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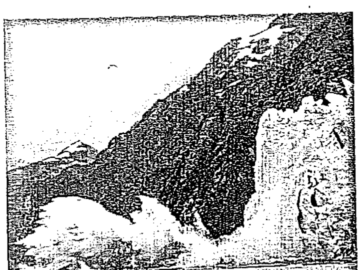
WHY GEOGRAPHY MATTERS

THREE CHALLENGES FACING AMERICA

CLIMATE CHANGE, THE RISE OF CHINA, AND GLOBAL TERRORISM



Harm de Blij

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EARTH'S CHANGEABLE ENVIRONMENTS

Few topics have aroused as much public debate and dispute over the past quarter century as global warming. It has become more than an argument over information such as temperature readings and evidence such as melting mountain glaciers and thinning polar ice. The global-warming issue pits scientists against politicians, environmentalists against energy-company representatives. The public is bombarded with dire warnings of rising sealevels, disastrous hurricane seasons, torrid summers, and searing droughts. It is risky for scientists to express even the slightest doubt that all of the past 30 years' global environmental change is due to humanity's pollution of the atmosphere. Global warming has become a moral as well as a scientific arena.

It is not surprising that many people do not know whom to believe. If large percentages of Americans cannot identify major physical or political features on a blank map, even fewer could be expected to be able to outline the reasons why atmospheric pressure systems form and move the way they can or ocean currents flow they way they do. An introductory college course in physical geography marvelously summarizes the essentials of the global-warming controversy, because it deals with all the interacting mechanisms that comprise the planetary system, from the evolution of continents to the impact of ice ages and from climate change to biogeography.

What we read in the press is not always helpful. A respected British journal, the *Economist*, not long ago stated in one of its editorial "leaders" that "climate change will be with us for at least another century" after anthropogenic emissions into the atmosphere are brought under control (in one of my numerous unpublished letters to editors, I wrote that after nearly 4.6 billion years of it, we should all rejoice). Another serious newspaper editorialized that "if we can get automobile exhaust gases under control, we can banish global warming forever." With that sort of nonsense from usually reliable sources, it is not surprising that many readers are mystified. Make no mistake: even if all emanations, from factory smokestacks, automobile exhausts, and methane-farting cows stopped tomorrow, global warming would eventually slow, but it would not stop until the natural cycle that drives it goes into reverse. And when that happens we will have a bigger problem still, for global cooling is a far greater long-range threat than global warming at a time when humanity's numbers approach 7 billion on this small planet.

So let us put the global-warming issue in geographic perspective, and take a chronological and spatial look at how we got here, environmentally speaking.

But before we get started, we should—just for this chapter—get used to thinking in terms of millions and billions of years, which isn't easy. One way to go about this is to relate our planet's age to our own. If you happen to be in your midforties, it is easy: a year in your life represents 100 million years of Earthly history. One month equals about 8.3 million years, and a week, just under two. A single day in your life equals some 275,000 years, and one hour about 11,000. Consider this: the emergence of modern humans has taken place, comparatively, in the last day of your life; the rise of modern civilizations, during just the past hour.

If you are in your early twenties, just double these figures; if you are in or near your late sixties, subtract about one-third. No matter what one's age, though, the recency and brevity of our human ascent and domination of this planet cannot but impress. No matter what your age, the dinosaurs held sway until less than a year ago!

DRAMATIC BEGINNINGS

Some 4,600 million years ago planet Earth congealed from an orbiting band of cosmic matter into a fiery ball of molten substance burning fiercely and emitting clouds of superheated gases that found its place in the evolving solar system as the third planet among the nine revolving around the Sun. Millions of lighting bolts struck the red-hot surface while, inside the young planet, heavier matter sank toward the center and lighter material accumulated in the outer layers, all of it kept in constant motion by the intense heat.

And then, when the Earth was a mere 100 million years old, a cataclysmic event changed it forever. In the continuing chaos of the evolving solar system, a large object, perhaps as large as Mars, approached our planet on a collision course. Even a thick, protective atmosphere would not have cushioned the Earth against the devastating impact that followed. The planetoid struck at a low angle, a glancing blow that briefly buried it in the molten mass of Earth's primordial shell. So great was the speed of the object, so huge was the collision, that much of it bounced outward again into space along with a large volume of Earthly matter.

But it did not fly out into space. Slowed, weighed down, and unable to escape the Earth's gravitational field, this giant ring of matter soon coagulated into a single ball that orbited the mother planet. The Earth had acquired its Moon.

Imagine the scene, 4,500 million years ago. Just a few hundred miles above the Earth's surface hung an incandescent Moon that filled the night sky from one horizon to the other, seemingly so close to the Earth that you could touch it. A gaping craterlike depression marked the place where the impact had occurred, threatening for a time the very structure of the planet. The low-angle blow from the impact object set the Earth spinning on a wobbly axis, so fast that one rotation may have lasted only about four hours. The force of this rapid rotation set up wild currents of motion in its outer as well as inner layers.

Yet our planet held together, and the Moon's orbit grew progressively larger during the several hundred million years that followed. By about four billion years ago, the Earth's rotation had slowed significantly as well, so that our planet's day had lengthened to around ten hours, and the Moon was nearly half as far away as it is today. (The Moon continues to move away from the Earth in very small but measurable increments.) At the same time, patches of the Earth's crust began to cool enough to harden molten material into the first solid rocks. Initially, these patches soon were melted down again by streams of hot lava, but eventually some of them survived. The Earth had begun to form a crust.

Not much survives from these ancient "rafts" of solid rock. Earth's continental landmasses are continuously recycled, pushed and pulled below the crust, heated, melted, and regurgitated along midocean ridges and trenches, so it is remarkable that rocks several billion years old do survive in a few places, including Western Australia and interior Africa. But the familiar continental outlines we see on globes and in atlases today are nothing like their antecedents three to four billion years past.

Not only are whole continents recycled: they move horizontally in a process the climatologist-geographer Alfred Wegener called continental drift. A century ago Wegener, observing the close "fit" of the shapes of continents across the Atlantic Ocean, theorized that this was unlikely to be matter of chance. The landmasses had once formed part of a supercontinent, he reasoned, that fractured into the continents we see on the map today. He called this hypothetical supercontinent Pangaea, and his map of (Fig. 3-1) is one of the most prescient ever drawn (Wegener, 1915).

Wegener's theory engendered the later theory of plate tectonics and crustal (sea-floor) spreading. Scientists now know that Pangaea and its breakup were

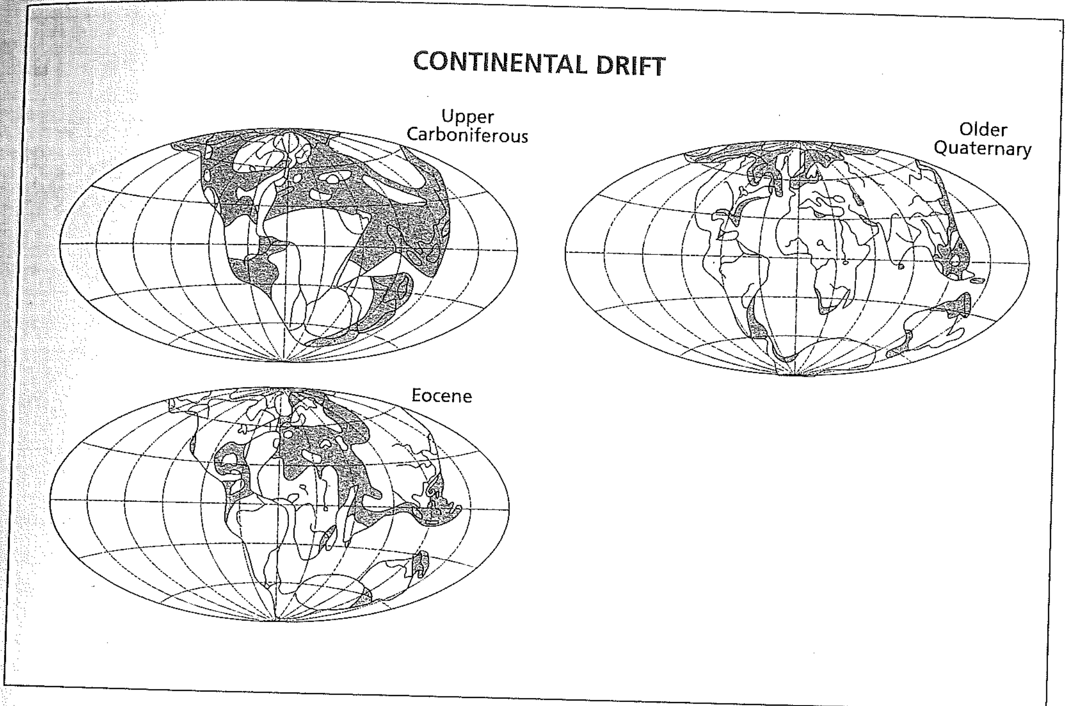

Fig. 3-1

only the latest episodes in a cycle of continental coalescence and splintering that spans billions of years. This latest Pangean fragmentation, however, began only about 180 million years ago and continues to this day. Where great slabs of the crust called plates collide and continental margins are pulled under, as is happening along the west coast of North America, earthquakes and volcanic eruptions accompany the process. That is why we recognize a circum-Pacific "Ring of Fire," marking these gigantic collisions from Chile to Alaska to Indonesia to New Zealand (Fig. 3-2). The earthquake that caused the December 26, 2004, tsunami (its epicenter is marked by the arrow off northwest Sumatra) was the result of such plate collision.

So the continents, made of the lightest rocks (solid or molten) on Earth, ride like rafts on the mobile, heavier plates below. And what makes those slablike plates move? That was Wegener's unsolved problem: the mechanism for his continental-drift theory. The answer came from an unlikely place: the ocean floors, where upwelling, red-hot lava creates new crust even as old crust elsewhere is pushed under (the process is called subduction) as plates collide. Wegener kept comparing North America and Europe and South America and Africa, but the crucial answer to his unsolved problem lay midway between them: along the Midatlantic Ridge, where the Transatlantic

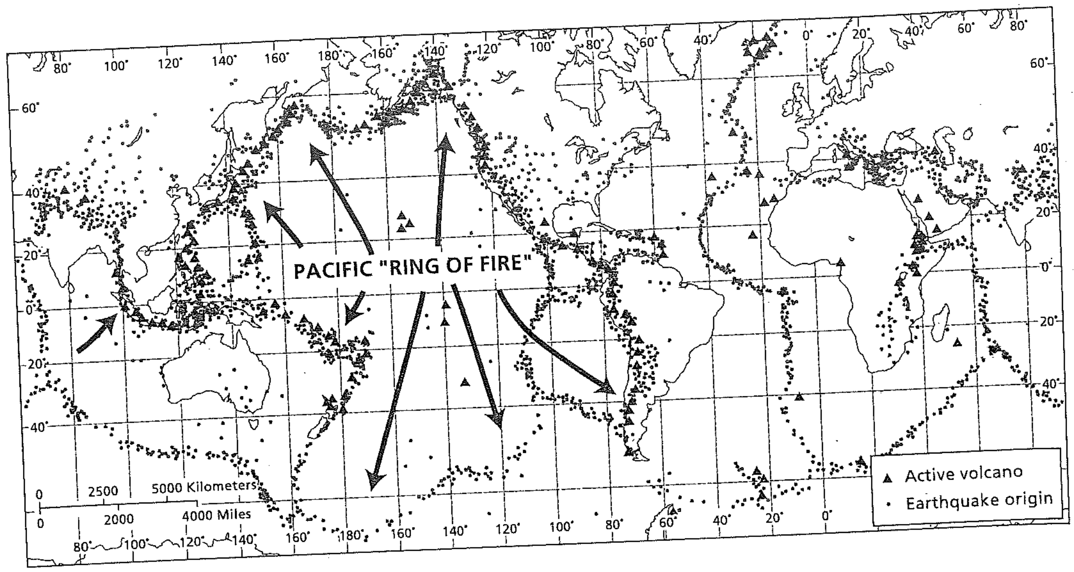

Fig. 3-2

continents were once conjoined. There, heavy, dark, basaltic rock forces its way upward, pushing earlier, hardened lava aside. We can actually observe the process occurring today near Iceland, where the normally submerged Midatlantic Ridge rises to the surface. New land is being formed as islands of lava rise above sealevel.

All this is not just theory any longer. We can now measure the movement of continents. One year from now, the room in which you are reading this will be about a half inch (13 mm) from where it is today, assuming you are somewhere in North America. That may not seem to be much, but calculate what it means over geologic time. In just 1 million years, the distance will be 8 miles (13 km). But the breakup of Pangaea started about 180 million years ago—and the North American plate is by no means the fastest-moving one. So the continental landmasses, and the plates that carry them, have moved thousands of kilometers since then.

What will the map of the distant future look like? At present the Earth exhibits the kind of pattern that attracts geographers' attention: so uneven is the distribution of landmasses that we routinely speak of a "Land Hemisphere" and a "Sea Hemisphere." This, of course, was far more pronounced when Pangaea still existed. Plate motion since then has already lessened the Land-Sea Hemisphere contrast. But the Pacific and its oceanic plates still cover nearly half the planet's surface, and the process has a long way to go. It may be, however, that plate movement is slowing down, and some geologists and others working on this problem suggest that continental motion may actually come to a halt, after which the landmasses may once again converge to form still another supercontinent. So "continental drift" may in fact be a cyclic process that has been moving the landmasses for as long as the Earth's crust has had plates and continents.

There is some evidence for this notion here in North America. As we noted, when plates converge and collide, the lighter continental plate overrides the heavier oceanic plate, but parts of both are pushed downward during subduction, and continental crust, with its fossils and telltale structures, is lost. That is happening now along North America's west coast, where spectacular coastal scenery bears witness to the forces at work. But before Pangaea broke up and North America started its westward journey, the continent was headed the other way, being carried toward the Pangaean cluster of landmasses. The coast of today's eastern United States was jammed into Morocco and other parts of West Africa, and the East, not the West, had the scenery associated with subduction. The Appalachian Mountains bear eroded witness to that pre-Pangaean time.

Over the long term, therefore, think of our planet's surface as ever changing, of continents moving and the crust shaking, of oceans and seas opening and closing, of land lost by subduction and gained by eruption. And this is only one dimension of the ceaseless transformation of Earth that began 4.6 billion years ago.

OCEANS PAST AND FUTURE

The fall of the Berlin Wall in 1989 led to much introspection—not only political, but also philosophical and scientific—and gave rise to a spate of books signaling the onset of a new era. Their titles were often misleading, such as *The End of History* by Francis Fukuyama, but none more so than one by John Horgan (1996) called *The End of Science*, which argued that all the great questions of science had been answered and that what remained, essentially, was a filling of the gaps. When it comes to global environments, however, some great questions remain open.

One of these relates to the oceans. Planet Earth today is often called the Blue Planet because more than 70 percent of its surface is covered by water and views from space are dominated by blue hues and swirls of white cloud, but in truth we do not know with any certainty how the Earth acquired its watery cloak, or exactly when. Some scientists hypothesize that the water was originally trapped inside the Earth during its formation and rose to the surface during the time when heavier constituents sank to form the core. The gases that are released during volcanic eruptions are mostly (more than 95 percent) water vapor, and massive volcanism marked Earth's early history, though lessening over time. Others calculate that most of the water that did reach the surface in this way would have been evaporated into space by the searing heat then prevailing, suggesting that another source must be identified. This has led to the comet hypothesis, which proposes that icy comets bombarded the Earth for more than a billion years while its atmosphere was still thin, accumulating fresh water from space that filled the basins in the formative crust. But studies published in late 2004 report that the chemistry of the oceans cannot be matched to that of icy comets (now much better known than before), casting doubt on the comet hypothesis.

Obviously, the "end of science" has not arrived when it comes to as crucial a question as this, and here is a related one: will the Earth retain its life-giving oceans permanently? Probes of our neighboring planet Mars produced some startling conclusions: Mars may have lost a global ocean more than 30 meters (100 feet) deep, and there are indications that Mars at one time had even more water (as a proportion of mass) than planet Earth. Why and how rapidly did Mars lose its ocean? And what may that loss portend for Earth?

ICE ON THE GLOBE

I always suggest to my students that they should be as familiar with the geologic time scale as they are with the months of the year and the days of the week—it is a great way to keep things geographic in temporal perspective. (Table 3-1). Geologists refer to the first 800 million years as the Hadean, and indeed the Earth was hot as Hades during that eon. The next 1,300 million years form the Archean, when the oldest surviving continental rocks and the first life forms are recorded. Next comes the Proterozoic eon, lasting from 2,500 million until 570 million years ago. It is late during this eon that something dramatic appears to have happened: the Earth went into a deep freeze.

The theory is known as Snowball Earth, and the evidence is coming from rocks as far apart as China and Australia. It suggests that the Earth did not just cool, as has happened several times since: apparently the entire planet froze, from pole to pole and from land to sea. The landmasses lay buried under ice and snow; the ocean surface was frozen solid. What might have caused this to happen? A temporary but significant decline in the Sun's radiative output is one possibility. A rapid decline in methane-producing microorganisms (methane was the key early greenhouse gas) with the rise of oxygen-generating microbes around 2,300 million years ago may have chilled the entire planet (Kasting, 2004). Some scientists suggest that the stabilizing crust and consequent decline of volcanic activity could be a factor. Whatever the cause,

THE GEOLOGIC TIME SCALE

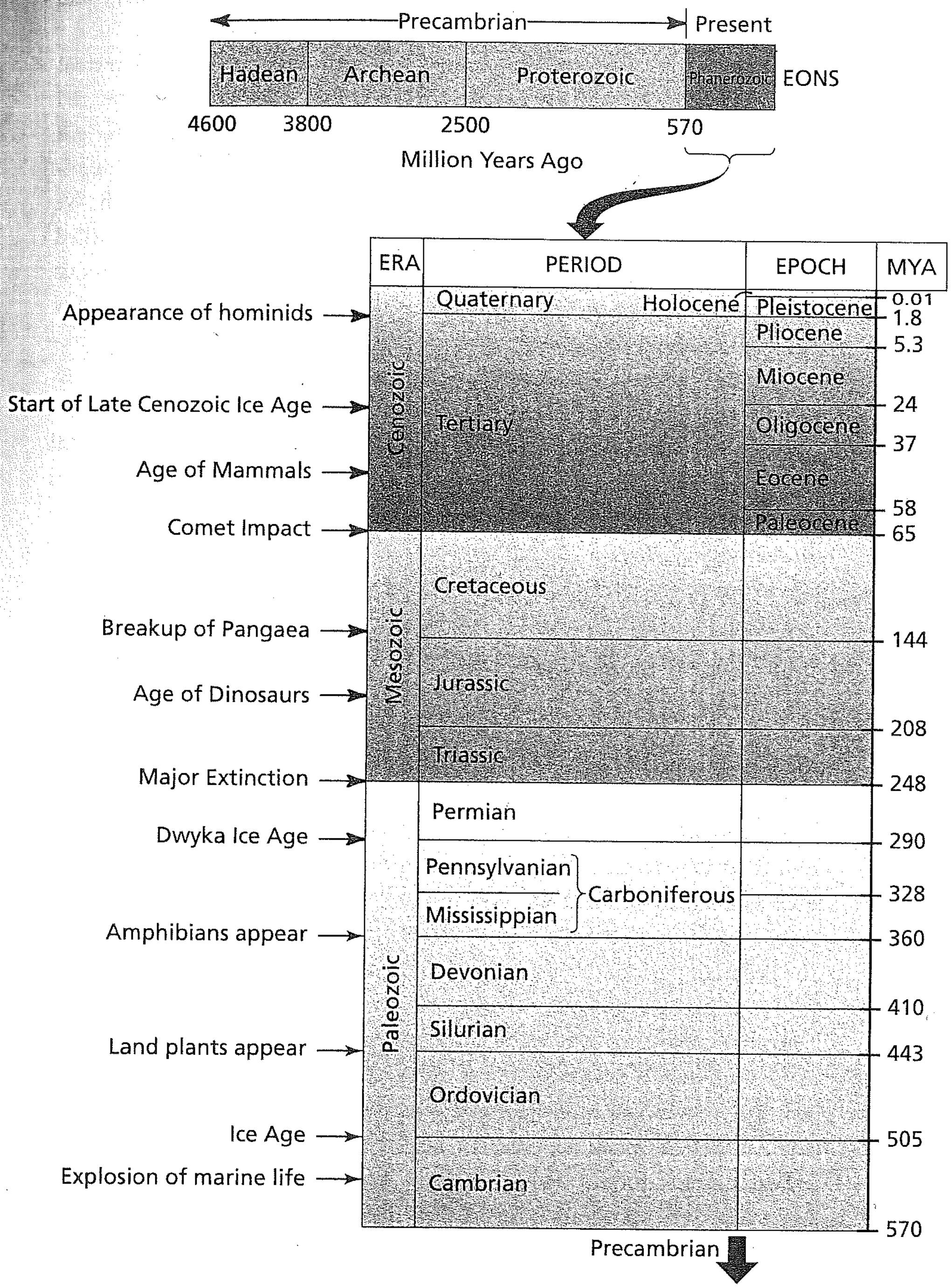

Table 3-1

the planet and its early life forms experienced a crisis. Whether the Earth was indeed a "snowball" or, as others suggest, it was a less frigid "slush ball," the days of sustained warmth as its hallmark were clearly over.

Whatever the outcome of the search for evidence relating to the Snowball Earth theory, we know that this was not the last time the Earth experienced an ice age. Several have followed, and the most recent one is in progress right now. All known ice ages, and perhaps even the Proterozoic one, have periods of severe cold separated by shorter phases of comparative warmth. We are experiencing such a warm interruption at this time, one that has lasted roughly 12,000 years—roughly, because the rapid warming that brought us today's mild climates actually started about 18,000 years ago but was sharply interrupted about 12,000 years ago, when frigid temperatures briefly returned. But the ice age of our time began about 40 million years ago and, as we will see later, continues.

What we do know about ice ages is that their often rapid environmental swings pose challenges to all life forms, from eukaryotes to humans. Ice ages are times of accelerated evolution; organisms that adapt tend to survive, those that cannot, perish. During the Snowball Earth Ice Age, single-celled eukaryotes evolved into multicelled, more complex organisms. Those with protective shells (there was plenty of calcium carbonate around) had a better chance of survival. When the ice age ended, life on Earth was set for its Cambrian Explosion, the burgeoning of marine organisms in unprecedented diversity that marks the oldest period of the Paleozoic era. Then, after more than 4,000 million years of the planet's existence, began the drama that would lead to the emergence of humanity, 570 million years later, again during an ice age.

How many ice ages have occurred between the Proterozoic and the current one? We are sure of one at least: the ice age that occurred when Pangaea as a supercontinent was still in one piece (Fig. 3-3), and it may have been unprecedented in its impact on life on Earth. This happened during the Permian period, the last of the Paleozoic era, between 290 and 251 million years ago. At the time, Pangaea consisted of a northern periphery called Laurasia, consisting of parts of Eurasia and North America, and a southern sector known as Gondwana, at whose core lay what is today Africa. The South Pole was just offshore from South Africa; Australia adjoined India and Antarctica. When the Permian Ice Age (known elsewhere as the Dwyka Ice Age) struck, forests were widespread, amphibians thrived, small reptiles had made their appearance, and insects had proliferated. When it was over, one of the greatest mass extinctions ever had decimated life on Earth. As the map shows, a vast area of Gondwana was buried under ice, but what the map cannot show is the ice age's impact on environments far beyond the

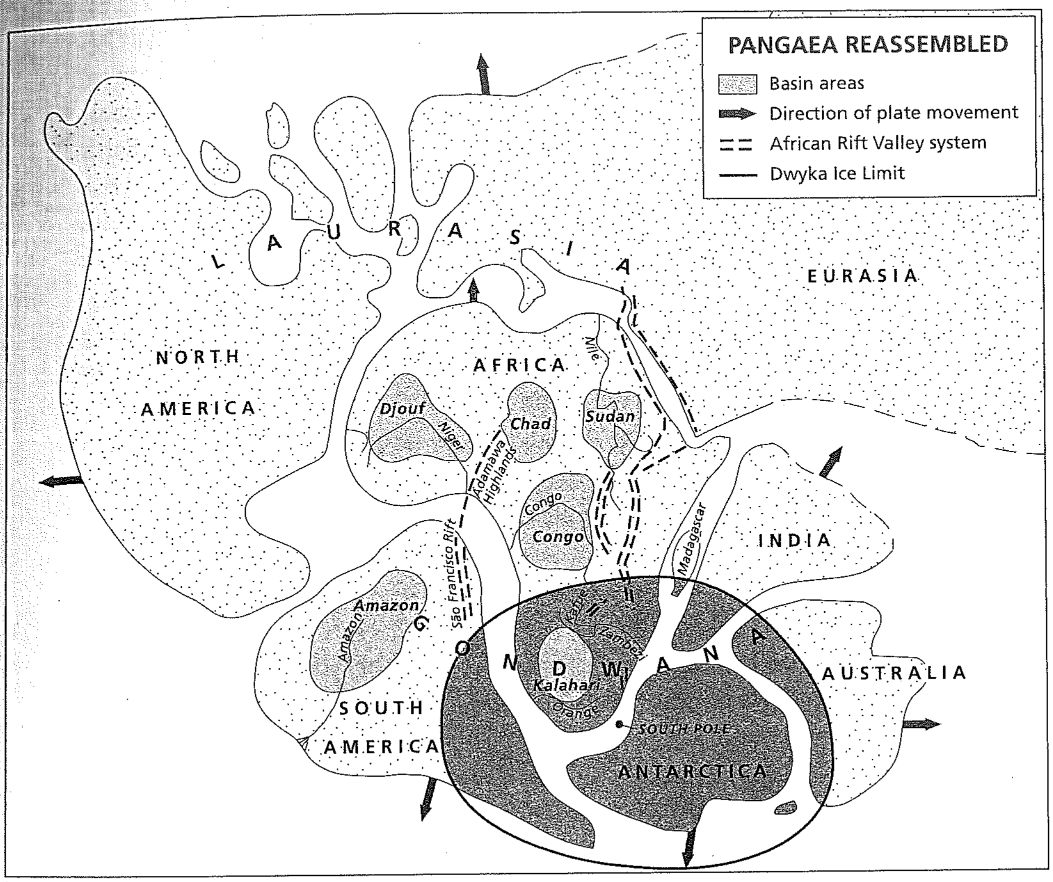

Fig. 3-3

high latitudes. Huge areas fell dry, forests withered, and countless species of plants and animals became extinct.

That, at least, was the state of knowledge until November 2003, when geologists produced evidence indicating that the Permian period ended in catastrophe, not frigidity. Asish Basu and a team of researchers found telltale bits of meteorite in Antarctica along with other indications that a huge meteor struck the Earth about 251 million years ago, killing as much as 90 percent of all life on the planet (Kerr, 2003). Rather than succumbing to ice-age cold alone, animals as well as plants were incinerated by the impact and its aftermath, which may have included huge volcanic eruptions pouring out vast volumes of molten rock from fissures and vents in the shaken crust. The scientists theorize that this may have been the most devastating of the Earth's five known mass extinctions, resulting from a combination of environmental, extraterrestrial, and geological forces that ended not only the Permian period but also the Paleozoic era (Table 3-1).

When the ice age ended and the Mesozoic era opened, there was little left of Permian life. But now the post-ice-age planet made up for that. Tropical warmth replaced Arctic cold, moisture and precipitation abounded, atmospheric oxygen increased markedly as luxuriant forests spread and the Earth was ready for the faunal exuberance of Jurassic Park. The age of the dinosaurs also saw the first birds, the first marsupials (animals whose females nurture their offspring externally in a pouch, not internally in a placenta), and the first angiosperms (plants whose seeds are encased in fruit).

Even the massive, sky-blackening volcanism that accompanied the breakup of Pangaea during the Jurassic failed to spoil the party. The dinosaurs grew larger and larger, specializing into herbivores and carnivores and competing fiercely for survival. As the landmasses separated and the seas between them widened, species found themselves isolated and evolved into distinctive forms. Only another ice age, it seemed, could end the Mesozoic's profusion.

SUDDEN DEATH

The diversity of dinosaurs and the flourishing of Mesozoic plants reached their zenith during the Cretaceous period, when huge birds flew in vast forests and flowering plants spread across the world. It was warmer even than it is today; polar and mountaintop ice were long gone and dinosaur species roamed from Alaska to Antarctica. Small mammals managed to survive in special niches, but the day belonged to the giant reptiles whose only enemy, it seemed, would be a sudden return to the frigid conditions of the Permian.

But the age of the dinosaurs came to a much more dramatic end—not with a glacial whimper but with an extraterrestrial bang. One day about 65 million years ago, a comet or asteroid only about 6 miles (10 km) in diameter streaked toward Earth at a speed of 55,000 mph (90,000 kph) on a collision course. It approached from the southeast at a low angle, striking Earth in what is today the area of the Yucatan Peninsula of Mexico. When you get off a boat at the small port of Progreso, there is a small, hand-painted sign that points to Chicxulub, a Maya name for a local village. But to geographers, Chicxulub means the end of one era and the start of another. Here the asteroid's impact produced an explosion equivalent to about 100 trillion tons of dynamite, forming a crater approximately 110 miles (180 km) in diameter, 40 miles (65 km) deep, and encircled by a geological fault 20 miles (about 30 km) beyond, all of it buried today by later sediments.

It is possible that the Chicxulub asteroid was one of a swarm, and that smaller ones struck the Earth elsewhere, including the ocean. In any case, the impact's devastation reached around the planet, and was at its worst in North America. The impact area was a shallow sea with soft, deep sediments, and the blast sent a mass of debris hurtling thousands of miles into the heart of the continent and high into the atmosphere and beyond. Researchers David King and Daniel Durda calculate that some of it reached halfway to the Moon before falling back to Earth. And when it did fall back, it rained red-hot rocks on the rotating planet, setting fires to forests almost everywhere. The atmosphere was heated enough to evaporate entire lakes, incinerate whole ecosystems, and extinguish most life over large low-latitude regions.

The Chicxulub impact ended the Cretaceous and marked the beginning of a new geologic-calendar period, the Tertiary. Popularly, the transition is called the K/T Boundary, but its significance is hard to overstate, because this was one of the three greatest known mass extinctions ever. While it is possible that some dinosaurs survived the original blast, notably in higher latitudes, food chains had been fatally disrupted and they, too, died out. Some small mammals were better equipped to outlive the crisis, perhaps keeping cool in high-latitude caves and burrows, depending less on the luxuriant vegetation and reptilian life the dinosaurs had needed. But the faunal and floral exuberance of the Mesozoic era came to a sudden, irrevocable end.

The K/T blast had long-term effects on global environments. Much of the enormous volume of pulverized, ejected rock remained in orbit around the Earth, choking the atmosphere and blocking the sun. The smoke from worldwide fires darkened the skies worldwide. Eventually the overheated atmosphere cooled, and the blockage of the sun sent temperatures plummeting still more, creating colder global conditions than had been experienced for 185 million years—since the Permian Ice Age. Now it becomes important to be familiar with the epochs of the Tertiary period, because the first of these epochs, the Paleocene, witnessed major climactic reversals, and the next one, the Eocene, saw the beginnings of a new ice age that probably would have come whether the K/T impact occurred or not.

BACK TO THE FUTURE

As the post-impact planet cooled, shrouded in dust and smoke, there was little to suggest that an era of recovery and renewed biodiversity lay ahead. The forest fires, and the explosion into the atmosphere of huge volumes of carbonates from the impact site, greatly raised the amount of carbon dioxide in the air, creating a powerful greenhouse effect when the skies began to clear. As Figure 3-4 shows, this global warming continued through much of the Paleocene, raising temperatures even higher than they had been during the warm Cretaceous. Biogeographers conclude that this killed many plant and animal species that might have survived the blast and its immediate aftermath. But the Paleocene's warming did not continue. The next epoch, the Eocene, was marked by an almost continuous drop in global temperatures, and by the time it ended, 36 million years ago, permanent ice was beginning to form on the Antarctic continent. The Cenozoic Ice Age was about to start.

Soon the evidence began to accumulate: the early phase of the Oligocene witnessed the beginning of the formation of the Antarctic Ice Sheet even as South America and Antarctica were separating. (Remember: through all of this activity, the continents continued to move on their crustal plates, the Atlantic Oceans, North and South, kept widening, and the distribution of land and water on the planet kept changing.) Even before the ice on Antarctica reached its shores, glaciers began to develop on the Earth's highest mountains, filling high-elevation valleys and sculpting a new, angular topography of sharp-edged peaks and ridges. Tree lines dropped to lower altitudes, vegetation shifted equatorward, and the mammals that had become the dominant species, including the now-common primate forms, responded by migrating and adapting as environments fluctuated.

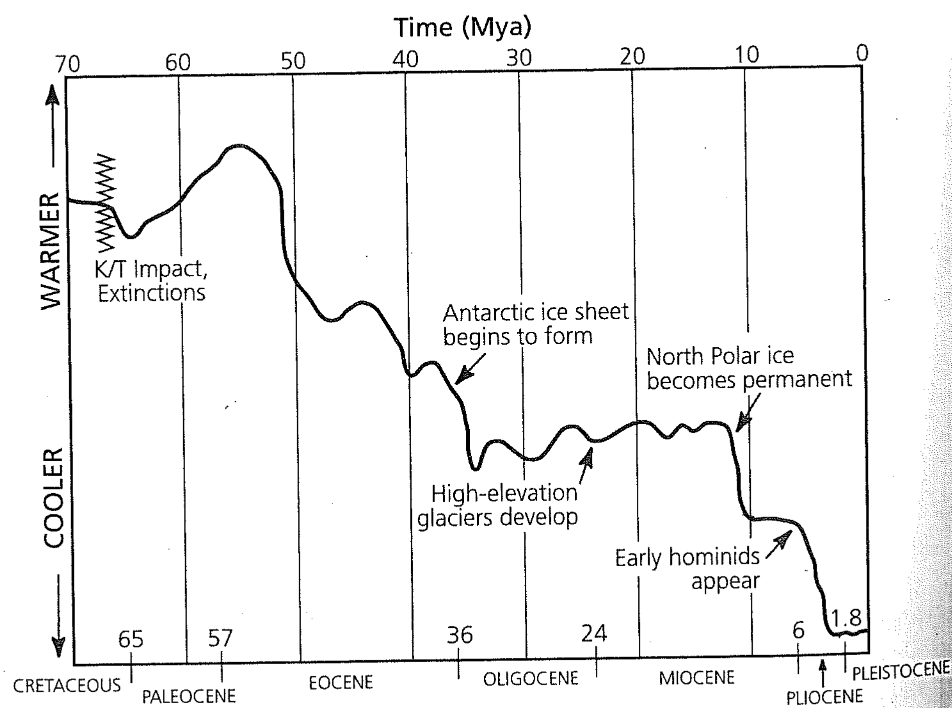

Fig. 3-4 **GLOBAL TEMPERATURE CHANGE, LATE CRETACEOUS TO PRESENT**

Ice ages are not uniform cooling events: surges of coldness and advances of glaciers are interrupted by temporary warming spells long enough to reverse much of the glacial impact. So it was from about the middle of the Oligocene to the middle of the Miocene when, it seemed, the Cenozoic Ice Age had reached an equilibrium that (had weather and climate analysts been around in those days) might have been taken as a sign that the worst was over. Antarctica still had coastal zones clear of ice; the high-mountain glaciers advanced and receded as global climate cooled and warmed, and while the planet overall was cooler and drier than it had been during the ages of the dinosaurs, there was plenty of environmental variety and related biodiversity. But then, about 14 million years ago, global cooling resumed with a vengeance. Antarctica's ice sheet not only reached the ocean all around its shores, but the ice floated from land onto water and cooled the Southern Ocean, affecting the entire global ocean in the process. Permanent ice appeared and rapidly thickened on the waters of the North Pole and environs. The temperature plunge continued until a comparatively brief period of stabilization marked the end of the Miocene, but the next, brief (4.2-million-year) Pliocene epoch saw another period of further cooling. Permanent glaciers appeared even on mountains in equatorial zones of the Andes, East Africa, and New Guinea. About 1.8 million years ago began what was on average the coldest epoch of the Cenozoic Ice Age, the Pleistocene. We are living under Pleistocene conditions today, enjoying the autumn of a warm phase that, as noted earlier, has been going on for about 12,000 years.

CLIMATES AND PRIMATES

An ice age is a long-term event, lasting tens of millions of years and bringing profound changes to all parts of the planet, not just those directly affected by advancing ice sheet and valley-filling glaciers. The overall process and its manifestations may operate slowly, but there are times when sudden surges of advancing ice move fast enough to encircle grazing animals and snap off mature trees like matchsticks.

Advances of ice into lower latitudes and altitudes during a cold ice-age period are called glaciations and temporary warm-ups between glacial advances are referred to as interglacials. It should not be necessary to emphasize these distinctions, but geologists and even some physical geographers occasionally get this wrong. One of the leading geology textbooks, for example, states that "periods during which the average temperature at the Earth's surface dropped by several degrees and stayed low long enough for existing ice sheets to grow larger . . . are called glaciations (or ice ages . . .)." What should have been said, of course, is that *during* an ice age, such temperature declines are marked by glaciations (Murck & Skinner, 1999). This is important, because even while global temperatures decline during an ice age and glaciations push ice into ever-larger areas, there are also periods of relief in the form of interglacial warmth and retreating ice (a better word is *receding*, because glaciers do not really reverse direction).

Let us keep in mind, therefore, that the overall drop in temperatures that began in earnest during the Eocene and reached unprecedented lows during the most recent, Pleistocene glaciations, was no steady or continuous process. As Figure 3-4 suggests, there were long periods when the Cenozoic Ice Age seemed to have reached its maximum, with its end in sight—only to plunge into even more frigid conditions. What is certain is that the impact of that ice age was evident all over the world. When a vigorous glaciation pushed ice sheets deep into present-day Canada and into lower latitudes of Eurasia, it got cooler and drier even in Africa and equatorial South America. Tropical forests shrank, savannas expanded, and animals as well as plants responded by migrating and adapting to new environments.

We all know that the story of the great apes, hominids, and humans played itself out in Africa. As another chapter in this book reminds us, all of us are, ancestrally, Africans. But any geographer looking at the world map would wonder: why Africa, when Eurasia is so much larger and seems to contain so much more environmental diversity? In that connection, one question that troubled me for decades after I first learned of it in graduate school a half century ago: why are chimpanzees and orangutans, two of humans' closest genetic relatives, separated by thousands of miles of land and ocean, the chimps in Africa and the orangs in Southeast Asia?

I remember sitting in an airport van full of archeologists and anthropologists going home from a meeting in Asheville, NC about five years ago, and raising this issue. Where, I asked, is the fossil record that would prove the migration of orangutans from Africa to Southeast Asia? It will be found, I was told. Fossils in humid South Asia don't survive like they do in Africa. We're talking 6, maybe 7 million years ago. The genetic relationship is beyond doubt, so the migration must have taken place. It's just a matter of time before the evidence appears.

Well, the evidence never surfaced, and I should have thought more carefully about the geographic implications of the question I raised. If the great apes of Southeast Asia did not descend from those of Africa, then each branch must have had ancestors in Eurasia. Postulate that, and you conclude that something drove one of those branches—the one leading to the gorilla and chimpanzee among others—to tropical Africa, while the other, leading to the orangutan, was pushed into tropical Southeast Asia.

What could have been the impetus for this dual migration? The worsening of Cenozoic Ice Age conditions, of course. Before Miocene climatic conditions deteriorated, the global environment, though cooler than it had been during the Oligocene, remained fairly stable (Fig. 3-4). During that time, the descendants of *Proconsul* and other early apes probably moved out of Africa into environmentally diverse Eurasia, where forest habitats varied widely and relatively warm temperatures ensured an ample supply of fruits and other forage. Now Eurasia, not Africa, was the heartland of differentiation and adaptation for the great apes, and numerous lineages evolved, some of them now part of the known fossil record.

But in the late Miocene the Cenozoic Ice Age took a turn for the worse, dropping global temperatures, freezing over the Arctic Ocean, drying up vast stretches of once-forested Eurasia, and destroying habitats that had for millions of years nurtured the great-ape families. Extinction was commonplace, but researchers have determined that two lineages managed to survive by adaptation and migration: *Dryopithecus*, which occupied southwestern Europe, and *Sivapithecus*, which was based in the forests of the northern Ganges River basin (Fig. 3-5).

Dryopithecus moved southward across what is today the Mediterranean into tropical and eventually equatorial Africa, probably around 9 million years ago, adapted to cope with the severe swings of environment prevailing at the time and destined to give rise to tool-making, large-brained descendants. It is somewhere along the *Dryopithecus* lineage that hominids and Africa's great apes had a common ancestor, but make no mistake: having escaped the rigors of the late Miocene in Eurasia, they found no African Garden of Eden. The increasing severity of the Cenozoic Ice Age, persisting into the Pliocene and the Pleistocene, affected tropical and equatorial Africa as well, causing rapid environmental swings that overwhelmed and extinguished numerous progenies, ape and hominid alike (Begun, 2003).

The other Eurasian great-ape lineage, *Sivapithecus*, moved down the Malayan Peninsula and into what is today Indonesia, where Miocene and Pliocene conditions may have been less rigorous than they were in ice-age Africa. In any case, no comparable evolutionary drama occurred here: the orangutan does not share a hominid ancestry and is the end of its line. Eventually and ironically, descendants of *Dryopithecus* and *Sivapithecus* would come face to face—but not ape to ape. When interglacials in the late Pliocene warmed the Earth enough to revive forests and refill desiccated lakes, Africa's hominids did what early Miocene apes had done before them: migrate

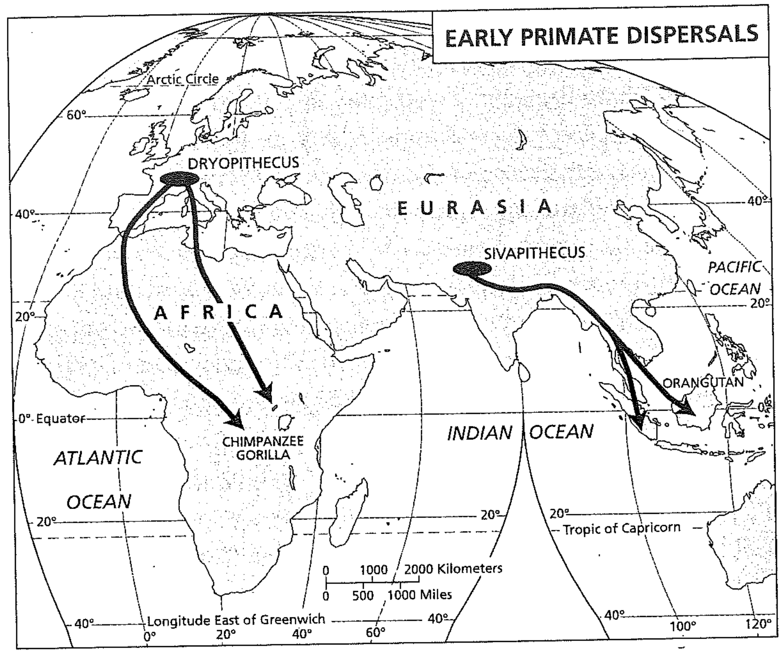

Fig. 3-5

out of Africa into Eurasia. And so the first of these emigrants, *Homo erectus*, moved across Arabia and southern Asia and, one day somewhere in Malaya or on Java or Borneo, saw a creature that, if the trip had been swifter, would have reminded her of the chimpanzees and gorillas left behind in Africa. Orangutan and hominid had closed a 9-million-year circle.

THE FRIGID PLEISTOCENE

Earlier we noted that the temperature plunge that began in the late Miocene and continued during the Pliocene (when early hominids made their appearance in Africa) set the stage for the Pleistocene epoch, beginning less than 2 million years ago with a series of the most severe glaciations of the entire Cenozoic Ice Age interrupted by short, warm interglacials. In Africa, where hominid evolution was under way, these phases were marked by fluctuating climates and sometimes wild fluctuations in ecologies that guided natural selection. *Homo erectus*, successor to *Australopithecus*, was the most successful of these hominids. *Homo erectus* managed to cope with forests that changed into savannas and back again, lakes that formed and evaporated, wildlife that ranged from easy to difficult and elusive prey and, as the fossil record shows, even with massive volcanic eruptions and huge ashfalls. Undoubtedly the numbers and dispersal of *H. erectus* also varied, but the species survived for perhaps as long as 2 million years and, as we noted, left Africa and spread across Eurasia, reaching not only Southeast Asia but also present-day China in the east and Europe in the west. *Homo erectus* and its successor, the tool-making *Homo habilis* ("handy man"), presaged the human expansion that was to follow similar paths.

Pleistocene environmental conditions are the subject of intense investigation today. When Pleistocene glaciations were severe, permanent ice advanced deep into the landmasses of the Northern Hemisphere (Fig. 3-6). This drastically changed the distribution of plants and animals, shifting them equatorward latitudinally and downslope altitudinally. Faunal ranges and refuges shrank, niches became unusable, and always there were species that failed to survive the transition. Such glaciations could last as long as a hundred thousand years, but eventually an interglacial would warm the planet, melt much of the ice, and living space as well as survival opportunity would expand again.

Physical evidence from various sources, including Greenland ice cores and Atlantic ocean-bottom mud deposits, coupled with analyses of broken and pulverized rocks left behind by the Pleistocene glaciers, at first seemed to suggest a remarkable regularity in the ups and downs of Pleistocene temperatures. Interglacials seemed to last an average of 10,000 years, so that, on average, a glaciation-interglacial sequence encompassed around 110,000 years or so. Over the past 425,000 years of the Pleistocene, there appeared to have been four major glaciations followed by four interglacials, the latter including the current one, the Holocene.

More recent analyses suggest that it has not been so simple. The most recent glaciation, the Wisconsinan, began about 100,000 years ago after a rather long interglacial, the Eemian. But the Wisconsinan was not one long cold spell. In fact, it was punctuated by several brief interglacials and longer (comparatively) mild spells that made habitation in higher latitudes possible for thousands of years. What is clear is that these alternations from warm to frigid and from mild to cool often happened quite suddenly, taking their toll not only on animals and plants but also on hominids and humans.

We now begin to put humans in the picture, because they appeared in Africa some time during the glaciation preceding the Wisconsinan, probably around 170,000 years ago. Hominids and humans shared not only parts of Africa but also the migration routes from Africa into Eurasia, and they met similar fates when the climate took its disastrous turn. We know something about this because early humans used the land bridge between Africa and Eurasia, across the Sinai Peninsula, late during the Eemian interglacial (Fig. 3-7). No

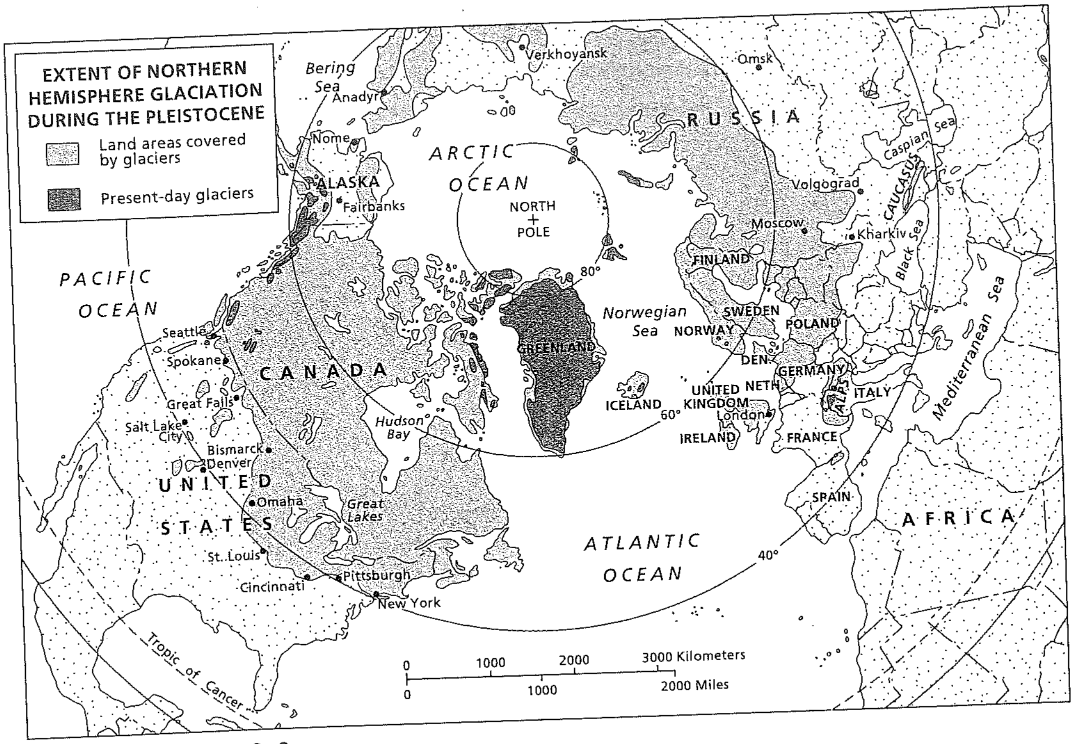

Fig. 3-6

sooner were they in the Middle East when the Wisconsinan Glaciation began with a ferocious drop in temperatures. All that is left of that early emigration are the bones of the migrants. They never made it to Europe.

The next time humans tried to leave Africa they used a different exit at the opposite end of the Red Sea around 85,000 years ago. The Wisconsinan Glaciation had converted so much water into ice that the surface of the Red Sea was hundreds of feet lower than it is today. The reefs in the Bab-al-Mandab (Arabic for "Gate of Grief"), where the Red Sea opens into the Indian Ocean, created the stepping stones that facilitated the crossing, and our African ancestors were on their way. First they moved along the shore of the Arabian Peninsula, then around the Persian Gulf and on into India and Southeast Asia, reaching Australia via New Guinea (another crossing facilitated by low sealevels) about 60,000 years ago (Oppenheimer, 2003).

In the process, modern humans met the hominids who had preceded them into Eurasia, and the hominids were no match for the resourceful newcomers. When the first modern humans (the Cro-Magnons, as they are known) reached Europe from India via the Middle East and found the Neanderthals, and earlier *Homo* species, on the scene, they quickly overwhelmed them with their complex culture ranging from cave art to tool kits and from

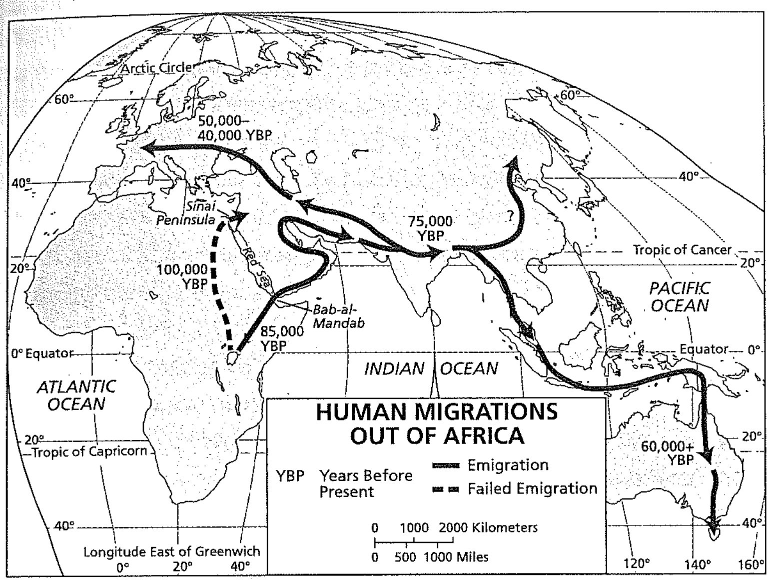

Fig. 3-7

inventive fishing gear to sewn clothing. They lived in cooperative communities and used sophisticated language, and thus modern humans had all the advantages over the survivors of earlier out-of-Africa migrations. Their technology gave them the opportunity to cope with the Wisconsinan's climatic swings: in milder times they expanded their frontiers, and when it got colder they devised ways to cope with increasingly harsh environments. That is why paleoanthropologists are finding fossil evidence of human settlements in Europe that survived through pretty severe cold periods. Humans were finding ways to combat the rigors of changeable climate.

A CLOSE CALL

In truth, humanity was fortunate to be able to expand into Europe at all, because the exodus from Africa via the Arabian Peninsula and South Asia almost came to a halt in spectacular fashion. We are not sure just where the vanguard of human migration was about 73,500 years ago, but the exodus across the Bab-al-Mandab was probably continuing. Then a catastrophic event in what is today Indonesia very nearly wiped all of humanity off the planet. On the island of Sumatera (Sumatra in the old spelling), a volcanic mountain now named Toba did not just erupt—it exploded. This explosion sent millions of tons of debris into orbit, obscuring the Sun, plunging much of the Earth into long-term darkness and altering global climate. Mount Toba's detonation could not have come at a worse time. The Wisconsinan

Glaciation was in full force, the Earth's habitable zone was already constricted, and a large part of the still-sparse human population faced death. Anthropologists refer to this event as humanity's "evolutionary bottleneck," suggesting that a great deal of genetic diversity must have been lost in that instant. Today, the filled-in-caldera marking Toba's cataclysm is 55 miles (90 km) long and 30 miles (50 km) wide, silent witness to the greatest threat to human survival since we emerged on the African savanna.

As has happened so many times in Earth's history, the skies eventually cleared, the atmosphere was cleansed, and normal conditions resumed. Toba was calamitous, but it was no Chicxulub. It did not generate fires around the world, and was not nearly as destructive as that incoming asteroid. Nevertheless, it posed a real danger to humanity, and reminds us that risks of this kind have not disappeared. Geologists refer to the Toba explosion as a 500,000-year event, something that happens, on average, once in a half-million years. That is no guarantee that another Toba-like eruption will not happen for a very long time. Our planet still poses unpredictable, incalculable natural hazards, as we were reminded on December 26, 2004.

So let us anticipate the geographic story of climate and civilization by revisiting the environmental saga of the Cenozoic Ice Age. For tens of millions of years, glaciers have been spreading during cold periods appropriately called glaciations, only to recede during warm spells we know as interglaciations. The entire planet and all its life forms, not just the polar regions, are affected by these environmental swings. Glacial advances pushed primates from cooling Eurasia into Africa and Southeast Asia; interglacial warm spells allowed hominids to leave Africa and survive in temperate Eurasian latitudes. All the while, average global temperatures declined until, about 1.8 million years ago, the start of the Pleistocene brought an alternation of long glaciations and short interglaciations. About 120,000 years ago, the Eemian interglacial was even warmer than the current one, the Holocene, but it ended abruptly some 110,000 years ago with a rapid advance of the ice of the Wisconsinan Glaciation. Humanity was on the scene by then, but our earliest emigrations from Africa were stymied by the sudden return to frigid conditions. When we finally made it out of Africa, we kept a southern route along Asian shores, but there were times when the Wisconsinan cold ameliorated and our ancestors took these opportunities to penetrate present-day Europe and confront—and overpower—Neanderthal predecessors. But the relentless advances of the ice came again, and just 20,000 years ago, glaciers stood as far south as the Ohio River in North America and southern England, central Germany, Slovakia, and Ukraine in Europe. Then, about 18,000 years ago, global warming sent those glaciers into fast recession, so fast that whole regions rapidly emerged from under the ice, huge ice sheets slid into the oceans, the sealevel rose, the margins of the continents were submerged, land bridges between continents and islands were inundated, and the map of the physical world began to look similar to the one we know today. Twelve thousand years ago, cold conditions made a brief comeback, but that did not last. From about 10,000 years ago until today, humanity has thrived in the warmth of a prolonged interglacial we call the Holocene, but unlike the Eemian, the Holocene has witnessed the emergence of complex cultures and civilizations, the population explosion, the formation of states and empires, the growth of megacities, and the burgeoning of technology in countless forms. It has also seen wars and destruction on an unprecedented scale. With our human numbers approaching 7 billion and global warming opening the last niches for habitation, the question is: what happens when the ice returns, as it has more than two dozen times during the Pleistocene?