

EXPLORING THE EARTH AND THE COSMOS

The Growth and Future
of Human Knowledge

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*Dedicated to
the memory of
Herbert Michelman (1913–1980)*

Introduction

These days we are so used to the broad range of human knowledge in a hundred different directions that we tend to forget how limited we are as individuals.

Forget all that came before you and all that exists beside you and consider what it is that *you* can experience. It isn't much!

To be aware of "all that the eye can see" is to penetrate a distance of, at most, a couple of kilometers. Travel without the help of other people or of inanimate devices and you'll find even a couple of dozen kilometers a daunting task. In fact, until quite recently, most people spent their entire lives within a few kilometers of the place where they were born. Everything else was, to them, hearsay.

What else? How high can you climb? How deep can you plumb? By yourself, a few meters upward into a tree or a few meters downward into a well. You might watch the birds and dream, but dreaming will have to be your master. And the heavenly bodies? They are the very epitome of the unreachable. To "cry for the moon" is the catchphrase for wanting what you cannot have, and the moon is the *nearest* of these bodies.

What can you remember, all by yourself? Your grandparents perhaps, and the stories they told you about how things were when they were young, and about *their* grandparents? A hundred years back, perhaps, and everything dissolves into mist.

What is the largest thing you can experience? A mountain? The smallest thing? A dust mote dancing in a beam of sunlight? The hottest thing? A bonfire? The coldest thing? A bitter winter morning?

In every direction you are limited, and the world closes in on you with its smallness.

But human beings have attributes no other living thing has as far as we know. We have endless curiosity and enormous ingenuity. Myriads of years ago we evolved a complex system of speech by which we could express abstract concepts and transfer them from one to another. Each of us can master not only our own thoughts and insights but those of others. A whole community can pool its gathered ideas and knowledge.

Later, we developed a system of writing, of recording speech, which meant that thoughts and insights could drift outward in space and time, reaching communities far removed from our own and generations yet unborn.

The pool of knowledge and ideas eventually became worldwide and permanent, so that the time arrived when every person had at his disposal all the gains made by those who share the world with us and by those who came before us.

Knowledge grew, first slowly, and then explosively, and the human horizon moved outward in every direction. We now roam the entire world from pole to pole. We climb the highest mountain, plumb the deepest sea, touch the moon, and send our vehicles past Saturn to tell us what they see.

We grasp and study, with equal ease, the largest star and the smallest atom, and consider such mind-bending concepts as black holes and quarks. We probe toward temperatures rivaling the cores of the hottest stars and the depths of the most isolated reaches of unlit space.

In this book I will try to show you the steps by which it all happened, to give you the tale of the heroic voyage of exploration that our species has taken and that we are heir to—and a glimpse also of the distances we have yet to go.

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PART I

The Horizons of Space

1

The Eastern Hemisphere

PREHISTORY

On Earth, life began at least 3,500,000,000 years ago, no more than 1,000,000,000 years after the planet had achieved more or less its present shape. Although we may suspect that Earth is not unique as a life-bearing planet, we do not as yet have any evidence that life exists anywhere else, so we must restrict our discussion of the expansiveness of life to our own planet.

Since we are going to deal with human beings primarily and with purposeful expansion of range, there isn't much to say about the expansion of life generally. Life originated in the sea, and for at least seven-eighths of its total duration on Earth, it remained in the sea. The land surfaces of Earth were barren. Why this should be we are not certain.

Perhaps certain key mutations in living cells finally took place that made them capable of protecting themselves from desiccation outside the seas, lakes, and rivers. Perhaps the ozone layer in the upper atmosphere finally formed to the extent that much of the ultraviolet radiation of the sun was blocked. This would mean that land life, exposed to direct solar radiation, would be protected from the dangerous disruption of too energetic wavelengths. Perhaps the moon was captured and consequently the range of tidal action was suddenly increased, and life was washed farther and farther up the shore and the forces of natural selection produced species adapted to periodic desiccations.

Whatever the cause, life invaded the land surface of Earth about

425,000,000 years ago. Following that invasion, life expanded to fill very nearly every conceivable niche on land. Only the polar ice sheets, the highest mountain peaks, and the driest deserts are relatively lifeless.

From beginning to end, life has consisted of tens of millions of different species, sufficiently distinct to be incapable of interbreeding. Of these, most are now extinct, but some 2,000,000 may exist at the moment.

The different species have different ranges. Some are widespread and range over continents and oceans; others are highly restricted and are found only on some particular small island or in some isolated valley. On the whole, the wider the range, the more nearly immune a species is to local change and disaster and the more successful it is by the one criterion that counts from the evolutionary standpoint—survival.

The group of species in which we are most interested, from a self-centered standpoint, are those belonging to the order Primates. The very name of the order is from the Latin word for “first,” for no better reason than that the human species is included.

On the whole, the order Primates is not a spectacularly successful one (always excepting human beings). The first primate may have evolved about 75,000,000 years ago, and there are some 200 species now existing, with a range (if we don’t count human beings) almost entirely confined to the tropics. What’s more, no one species (if, again, we don’t count human beings) is to be found over a large fraction of the range. Some groups are confined to sections of South America, some to sections of Africa, some to sections of southeastern Asia, and so on.

Nevertheless, successful or not, the primates did specialize in brainpower. For their size, they had remarkably large and well-developed brains, and as time went on, newly developed primate species produced still larger brains.

The group of species in the order Primates which developed the brain to its highest pitch were those belonging to the family Hominidae. We may refer to individual species of this family as *hominids*, from the Latin word for “man,” since all of them, even the most primitive, were more similar to modern human beings than to the modern great apes that are humanity’s closest relatives among living species.

The hominids developed an erect posture at least 14,000,000 years ago. This may have taken place in East Africa to begin with, but the hominids in time spread to South Africa and South Asia.

Despite their expanding brain, there could scarcely be any pur-

posefulness in the expansion of the hominid range. As was true of all other species up to that time, the hominids reacted to pushes and pulls—the push of others (of either their own or other species who already filled an area and who directly competed) and the pull of relatively empty areas rich in food just beyond the already-occupied range.

Like other primates, the early hominids did not expand out of the tropics, for they were not adapted to withstand the cold nights and winters of the temperate zones, nor could they find enough food in the winter months.

Homo erectus first evolved about 1,500,000 years ago and had a brain midway in size between that of the earliest hominids and that of present-day human beings.

It was *Homo erectus* that made the most significant advance in the history of humanity, for it was this species that first made deliberate use of fire. That was something that no other species had ever done before, and no other species (except for still more advanced hominids) has done since.

The use of fire made it possible for *Homo erectus* to move farther north than earlier hominids had been able to do—certainly to the vicinity of Peking in China, where fossils and also the remains of campfires have been found, and possibly to Europe.

Perhaps as long as 250,000 years ago, large-brained hominids appeared, members of the species *Homo sapiens*, the one to which we belong. They ranged far north into Europe even though the presence of an Ice Age made the climate particularly severe.

Almost from the start, *Homo sapiens*, using fire and animal skins for warmth, and sharpened stone axes and stone-tipped spears as weapons of offense and defense, developed an unprecedented range for a primate.

The early representatives of *Homo sapiens* were not quite like the representatives who live today, but showed differences in skull shape, for instance. We call them “Neanderthal man” (*Homo neanderthalensis*). To the very end of their existence, Neanderthal men were confined to the “World Island” of Europe, Asia, and Africa.

By 35,000 years ago, however, “modern man” had appeared, a variety of *Homo sapiens* to which we belong. This was soon the only kind of hominid to exist. Presumably, modern men were more efficient in war and wiped out the Neanderthals, though there is evidence they may have interbred with them, too.

It was after the appearance of modern man that the hominid range finally extended outside the World Island.

When each of the periodic Ice Ages was at its height, the sea level

sank so low, thanks to the water tied up in the gigantic ice sheets that covered Canada, Siberia, and Scandinavia, that Siberia and Alaska were connected by a wide land bridge, parts of which were not covered by ice.

In those days, Siberian hunters pursued mammoths, a now-extinct relative of the elephant, one which was adapted for Arctic life. In the pursuit they crossed over into North America, where, until then, no hominids or, indeed, apes had ever existed. This was some time before 20,000 B.C. By 16,000 B.C., human beings had reached South America, and by 8700 B.C. they were at the Strait of Magellan, and then across it and into Tierra del Fuego, the island to the southeast of the strait. This was the southernmost bit of land to undergo permanent occupation by precivilized human beings anywhere in the world.

Even before this, human beings took advantage of the lowered sea level to cross into New Guinea and Australia.

By then, almost every land area of significant size that wasn't covered by a solid ice sheet carried its population of *Homo sapiens*.

Homo sapiens was the first land species to have a worldwide range, and since then it has grown to be the most populous species of its size the world has ever seen. What's more, no one species of life has ever in all the history of the world made up so large a fraction of the total life mass of the planet.

ANCIENT LAND TRAVEL

And yet although human beings spread over the face of the globe and occupied all the continents of Earth except Antarctica before civilization began, no individual groups of human beings knew any more of Earth's land surface than their own immediate neighborhood, their own town, their own fields.

Even where trade was conducted over long stretches of land, material changed hands many times and no one trader was likely to have traveled far.

It was not till civilization began that the horizon began to spread outward, and then it was for a sad reason, since human beings learned to use military techniques to build empires. Once empires were in existence, some individuals, at least—rulers, soldiers, couriers—gained a general overview of the whole.

The largest of the ancient empires rivaled the modern United States in area. The Persian Empire and the Roman Empire were

each close to 7,500,000 square kilometers * in area, though the former had a population of not more than 15,000,000 and the latter not more than 40,000,000. The early empires of India and China were a bit smaller in area but were more populous. The Han Empire of China, which existed in the time of the Roman Empire, had a population in excess of 50,000,000.

The largest of the preindustrial empires was that of the Mongols. Kublai Khan, in 1270, ruled over an area of more than 28,500,000 square kilometers; his realm was larger in area than that of any contiguous land empire before or since. It stretched from the Danube River to the Pacific Ocean, made up a fifth of all the land area in the world, and had a population of 120,000,000 people.

Through all this, Western Europe had remained comparatively provincial. In ancient times much of it had been part of the Roman Empire, and educated Westerners knew the Mediterranean world at least through their reading and had a notion of the Middle East as far as India.

After the breakup of the Roman Empire in the 400s, however, western Europe grew barbarous, and its awareness was confined within narrow borders by the hostile world of Islam to the east and south.

The first Western European to penetrate Islamic territories in the east and to write an account of his travels was not a Christian but a Jew. He was Benjamin of Tudela, who was born in Navarre on the Franco-Spanish border in the early 1100s. Between 1159 and 1173, he engaged in a journey far to the east, partly out of an interest in trade and partly to visit various communities of Jews. He penetrated to the western border of China itself. His account, however, being that of a Jew, did not much influence the Christian world of the time. Western Europe encountered the conquering Mongols in 1240 but remained outside the Mongol Empire only because at a crucial moment the Mongol khan died and the Mongol armies retired to elect a new one. The existence of the empire, which brought a vast territory under a single strong rule, made overland travel much easier, at least to the extent that there was less danger from anarchic banditry. The West took advantage of this.

Under the sponsorship of the pope, expeditions were sent eastward to convert the Mongols, gain their help against Islam, and obtain assurance of no further invasion of Christian lands. The first

* In this book I am using the metric system, standard in virtually all the world except for the United States. A kilometer is equal to 5/8 of a mile; a square kilometer is equal to a little over 3/8 of a square mile. In reverse, a mile equals 1.6 kilometers; a square mile equals 2.6 square kilometers.

of these missions left in the spring of 1245, under the leadership of a Franciscan friar, Giovanni de Piano Carpini, born about 1180. The mission penetrated all the way to the Mongolian capital at Karakorum (in what is now the Mongolian People's Republic) and returned to Europe after a journey that took more than two years.

Nothing was gained from the Mongols, but soon after his return, Carpini wrote an account of his travels, a sober and accurate one. It was the first opportunity Western readers had to read a reasonable account of Central Asia.

He was outdone, however, by William of Rubruck, a French Franciscan friar, born about 1215. King Louis IX of France was in Palestine participating in a crusade and sent a mission under Rubruck to the Mongols on September 16, 1253. Following in Carpini's tracks, eight years after the earlier expedition, Rubruck accomplished as little, but wrote a still better account than that of Carpini.

The climax came with Marco Polo (1254-1324), a Venetian explorer. While he was still a young boy, his father, Niccolo, and his uncle, Maffeo, had gone eastward on a trading mission. They set forth in 1260, at which time the Mongol Empire was at the peak of its power under Kublai Khan.

The Venetians visited Kublai Khan at his summer palace at Shangtu (which became known as Xanadu in Europe). The khan treated them well and sent them back to Europe.

The Polos returned to China in 1275, and this time Marco was with them. Marco caught the fancy of the khan and rose to high position under him, serving as a trusted diplomat. In the khan's old age, however, the Polos felt they could not trust in the favor of his successor, and when they were given the mission of escorting a Mongol princess to Persia, they seized the opportunity of continuing onward toward home. They finally reached Venice again in 1295.

In 1298, Venice was at war with the rival Italian coastal city of Genoa, and Marco Polo, who held a command in the Venetian fleet, was captured. While in a Genoese prison, he dictated the story of his travels. He did not deal so much with personal matters as with a description of the portions of Asia and Africa with which he was reasonably acquainted. The book proved enormously popular, and from that time on, educated Europeans knew of much of the World Island.

ANCIENT SEA TRAVEL

Travel overland, right down to the time of Marco Polo, and for five