et al. 1987). After analyzing mtDNA samples from 147 different people from five geographic regions, Wilson and his team concluded that all humans living today are descended from a single woman who lived in Africa about 200,000 years ago.

After this conclusion was published, the press soon touted this ancestral woman as the "Mitochondrial Eve," the "African Eve," and the "Black Eve," and many misconceptions have swirled around the idea ever since, including the notion that she was the first woman, or the Biblical Eve (see Science and Discovery). More recently, Y-chromosome studies of living males indicate that all living males are descended from a single man in Africa who lived about 60,000 years ago—the "Y chromosome Adam" (Chapter 11).

Science and Discovery

Finding Mitochondrial Eve

Most of our DNA resides in the nucleus of each of our cells, organized in 23 pairs of chromosomes. This nuclear DNA encodes the vast human genome in long strings of more than 3 billion base pairs of nucleotides organized into at least 70,000 genes (this number is creeping upward each year as we learn more). Outside the nucleus is another much smaller genome. Every one of our cells contains anywhere from 100 to 1000 mitochondria, and each of these contains its own small ring of DNA, remnants of the days long ago when mitochondria were independent bacterial organisms. This mitochondrial DNA, or mtDNA, is made up of a mere 16,500 base pairs in only 37 genes that govern the operation of the mitochondrion. Each mitochondrion can reproduce like bacteria, duplicating its small genome exactly—almost.

The human egg and sperm cells are powered by mitochondria, just like all of our other cells. During the process of fertilization, the sperm has just enough power to reach the surface of the egg and deliver its 23 chromosomes that combine with the 23 female chromosomes in the egg, but it otherwise does not enter the egg. The fertilized egg that becomes a new human contains only the female's mitochondrial DNA. Because we inherit only our mother's mtDNA, it is passed along only through the female lineage. Furthermore, mtDNA is passed along very cleanly with almost perfect duplication, generation after generation. This is very different from the shuffling and recombining that nuclear DNA experiences in the process of sexual reproduction.

However mtDNA does change slowly over many generations because of random mutations. In the simplest case, a single letter (a nucleotide) in the genetic code gets switched to another letter. This is called a *single nucleotide polymorphism* (or *SNP*). Most mutations like this are harmless, or neutral, but in rare instances one may be beneficial; natural selection eliminates any that are truly harmful because the individuals having them do not survive. If a woman acquires a specific neutral mutation in her mtDNA, she will pass this on to her children, and her daughters will pass it on to their children. This single mutation will mark her descendents as distinct from all other humans. Geneticists call such a mutation a *genetic marker*, and they can use these markers to group people in lineages that originated from a single mother.

Allan Wilson and his team at Berkeley in 1986 were the first to compare specific stretches of mtDNA in people from around the world, and they found that different groups shared certain markers. Europeans had specific markers that no one else did, Asians had unique markers, and Africans had the most diverse set of markers of all. From these comparisons, they were able to construct an evolutionary tree for humans, and at the trunk of the tree were Africans. They were also able to make time estimates by using the molecular clock technique, which Wilson had pioneered in the late 1960s. This assumes that mtDNA mutates at a known constant rate.* When the mtDNA of two individuals is compared, the number of differences is a measure of the time since the two had a common female ancestor. When Wilson's team did this for their sample of 147 humans from around the world, they found that all of them shared a common female ancestor who lived about 200,000 years ago in Africa; she soon came to be known as mitochondrial Eve.

Wilson's discovery was immediately misunderstood and criticized. Many people thought that he had found the first woman or even the Biblical Eve, and some scientists questioned the validity of the team's conclusions because only a small number of single mutations (SNPs) were used for comparison, and the Africans he sampled were mostly African Americans. Wilson was not, however, saying that this Eve was the first woman. In fact many other women were alive at the same time she lived, but none of their mtDNA survived. The descendants of these other women eventually had only sons, or no children at all; or some of these other lineages may have been eliminated when large groups of people died during the massive droughts that swept through Africa. Yet Eve's mitochondrial DNA did survive, and it resides in every one of us today.

Since 1987, others have duplicated and extended Wilson's work using better and faster DNA sequencing techniques, and his original conclusions have largely been supported. A study published in 2000 (Ingman et al.) compared the entire mitochondrial genome of 53 different people from around the world and concluded that mitochondrial Eve lived in Africa about 170,000 years ago, plus or minus 50,000 years—that is, somewhere between 220,000 and 120,000 years ago. Many researchers today accept a rough date of about 150,000 years ago for the time of *the most recent common matrilineal ancestor of all living humans*, which is what mitochondrial Eve really is.

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* The mutation rate of human mitochondrial DNA has been the subject of considerable research and debate. In 2000 it was estimated to be about one mutation per 232 generations, or about one mutation every 4500 years. See Donnelly, Peter et al., The mutation rate in the human mtDNA control region, *The American Journal of Human Genetics*, 1 May 2000. However, in 2005 Mark Stoneking and Brigitte Pakendorf reported that different regions of the mtDNA ring had substantially different mutation rates. See Mitochondrial DNA and human evolution, *Annual Review of Genomics and Human Genetics*, 2005. 6:165-183.

Both the fossil record and the genetic record indicate that the last of the hominids, *Homo sapiens*, originated in Africa about 200,000 years ago. Yet the details of the next

195,000 years are puzzling and contentious, until about 5000 years ago when systems of writing emerged and the written history of humanity could begin.

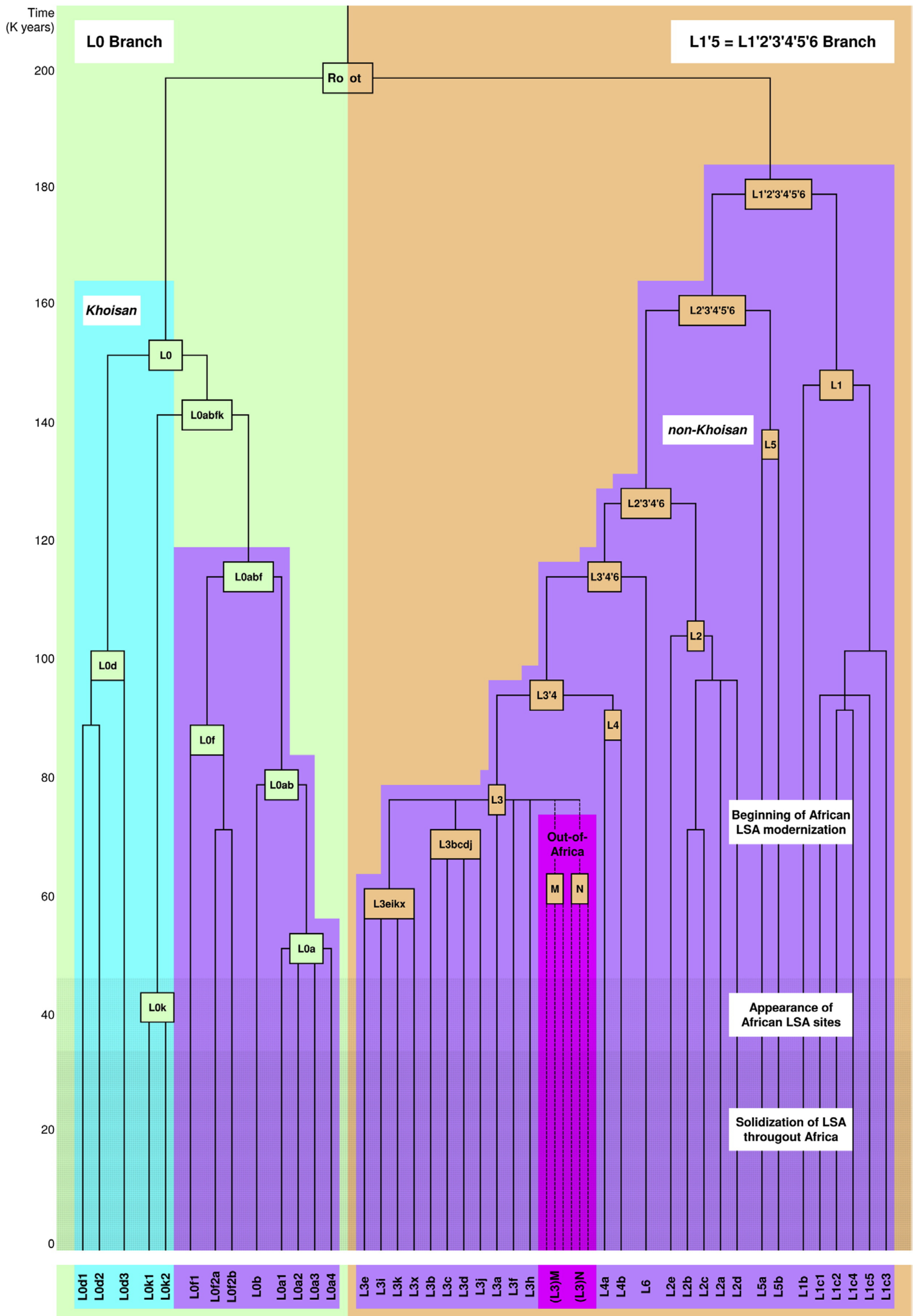
Like their ancestors *erectus* and *heidelbergensis*, the first people (for we can finally call them that) moved around as hunter-gatherers, constantly in search of new food supplies. Between 200,000 and 100,000 years ago, people spread throughout much of Africa, from Cape Horn to the Mediterranean and even to the Atlantic coast in some places, but apparently in small isolated groups. Survival was tenuous for these early humans, and their population remained small because of severe drought conditions that lasted from about 135,000 to about 75,000 years ago. This mega-drought shows up clearly in core samples taken from the bottom of Lake Malawi in Southwestern Africa (Scholz et al. 2007). Lake Malawi, which today is about 600 meters (2000 feet) deep, lost 95% of its water at times during the megadrought and humans must have been pushed repeatedly to the brink of extinction. Not until about 70,000 years ago did the climate become wetter again so that the human population could grow.

Paleoanthropologists have very limited knowledge about what early humans were doing between 200,000 and 100,000 years ago because very little physical evidence has been found from this period. There is, however, a growing belief that humans made a significant developmental change during this period, perhaps beginning around 150,000 years ago. In 2007 an international team of researchers published their findings from caves that were occupied by early humans at Pinnacle Point on the southern coast of Africa (Marean 2007). Here, some 125,000 years ago, people began eating food from the sea, using pigments for symbolic purposes, and making the first bladelet tools. By about 100,000 years ago, decorative seashells and ochre pigments were being used as jewelry and symbolic art in locations as widely separated as South Africa, North Africa, and Israel (Vanhaeren et al. 2006). These are all signs that culture was evolving and symbolic thought was beginning to emerge in humans.

Adding to the physical evidence that paleoanthropologists dig up in the trash piles and burial mounds of early humans is the genetic evidence that is now emerging as molecular geneticists analyze the DNA of living humans. In the spring of 2008, a team of researchers from around the world published the results of a large-scale analysis of the complete mitochondrial genomes of over 600 living Africans (Behar et al. 2008). They found that the early human population had split into two main groups by about 150,000 years ago, one living in South Africa and the other living in Eastern Africa (present day Ethiopia). There is also evidence of many other small isolated groups throughout Africa who did not survive. All humans living today are descended from the two early populations, with most of us coming from the East African side of the split. The Khoisan Bushmen of South Africa are the only survivors of the South African side of the split (Figure 10-1).

Figure 10-1

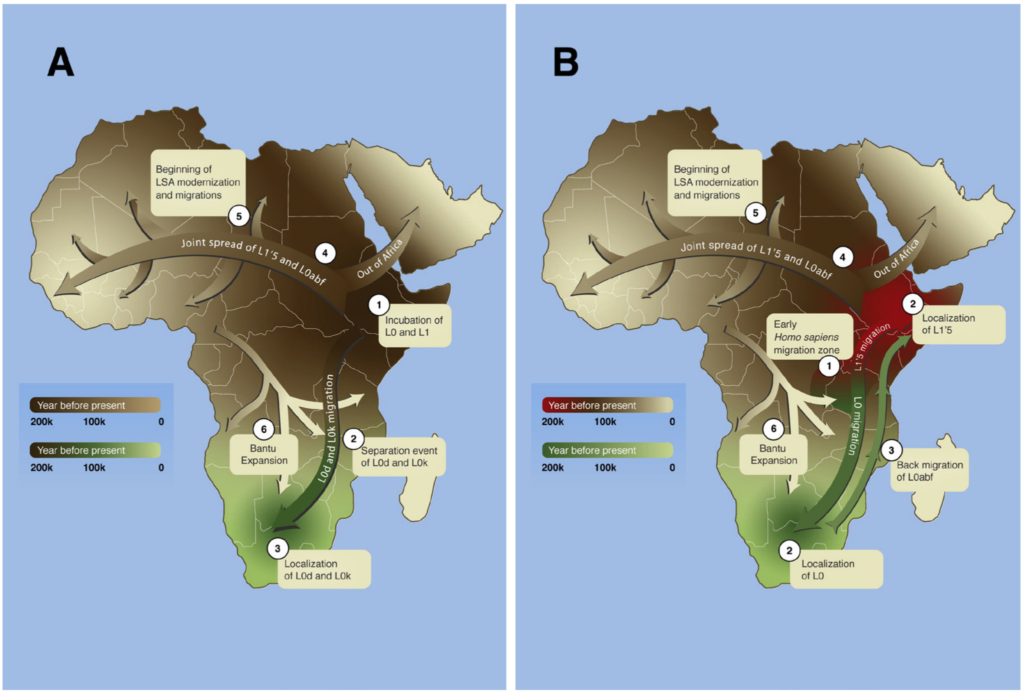
A detailed evolutionary tree of humans for the last 200,000 years, derived from mtDNA studies published in 2008(Behar et al.). The final migration out of Africa that gave rise to all modern non-Africans is shaded in maroon. (LSA=Late Stone Age)



Courtesy: American Journal of Human Genetics

Figure 10-2

Two theories of early human migrations within Africa, before the final exodus about 60,000 years ago. From mtDNA studies published in 2008 (Behar et al.).



Courtesy: American Journal of Human Genetics

By about 100,000 years ago, humans from the East African group living in modern-day Kenya and Ethiopia began to leave Africa, perhaps in response to the deteriorating environment. Two different groups, using two widely separate exit routes were apparently successful in this bold and difficult exodus. A northern group followed the Nile River to the Mediterranean Sea, then crossed the Sinai Peninsula and moved into the Levant (a historical name for the region around modern day Israel and Lebanon). Human remains dating to about 92,000 years ago have been found at the Qafzeh Caves in Israel, leaving no question that early humans got that far out of Africa.

Apparently that was as far north as this group went, because there is no evidence of humans north of the Levant from this time. Something stopped them, and that something may well have been the Neanderthals, whose territory they were moving into. There is also clear evidence of Neanderthal presence in the Levant at this time. The human population was probably small and struggling for survival, while the Neanderthals were physically stronger, had a comparable level of tool technology, and a larger, well-established population that covered the Middle East, Western Asia, and Europe.

Some scientists have speculated that there was interbreeding between the two populations, based on skeletal remains that have a mix of Neanderthal and human characteristics. Until recently, the genetic evidence from comparing the human and

Neanderthal genomes did not support this possibility, instead suggesting that there was no mixing of genes, that the two were distinctly separate species incapable of producing viable offspring. However in 2010 this view was reversed when genome studies of living humans showed that people of Eurasian descent carry Neanderthal genes—anywhere from 1 to 4 percent (Green et al. 2010). It now seems that humans and Neanderthals must have interbred somewhere along the way, perhaps during this first encounter in the Levant. No one yet knows what the relationship was between Neanderthals and humans, but what does seem clear is that this first group of humans in the Levant did not (or could not) move any further north. In fact they may not have survived at all in the end, as we will see.

By about 100,000 years ago, another group of humans left Africa by a different route, a thousand miles south at the Strait of Bab-El-Mandeb on the Red Sea. Here the Horn of Africa nearly touches the Arabian Peninsula, separated by only 17 miles of water. There is uncertainty about how far this southern group moved into the Arabian Peninsula, but there is evidence that some of them made it all the way into India and perhaps China,* probably following coastlines and living as "beach combers."

It is clear that by about 75,000 years ago, humans had successfully moved out of Africa and should have been ready to populate the Earth. Then something went terribly wrong for *Homo sapiens*, because the genetic evidence suggests that the entire human population was very nearly wiped out, and only a small number of humans would survive the next few thousand years; they were the people who had stayed back in Africa. Those few African survivors are the common ancestors of all of us today.

Bottleneck

When scientists in the early1990s began looking at the nuclear DNA from many living humans, it became evident that our ancestors must have gone through something that reduced our total population to a very small number—a *population bottleneck*. Because the genes of all humans living today are found to be 99.9% similar, it must be that all of us are very closely related and had a common ancestor not long ago. By comparison, there is more variation in the genes of one social group of 50 chimps than in the entire human population.

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* Michael Petraglia and his team found stone tools below and above the layer of volcanic ash from the eruption of Mount Toba (73,000 years ago) at a site in Jwalapurim, India, suggesting that the users of these tools were in India before 73,000 years ago, and that they survived the Toba event. The users are presumed to be humans.

See Petraglia, Michael, et al., Middle Paleolithic assemblages from the Indian subcontinent before and after the Toba super-eruption, *Science,* 5 July 2007.

Also, in 1958 a human skull was found in Liujiang, China and tentatively dated to 20,000-30,000 years ago, but more recent dating of the presumed site (there is some uncertainty about this) has produced a range of ages from 68,000 to 150,000 years old, long before humans were thought to have been in China. See Bower, Bruce. 2002, Chinese roots: Skull may complicate human-origins debate, *Science News*, 21 December.

Y chromosome studies on living males from worldwide populations now suggest that modern humans did not successfully leave Africa until about 60,000 years ago (Stix 2008) (see *Exploring Deeper: Y Chromosome Adam, p. 175*). This means that none of those first ventures out of Africa between 100,000 and 75,000 ago years were successful in the long term because none of that genetic material survived. It seems that the entire human population was culled back to just a few thousand members who lived in Eastern Africa and became the founding population of all of modern humanity. Our species was on the brink of extinction about 70,000 years ago.

What could have caused this population bottleneck that nearly wiped out humanity? Two factors are now thought to have contributed to our near-extinction: a mega-drought that lasted from 135,000 to 75,000 years ago probably created a series of bottlenecks that kept the human population small and scattered; and something even more deadly was first suggested by Stanley Ambrose from the University of Illinois in 1998: the eruption of Mount Toba on the Island of Sumatra about 73,000 years ago (Ambrose 1998).

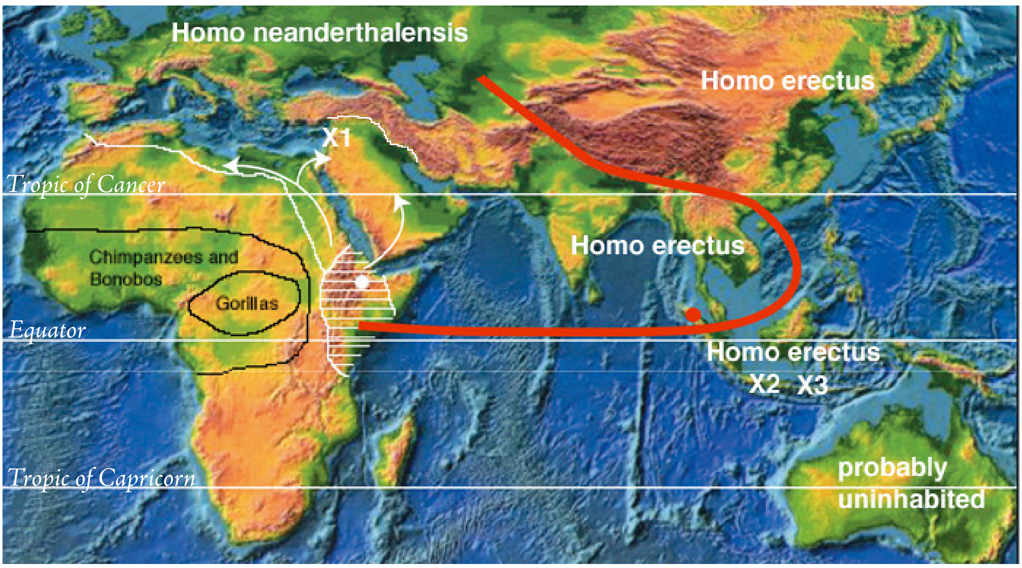
The Toba event shows up clearly as thick layers of volcanic ash across India, and in ice cores from Greenland with elevated levels of atmospheric sulfuric acid. This was the largest volcanic eruption of the last 28 million years, spewing out lava that flowed for hundreds of miles and hurling gases, dust particles, and ash into the atmosphere. Mount Toba ejected *2,800 cubic kilometers* of material from inside the Earth, compared to the Mount Krakatoa eruption of 1883 which produced only *ten cubic kilometers* of material, and Mount St. Helens in 1980 which produced a mere *one cubic kilometer*.

The super-eruption of Toba probably lasted a few weeks and produced a thick blanket of volcanic ash as much as thirty feet deep in some locations thousands of miles away. The material that was immediately hurled into the atmosphere did not spread out in all directions but was carried by the prevailing winds for thousands of miles to the west and north (see 10-3). This "kill zone" extended directly into nearly all the areas where early humans had migrated, including the Levant. Eventually the entire atmosphere of the Earth filled with dust, blocking the Sun and triggering a devastating volcanic winter. It is not known whether the people who were downstream from Toba survived the initial effects of the eruption, but any that did survive would have faced a volcanic winter of extreme cold for the next five to ten years, and ice age conditions that brought widespread drought and famine for the next thousand years. Plant samples from the Levant at this time show a drastic change from an Afro-Asian community to a paleoarctic biome, typical of a much colder climate. For people who were hunter-gatherers with no reserves of food, survival would have been nearly impossible. The effects of Toba lingered for thousands of years before Earth's climate finally began to warm and the human population recovered.

At the time of the Toba eruption 73,000 years ago, there were at least three species of hominids living on the Earth (Figure 10-3). The Neanderthals were well established from Europe to Central Asia and south to the Levant. *Homo erectus* occupied Asia, from China to New Guinea. And the newcomers—*Homo sapiens*—lived in Africa and some had spread north into the Levant, east into the Arabian Peninsula, and perhaps into India and China. Two of these three hominid species—the Neanderthals and *erectus*—were spared the brunt of Toba's eruption because their territory was largely out of the kill zone. The volcanic winter and ice age that followed probably forced them closer to the equator—the *erectus* population moved toward Indonesia and New Guinea, while the Neanderthals moved into southern Europe and the Levant. The Neanderthals were already cold-adapted and probably handled the effects of Toba better than their cousins.

Figure 10-3

The scene of Homo sapiens exploits between 195,000 years ago and 73,000 years ago when Mt. Toba erupted. See more detailed key below.



Courtesy: George Weber, The Andaman Association (Weber 2004)

Red Dot: Mount Toba

Red Line: The Toba kill zone where ashfall may have had a lethal and almost instant impact. In India the thickness of the ash layer found today ranges from 10 feet to 20 feet, and in Malaysia as much as 30 feet. Further west, the ash-falls would have thinned gradually, but dust and aerosol clouds would still have blocked the sun and brought on a calamitous drop in temperature—the forerunner of volcanic winter.

White Dot: Herto, Ethiopia, site of one of the oldest known Homo sapiens idaltu, dating from 154.000 to 160,000 years ago. Close by is Kibish, Ethiopia with human remains dating to 195,000 years ago.

White shaded area: Area occupied by the first anatomically modern Humans. 200,000-150,000 years ago

White-bordered area without hatching: Vulnerable areas into which Homo sapiens had expanded by about 100,000 years ago until the Toba eruption. The limits of this expansion are highly uncertain and include only the Levant for sure. Whether Mesopotamia, the Arabian Peninsula, and India were also settled is not yet certain but it remains a possibility.

White X1: The Levant, site of Homo sapiens/Homo neanderthalensis interaction about 95,000 years ago.

White X2: Toba survivor Homo erectus on Java, Indonesia

White X3: Toba survivor Homo floresiensis on Flores, Indonesia