinguished *Homo habilis* from other previous hominids and from other lines living at the same time; some evidence even suggests that *Homo habilis* possessed the capacity for speech.

Why did *Australopithecus* evolve, perhaps as long ago as six million years? Why did *Australopithecus afarensis*, our common ancestor, split into two types about three MYA? Why did one of these become extinct about a million years ago? Although we are uncertain of the answers, there is evidence to suggest that global climatic change was a causal factor. Declines in global temperatures correspond with each of these evolutionary events. Such declines prompted drying trends in Africa: drying reduced the extent of tropical forest, increasing that of open woodland and dry savanna. It is in this way that evolutionary changes can be seen as adaptations to changing physical environments.

## Out of Africa: *Homo Erectus*

Beginning about 1.8 MYA, *Homo erectus* appeared. This new species was distinguished from *Homo habilis* primarily by a brain size of about 1,000 ml—roughly the lower limit of modern human brain size. Until recently, it was widely accepted that *Homo habilis* evolved into *Homo erectus*, but

### hominids

Bipedal primates; humans and their ancestors.

the 2007 discovery of two hominid fossils in the Turkana Basin area of East Africa indicates that the species overlapped in this region for about 500,000 years. *Homo erectus* subsequently spread over much of Africa and into the warm temperate areas of Europe and Asia. This hominid species is currently thought to have been the first to move out of Africa. Some recent evidence suggests that it may have reached Asia not long after emerging in Africa. The reasons for this movement are not known, but they probably had to do with climatic change, population increases, and the associated search for food. Again, the basis of subsistence was hunting and gathering.

After the appearance of *Homo erectus*, human biological evolution stabilized for some time. But cultural developments, including the introduction of clothing and shelter, were considerable. Different cultural adaptations were devised for different environments. By about 400,000 years ago, hunting strategies had progressed to include the use of fire and possibly the planned hunting of larger game. An innovation at this time was the introduction of relatively permanent pair bonding, or monogamy. Human language use also increased substantially, encouraging the gradual development of human culture. All these adaptations took place against a background of changing physical environments, as the geological period beginning about 1.5 MYA, the **Pleistocene**, was one of considerable fluctuation in global temperatures. Several extremely cold periods, when large areas of the earth were covered in ice, were punctuated by periods with average temperatures comparable to those of today—an alternation of glacial and interglacial phases. These fluctuations continued until as recently as 10,000 years ago and may indeed be continuing; it is possible that we are in an interglacial period at present.

#### Pleistocene

The geological time period, from about 1.5 million years ago to 10,000 years ago, characterized by a series of glacial advances and retreats; succeeded by the Holocene.

## Modern Human: *Homo Sapiens Sapiens*

Some 400,000 BP (before present) a new hominid evolved from *Homo erectus*. This species was similar to modern humans, but they are often called archaic *Homo sapiens* because there are physical differences between them and modern humans. Their mean brain size of 1,220 ml was about 85 per cent that of modern humans. The best-known subset of these archaic humans is the Neanderthals, who diverged from the modern

human line sometime after 440,000 BP and lasted until about 30,000 BP. They lived throughout much of Eurasia during this time, although the population probably never exceeded about 15,000. In the early twentieth century, following the first fossil discoveries, Neanderthals were regarded as subhuman in intellect, but by the 1950s it was not uncommon for them to be regarded as virtually modern in appearance and behaviour. The current interpretation is a compromise—neither apes nor modern humans.

The ongoing uncertainty about specific details of human evolution was highlighted by the 2004 discovery on the remote Indonesian island of Flores of what some believe to be a previously unknown *Homo erectus* species, *Homo floresiensis*, which survived until as recently as 13,000 BP. The presumed species was nicknamed “the Hobbit” because it was no taller than 1 m (3 feet). Subsequent research divided into two camps: those who claim the discovery was of a human suffering from a genetic illness that caused both body and brain to shrink and those who consider it a new species.

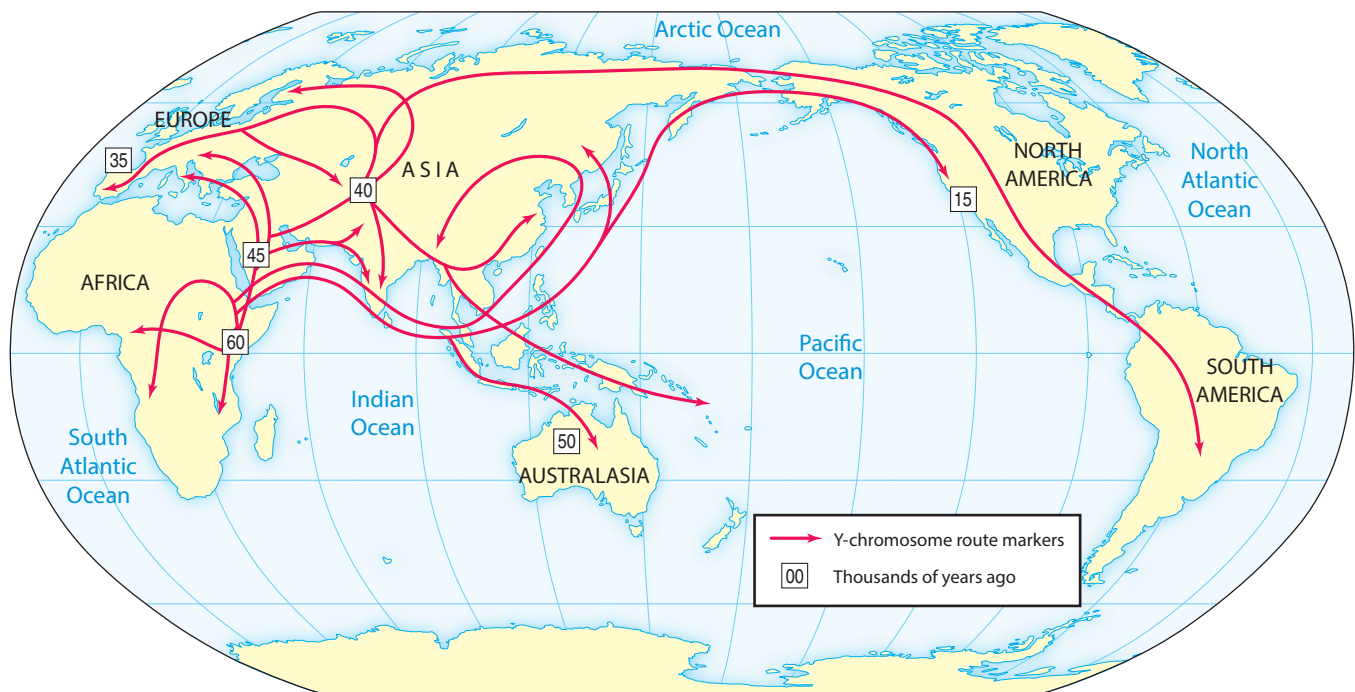
We have now reached a critical point: the emergence of anatomically modern humans, officially called *Homo sapiens sapiens*. Where and how did this come about? There are two rather different explanations. The multi-regional hypothesis proposes that modern humans evolved independently from archaics, at more or less the same time in a number of different geographic areas. However, most of the currently available paleontological, genetic, and archaeological evidence favours a second hypothesis. This replacement hypothesis proposes a single evolution in a limited geographic area and a subsequent spread to replace archaics elsewhere. Specifically, modern humans, *Homo sapiens sapiens*, evolved from a group of archaics in a single place, in Africa, by 195,000–150,000 BP. This hypothesis received additional confirmation with the 2003 discovery in Ethiopia of anatomically modern human skulls dated to 160,000 BP and the 2005 re-dating of two similar skulls found in 1967 showing that they are about 195,000 years old. But two other recent discoveries resulting from genomic research are complicating this relatively clear picture, at least in detail.

First, human remains that are genetically different from all other known human types have been discovered in a cave in Denisova, Siberia; these Denisovans have contributed to the modern

human stock in Melanesia. It is not known when this group moved out of Africa, but they share a common ancestor with modern humans about a million years ago—this is called the divergence date. Second, it is now known that modern humans in Europe and Asia, but not in Africa, have some Neanderthal genes—as noted, Neanderthals diverged from modern humans perhaps as early as 440,000 BP. These two discoveries reveal important information: there was some interbreeding between modern humans and at least two earlier types, Neanderthals and Denisovans.

Despite these complications, most researchers agree that humans spread throughout the world and replaced existing archaic groups, including the Neanderthals, because of some adaptive advantage. From that time onward, human evolution, insofar as we can determine, has been primarily cultural, not biological. However, there is now evidence that new cultural practices can cause genetic changes. For example, the domestication of cattle resulted in northern Europeans being able to digest cow's milk. There seems no doubt that ongoing genomic research will continue to provide new information about specific details of human evolution.

Acceptance of the favoured replacement hypothesis, centred on a single exodus from Africa—even if modified in detail following recent discoveries—has enormous implications for our understanding of ourselves. Simply put, we are all related. Modern humans settled much of Africa, Asia, and Europe, with movement out of Africa begun about 60,000 BP. The routes and dates shown in Figure A3.1 reflect ongoing genetic research (part of a major study known as the Genographic Project). Of particular note is the evidence that the first humans to leave Africa travelled along the Indian Ocean coast to Arabia, India, and Indonesia, reaching Australasia 50,000 BP. This route was probably favoured because of cold temperatures further north and because of the availability of a seafood diet. The next principal moves were into the Middle East, inland Asia, and Europe by about 35,000 BP, and America perhaps by 25,000 BP but certainly by 15,000 BP. These movements were, of course, related to the continuing climatic changes associated with the glacial and interglacial periods. Modern humans began to evolve and spread across the earth during a period of harsh climate. Evidence suggests that favoured locations were at the boundaries



**FIGURE A3.1 | Probable directions of movement out of Africa by early humans**

Source: The Genographic Project. <https://genographic.nationalgeographic.com/human-journey>.



of geographic regions, where the first permanent settlements appeared about 12,000 BP. The most recent glacial period ended 10,000 BP, marking the end of the Pleistocene and the beginning of the Holocene period.

The fact that early humans effectively settled most areas of the earth is particularly significant. It suggests that humans had some adaptive (probably cultural) advantage over other primates, something that allowed them to adjust and survive in harsh new environments where other species could not. Brain growth is important, but it does not seem to be the whole story. Several related hypotheses

share a focus not on competition but on social interaction. It seems clear that humans related to one another collaboratively because they trusted one another. Migration to previously unsettled areas enlarged the overall resource base and allowed slow but steady increases in human populations. We can only estimate the number of people in these early stages. *Australopithecus* was restricted to Africa, and population estimates range from 70,000 to 1 million. *Homo erectus* covered much more of the globe and possibly attained a population of 1.7 million. A figure of 4 million seems reasonable for the human population about 12,000 years ago.



## Suggested Readings

Dawkins, R. 2004. *The Ancestor's Tale: A Pilgrimage to the Dawn of Evolution*. Boston: Houghton Mifflin.

A wonderfully entertaining and informative book that looks at the evolutionary tree of life; loosely based on Chaucer's *Canterbury Tales*.

MacDonald, G. 2003. *Biogeography: Space, Time, and Life*. New York: Wiley.

Features a chapter that offers an excellent overview of the relationships between biogeography and human evolution, including an account of the geographic expansion of modern humans.

Stringer, C. 2011. *The Origin of Our Species*. London: Allen Lane.

Excellent summary of our understanding of human evolution; written by a leading researcher.



## On the Web

### The Genographic Project

<https://genographic.nationalgeographic.com/>

A remarkable site that provides a wealth of information on the Genographic Project.