killed by epidemics beginning with the first European visit, in 1791). Syphilis, gonorrhea, tuberculosis, and influenza arriving with Captain Cook in 1779, followed by a big typhoid epidemic in 1804 and numerous "minor" epidemics, reduced Hawaii's population from around half a million in 1779 to 84,000 in 1853, the year when smallpox finally reached Hawaii and killed around 10,000 of the survivors. These examples could be multiplied almost indefinitely.

However, germs did not act solely to Europeans' advantage. While the New World and Australia did not harbor native epidemic diseases awaiting Europeans, tropical Asia, Africa, Indonesia, and New Guinea certainly did. Malaria throughout the tropical Old World, cholera in tropical Southeast Asia, and yellow fever in tropical Africa were (and still are) the most notorious of the tropical killers. They posed the most serious obstacle to European colonization of the tropics, and they explain why the European colonial partitioning of New Guinea and most of Africa was not accomplished until nearly 400 years after European partitioning of the New World began. Furthermore, once malaria and yellow fever did become transmitted to the Americas by European ship traffic, they emerged as the major impediment to colonization of the New World tropics as well. A familiar example is the role of those two diseases in aborting the French effort, and nearly aborting the ultimately successful American effort, to construct the Panama Canal.

Bearing all these facts in mind, let's try to regain our sense of perspective about the role of germs in answering Yali's question. There is no doubt that Europeans developed a big advantage in weaponry, technology, and political organization over most of the non-European peoples that they conquered. But that advantage alone doesn't fully explain how initially so few European immigrants came to supplant so much of the native population of the Americas and some other parts of the world. That might not have happened without Europe's sinister gift to other continents—the germs evolving from Eurasians' long intimacy with domestic animals.

CHAPTER 12

Blueprints and Borrowed Letters

Nineteenth-century authors tended to interpret history as a progression from savagery to civilization. Key hallmarks of this transition included the development of agriculture, metallurgy, complex technology, centralized government, and writing. Of these, writing was traditionally the one most restricted geographically: until the expansions of Islam and of colonial Europeans, it was absent from Australia, Pacific islands, subequatorial Africa, and the whole New World except for a small part of Mesoamerica. As a result of that confined distribution, peoples who pride themselves on being civilized have always viewed writing as the sharpest distinction raising them above "barbarians" or "savages."

Knowledge brings power. Hence writing brings power to modern societies, by making it possible to transmit knowledge with far greater accuracy and in far greater quantity and detail, from more distant lands and more remote times. Of course, some peoples (notably the Incas) managed to administer empires without writing, and "civilized" peoples don't always defeat "barbarians," as Roman armies facing the Huns learned. But the European conquests of the Americas, Siberia, and Australia illustrate the typical recent outcome.

Writing marched together with weapons, microbes, and centralized political organization as a modern agent of conquest. The commands of the monarchs and merchants who organized colonizing fleets were conveyed in writing. The fleets set their courses by maps and written sailing directions prepared by previous expeditions. Written accounts of earlier expeditions motivated later ones, by describing the wealth and fertile lands awaiting the conquerors. The accounts taught subsequent explorers what conditions to expect, and helped them prepare themselves. The resulting empires were administered with the aid of writing. While all those types of information were also transmitted by other means in preliterate societies, writing made the transmission easier, more detailed, more accurate, and more persuasive.

Why, then, did only some peoples and not others develop writing, given its overwhelming value? For example, why did no traditional hunters-gatherers evolve or adopt writing? Among island empires, why did writing arise in Minoan Crete but not in Polynesian Tonga? How many separate times did writing evolve in human history, under what circumstances, and for what uses? Of those peoples who did develop it, why did some do so much earlier than others? For instance, today almost all Japanese and Scandinavians are literate but most Iraqis are not: why did writing nevertheless arise nearly four thousand years earlier in Iraq?

The diffusion of writing from its sites of origin also raises important questions. Why, for instance, did it spread to Ethiopia and Arabia from the Fertile Crescent, but not to the Andes from Mexico? Did writing systems spread by being copied, or did existing systems merely inspire neighboring peoples to invent their own systems? Given a writing system that works well for one language, how do you devise a system for a different language? Similar questions arise whenever one tries to understand the origins and spread of many other aspects of human culture—such as technology, religion, and food production. The historian interested in such questions about writing has the advantage that they can often be answered in unique detail by means of the written record itself. We shall therefore trace writing's development not only because of its inherent importance, but also for the general insights into cultural history that it provides.

THE THREE BASIC strategies underlying writing systems differ in the size of the speech unit denoted by one written sign: either a single basic sound, a whole syllable, or a whole word. Of these, the one employed

today by most peoples is the alphabet, which ideally would provide a unique sign (termed a letter) for each basic sound of the language (a phoneme). Actually, most alphabets consist of only about 20 or 30 letters, and most languages have more phonemes than their alphabets have letters. For example, English transcribes about 40 phonemes with a mere 26 letters. Hence most alphabetically written languages, including English, are forced to assign several different phonemes to the same letter and to represent some phonemes by combinations of letters, such as the English two-letter combinations *sh* and *th* (each represented by a single letter in the Russian and Greek alphabets, respectively).

The second strategy uses so-called logograms, meaning that one written sign stands for a whole word. That's the function of many signs of Chinese writing and of the predominant Japanese writing system (termed kanji). Before the spread of alphabetic writing, systems making much use of logograms were more common and included Egyptian hieroglyphs, Maya glyphs, and Sumerian cuneiform.

The third strategy, least familiar to most readers of this book, uses a sign for each syllable. In practice, most such writing systems (termed syllabaries) provide distinct signs just for syllables of one consonant followed by one vowel (like the syllables of the word "fa-mi-ly"), and resort to various tricks in order to write other types of syllables by means of those signs. Syllabaries were common in ancient times, as exemplified by the Linear B writing of Mycenaean Greece. Some syllabaries persist today, the most important being the kana syllabary that the Japanese use for telegrams, bank statements, and texts for blind readers.

I've intentionally termed these three approaches strategies rather than writing systems. No actual writing system employs one strategy exclusively. Chinese writing is not purely logographic, nor is English writing purely alphabetic. Like all alphabetic writing systems, English uses many logograms, such as numerals, $, %, and + : that is, arbitrary signs, not made up of phonetic elements, representing whole words. "Syllabic" Linear B had many logograms, and "logographic" Egyptian hieroglyphs included many syllabic signs as well as a virtual alphabet of individual letters for each consonant.

INVENTING A WRITING system from scratch must have been incomparably more difficult than borrowing and adapting one. The first scribes had to settle on basic principles that we now take for granted. For example, they had to figure out how to decompose a continuous utterance into speech units, regardless of whether those units were taken as words, syllables, or phonemes. They had to learn to recognize the same sound or speech unit through all our normal variations in speech volume, pitch, speed, emphasis, phrase grouping, and individual idiosyncrasies of pronunciation. They had to decide that a writing system should ignore all of that variation. They then had to devise ways to represent sounds by symbols.

Somehow, the first scribes solved all those problems, without having in front of them any example of the final result to guide their efforts. That task was evidently so difficult that there have been only a few occasions in history when people invented writing entirely on their own. The two indisputably independent inventions of writing were achieved by the Sumerians of Mesopotamia somewhat before 3000 B.C. and by Mexican Indians before 600 B.C. (Figure 12.1); Egyptian writing of 3000 B.C. and Chinese writing (by 1300 B.C.) may also have arisen independently. Probably all other peoples who have developed writing since then have borrowed, adapted, or at least been inspired by existing systems.

The independent invention that we can trace in greatest detail is history's oldest writing system, Sumerian cuneiform (Figure 12.1). For thousands of years before it jelled, people in some farming villages of the Fertile Crescent had been using clay tokens of various simple shapes for accounting purposes, such as recording numbers of sheep and amounts of grain. In the last centuries before 3000 B.C., developments in accounting technology, format, and signs rapidly led to the first system of writing. One such technological innovation was the use of flat clay tablets as a convenient writing surface. Initially, the clay was scratched with pointed tools, which gradually yielded to reed styluses for neatly pressing a mark into the tablet. Developments in format included the gradual adoption of conventions whose necessity is now universally accepted: that writing should be organized into ruled rows or columns (horizontal rows for the Sumerians, as for modern Europeans); that the lines should be read in a constant direction (left to right for Sumerians, as for modern Europeans); and that the lines should be read from top to bottom of the tablet rather than vice versa.

But the crucial change involved the solution of the problem basic to

Locations of some scripts mentioned in the text

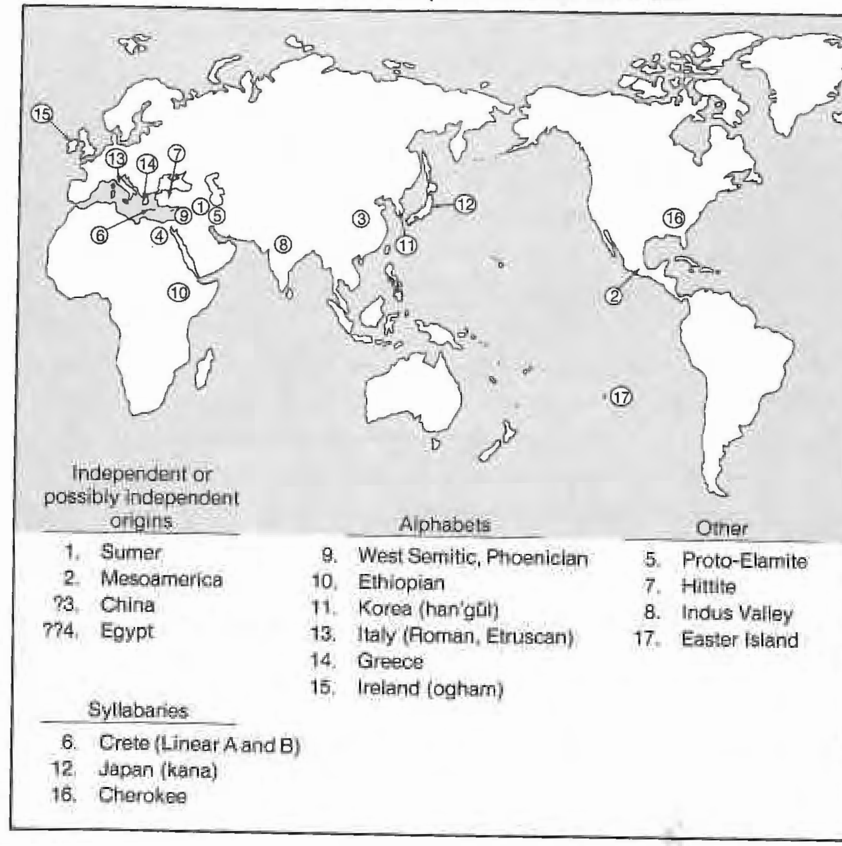


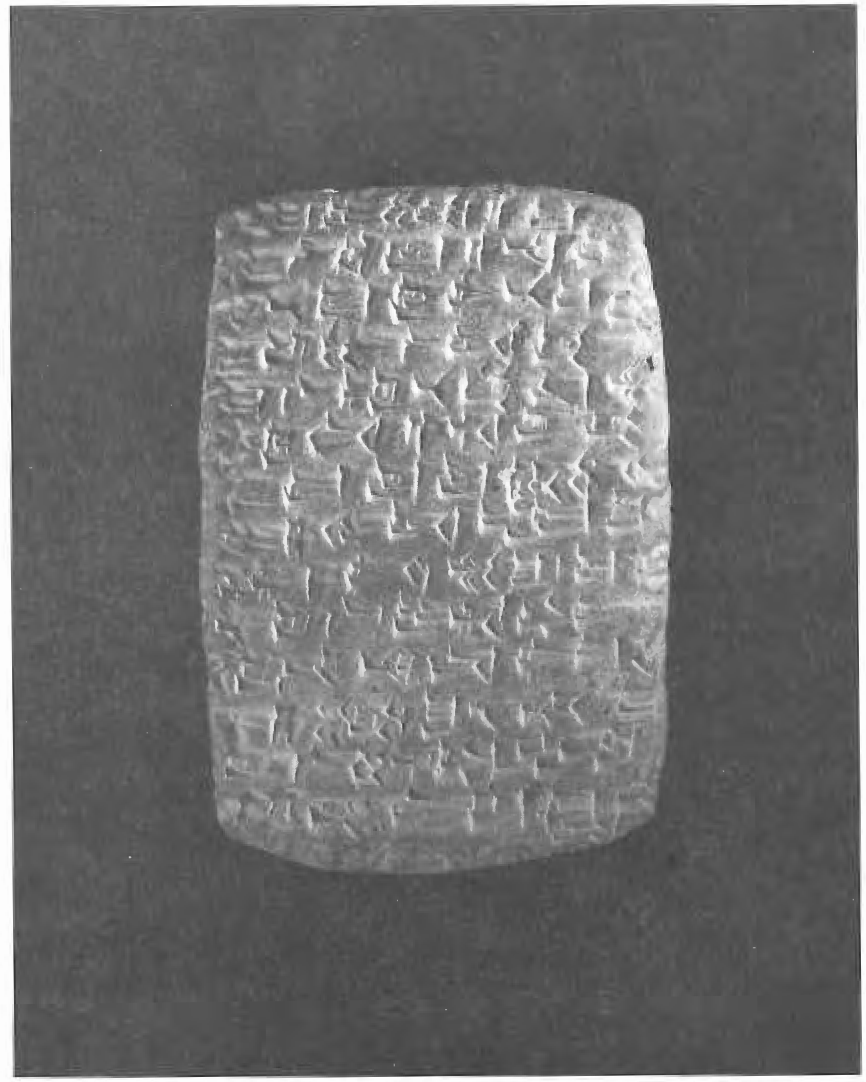
Figure 12.1. The question marks next to China and Egypt denote some doubt whether early writing in those areas arose completely independently or was stimulated by writing systems that arose elsewhere earlier. "Other" refers to scripts that were neither alphabets nor syllabaries and that probably arose under the influence of earlier scripts.

virtually all writing systems: how to devise agreed-on visible marks that represent actual spoken sounds, rather than only ideas or else words independent of their pronunciation. Early stages in the development of the solution have been detected especially in thousands of clay tablets excavated from the ruins of the former Sumerian city of Uruk, on the Euphrates

River about 200 miles southeast of modern Baghdad. The first Sumerian writing signs were recognizable pictures of the object referred to (for instance, a picture of a fish or a bird). Naturally, those pictorial signs consisted mainly of numerals plus nouns for visible objects; the resulting texts were merely accounting reports in a telegraphic shorthand devoid of grammatical elements. Gradually, the forms of the signs became more abstract, especially when the pointed writing tools were replaced by reed styluses. New signs were created by combining old signs to produce new meanings: for example, the sign for *head* was combined with the sign for *bread* in order to produce a sign signifying *eat*.

The earliest Sumerian writing consisted of nonphonetic logograms. That's to say, it was not based on the specific sounds of the Sumerian language, and it could have been pronounced with entirely different sounds to yield the same meaning in any other language—just as the numeral sign *4* is variously pronounced *four, chetwíre, neljä,* and *empat* by speakers of English, Russian, Finnish, and Indonesian, respectively. Perhaps the most important single step in the whole history of writing was the Sumerians' introduction of phonetic representation, initially by writing an abstract noun (which could not be readily drawn as a picture) by means of the sign for a depictable noun that had the same phonetic pronunciation. For instance, it's easy to draw a recognizable picture of *arrow,* hard to draw a recognizable picture of *life,* but both are pronounced *ti* in Sumerian, so a picture of an arrow came to mean either *arrow* or *life*. The resulting ambiguity was resolved by the addition of a silent sign called a determinative, to indicate the category of nouns to which the intended object belonged. Linguists term this decisive innovation, which also underlies puns today, the rebus principle.

Once Sumerians had hit upon this phonetic principle, they began to use it for much more than just writing abstract nouns. They employed it to write syllables or letters constituting grammatical endings. For instance, in English it's not obvious how to draw a picture of the common syllable *-tion,* but we could instead draw a picture illustrating the verb *shun,* which has the same pronunciation. Phonetically interpreted signs were also used to "spell out" longer words, as a series of pictures each depicting the sound of one syllable. That's as if an English speaker were to write the word *believe* as a picture of a bee followed by a picture of a leaf. Phonetic signs also permitted scribes to use the same pictorial sign for a set of related words (such as *tooth, speech,* and *speaker*), but to resolve the ambiguity



An example of Babylonian cuneiform writing, derived ultimately from Sumerian cuneiform.

with an additional phonetically interpreted sign (such as selecting the sign for *two, each,* or *peak*).

Thus, Sumerian writing came to consist of a complex mixture of three types of signs: logograms, referring to a whole word or name; phonetic signs, used in effect for spelling syllables, letters, grammatical elements, or parts of words; and determinatives, which were not pronounced but were used to resolve ambiguities. Nevertheless, the phonetic signs in Sumerian writing fell far short of a complete syllabary or alphabet. Some Sumerian syllables lacked any written signs; the same sign could be pronounced in different ways; and the same sign could variously be read as a word, a syllable, or a letter.

Besides Sumerian cuneiform, the other certain instance of independent origins of writing in human history comes from Native American societies of Mesoamerica, probably southern Mexico. Mesoamerican writing is believed to have arisen independently of Old World writing, because there is no convincing evidence for pre-Norse contact of New World societies with Old World societies possessing writing. In addition, the forms of Mesoamerican writing signs were entirely different from those of any Old World script. About a dozen Mesoamerican scripts are known, all or most of them apparently related to each other (for example, in their numerical and calendrical systems), and most of them still only partially deciphered. At the moment, the earliest preserved Mesoamerican script is from the Zapotec area of southern Mexico around 600 B.C., but by far the best-understood one is of the Lowland Maya region, where the oldest known written date corresponds to A.D. 292.

Despite its independent origins and distinctive sign forms, Maya writing is organized on principles basically similar to those of Sumerian writing and other western Eurasian writing systems that Sumerian inspired. Like Sumerian, Maya writing used both logograms and phonetic signs. Logograms for abstract words were often derived by the rebus principle. That is, an abstract word was written with the sign for another word pronounced similarly but with a different meaning that could be readily depicted. Like the signs of Japan's kana and Mycenaean Greece's Linear B syllabaries, Maya phonetic signs were mostly signs for syllables of one consonant plus one vowel (such as *ta, te, ti, to, tu*). Like letters of the early Semitic alphabet, Maya syllabic signs were derived from pictures of the object whose pronunciation began with that syllable (for example, the Maya syllabic sign "*ne*" resembles a tail, for which the Maya word is *neh*).

All of these parallels between Mesoamerican and ancient western Eurasian writing testify to the underlying universality of human creativity. While Sumerian and Mesoamerican languages bear no special relation to each other among the world's languages, both raised similar basic issues in reducing them to writing. The solutions that Sumerians invented before

A painting of the Rajasthani or Gujarati school, from the Indian subcontinent in the early 17th century. The script, like most other modern Indian scripts, is derived from ancient India's Brahmi script, which was probably derived in turn by idea diffusion from the Aramaic alphabet around the seventh century B.C. *Indian scripts incorporated the alphabetic principle but independently devised letter forms, letter sequence, and vowel treatment without resort to blueprint copying.*

3000 B.C. were reinvented, halfway around the world, by early Mesoamerican Indians before 600 B.C.

WITH THE POSSIBLE exceptions of the Egyptian, Chinese, and Easter Island writing to be considered later, all other writing systems devised anywhere in the world, at any time, appear to have been descendants of systems modified from or at least inspired by Sumerian or early Mesoamerican writing. One reason why there were so few independent origins of writing is the great difficulty of inventing it, as we have already discussed. The other reason is that other opportunities for the independent invention of writing were preempted by Sumerian or early Mesoamerican writing and their derivatives.

We know that the development of Sumerian writing took at least hundreds, possibly thousands, of years. As we shall see, the prerequisites for those developments consisted of several features of human society that determined whether a society would find writing useful, and whether the society could support the necessary specialist scribes. Many other human societies besides those of the Sumerians and early Mexicans—such as those of ancient India, Crete, and Ethiopia—evolved these prerequisites. However, the Sumerians and early Mexicans happened to have been the first to evolve them in the Old World and the New World, respectively. Once the Sumerians and early Mexicans had invented writing, the details or principles of their writing spread rapidly to other societies, before they could go through the necessary centuries or millennia of independent experimentation with writing themselves. Thus, that potential for other, independent experiments was preempted or aborted.

The spread of writing has occurred by either of two contrasting methods, which find parallels throughout the history of technology and ideas. Someone invents something and puts it to use. How do you, another would-be user, then design something similar for your own use, knowing that other people have already got their own model built and working?

Such transmission of inventions assumes a whole spectrum of forms. At the one end lies "blueprint copying," when you copy or modify an available detailed blueprint. At the opposite end lies "idea diffusion," when you receive little more than the basic idea and have to reinvent the details. Knowing that it can be done stimulates you to try to do it yourself, but

your eventual specific solution may or may not resemble that of the first inventor.

To take a recent example, historians are still debating whether blueprint copying or idea diffusion contributed more to Russia's building of an atomic bomb. Did Russia's bomb-building efforts depend critically on blueprints of the already constructed American bomb, stolen and transmitted to Russia by spies? Or was it merely that the revelation of America's A-bomb at Hiroshima at last convinced Stalin of the feasibility of building such a bomb, and that Russian scientists then reinvented the principles in an independent crash program, with little detailed guidance from the earlier American effort? Similar questions arise for the history of the development of wheels, pyramids, and gunpowder. Let's now examine how blueprint copying and idea diffusion contributed to the spread of writing systems.

TODAY, PROFESSIONAL LINGUISTS design writing systems for unwritten languages by the method of blueprint copying. Most such tailor-made systems modify existing alphabets, though some instead design syllabaries. For example, missionary linguists are working on modified Roman alphabets for hundreds of New Guinea and Native American languages. Government linguists devised the modified Roman alphabet adopted in 1928 by Turkey for writing Turkish, as well as the modified Cyrillic alphabets designed for many tribal languages of Russia.

In a few cases, we also know something about the individuals who designed writing systems by blueprint copying in the remote past. For instance, the Cyrillic alphabet itself (the one still used today in Russia) is descended from an adaptation of Greek and Hebrew letters devised by Saint Cyril, a Greek missionary to the Slavs in the ninth century A.D. The first preserved texts for any Germanic language (the language family that includes English) are in the Gothic alphabet created by Bishop Ulfilas, a missionary living with the Visigoths in what is now Bulgaria in the fourth century A.D. Like Saint Cyril's invention, Ulfilas's alphabet was a mishmash of letters borrowed from different sources: about 20 Greek letters, about five Roman letters, and two letters either taken from the runic alphabet or invented by Ulfilas himself. Much more often, we know nothing about the individuals responsible for devising famous alphabets of the past. But it's still possible to compare newly emerged alphabets of the past with previously existing ones, and to deduce from letter forms which existing ones served as models. For the same reason, we can be sure that the Linear B syllabary of Mycenaean Greece had been adapted by around 1400 B.C. from the Linear A syllabary of Minoan Crete.

At all of the hundreds of times when an existing writing system of one language has been used as a blueprint to adapt to a different language, some problems have arisen, because no two languages have exactly the same sets of sounds. Some inherited letters or signs may simply be dropped, when the sounds that those letters represent in the lending language do not exist in the borrowing language. For example, Finnish lacks the sounds that many other European languages express by the letters *b, c, f, g, w, x,* and *z,* so the Finns dropped these letters from their version of the Roman alphabet. There has also been a frequent reverse problem, of devising letters to represent "new" sounds present in the borrowing language but absent in the lending language. That problem has been solved in several different ways: such as using an arbitrary combination of two or more letters (like the English *th* to represent a sound for which the Greek and runic alphabets used a single letter); adding a small distinguishing mark to an existing letter (like the Spanish tilde *ñ,* the German umlaut *ö,* and the proliferation of marks dancing around Polish and Turkish letters); co-opting existing letters for which the borrowing language had no use (such as modern Czechs recycling the letter *c* of the Roman alphabet to express the Czech sound *ts*); or just inventing a new letter (as our medieval ancestors did when they created the new letters *j, u,* and *w*).

The Roman alphabet itself was the end product of a long sequence of blueprint copying. Alphabets apparently arose only once in human history: among speakers of Semitic languages, in the area from modern Syria to the Sinai, during the second millennium B.C. All of the hundreds of historical and now existing alphabets were ultimately derived from that ancestral Semitic alphabet, in a few cases (such as the Irish ogham alphabet) by idea diffusion, but in most by actual copying and modification of letter forms.

That evolution of the alphabet can be traced back to Egyptian hieroglyphs, which included a complete set of 24 signs for the 24 Egyptian consonants. The Egyptians never took the logical (to us) next step of discarding all their logograms, determinatives, and signs for pairs and trios of consonants, and using just their consonantal alphabet. Starting around

1700 B.C., though, Semites familiar with Egyptian hieroglyphs did begin to experiment with that logical step.

Restricting signs to those for single consonants was only the first of three crucial innovations that distinguished alphabets from other writing systems. The second was to help users memorize the alphabet by placing the letters in a fixed sequence and giving them easy-to-remember names. Our English names are mostly meaningless monosyllables ("a," "bee," "cee," "dee," and so on). But the Semitic names did possess meaning in Semitic languages: they were the words for familiar objects ('aleph = ox, beth = house, gimel = camel, daleth = door, and so on). These Semitic words were related "acrophonically" to the Semitic consonants to which they refer: that is, the first letter of the word for the object was also the letter named for the object (*'a, b, g, d,* and so on). In addition, the earliest forms of the Semitic letters appear in many cases to have been pictures of those same objects. All these features made the forms, names, and sequence of Semitic alphabet letters easy to remember. Many modern alphabets, including ours, retain with minor modifications that original sequence (and, in the case of Greek, even the letters' original names: alpha, beta, gamma, delta, and so on) over 3,000 years later. One minor modification that readers will already have noticed is that the Semitic and Greek *g* became the Roman and English *c,* while the Romans invented a new *g* in its present position.

The third and last innovation leading to modern alphabets was to provide for vowels. Already in the early days of the Semitic alphabet, experiments began with methods for writing vowels by adding small extra letters to indicate selected vowels, or else by dots, lines, or hooks sprinkled over the consonantal letters. In the eighth century B.C. the Greeks became the first people to indicate all vowels systematically by the same types of letters used for consonants. Greeks derived the forms of their vowel letters α - ϵ - η - ι - o by "co-opting" five letters used in the Phoenician alphabet for consonantal sounds lacking in Greek.

From those earliest Semitic alphabets, one line of blueprint copying and evolutionary modification led via early Arabian alphabets to the modern Ethiopian alphabet. A far more important line evolved by way of the Aramaic alphabet, used for official documents of the Persian Empire, into the modern Arabic, Hebrew, Indian, and Southeast Asian alphabets. But the line most familiar to European and American readers is the one that led via the Phoenicians to the Greeks by the early eighth century B.C., thence to the Etruscans in the same century, and in the next century to the Romans, whose alphabet with slight modifications is the one used to print this book. Thanks to their potential advantage of combining precision with simplicity, alphabets have now been adopted in most areas of the modern world.

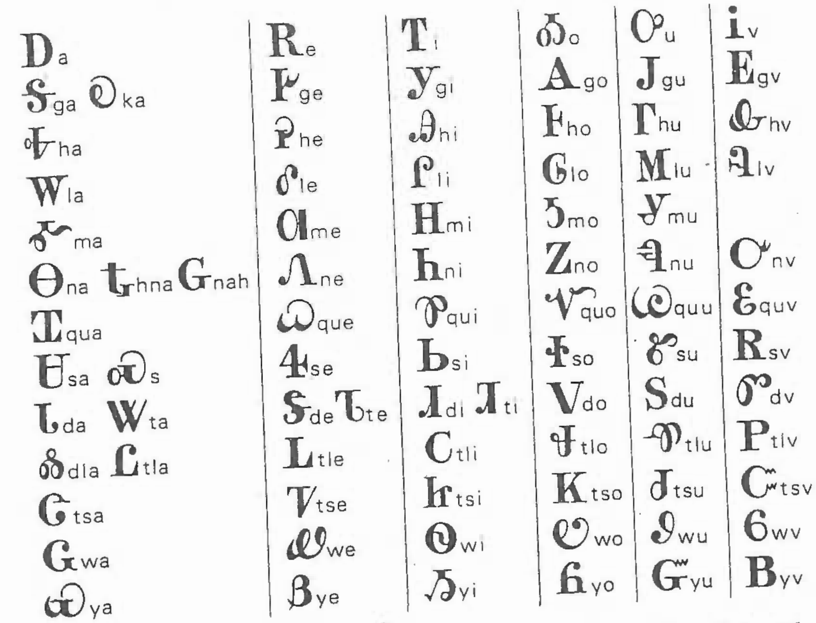
WHILE BLUEPRINT COPYING and modification are the most straightforward option for transmitting technology, that option is sometimes unavailable. Blueprints may be kept secret, or they may be unreadable to someone not already steeped in the technology. Word may trickle through about an invention made somewhere far away, but the details may not get transmitted. Perhaps only the basic idea is known: someone has succeeded, somehow, in achieving a certain final result. That knowledge may nevertheless inspire others, by idea diffusion, to devise their own routes to such a result.

A striking example from the history of writing is the origin of the syllabary devised in Arkansas around 1820 by a Cherokee Indian named Sequoyah, for writing the Cherokee language. Sequoyah observed that white people made marks on paper, and that they derived great advantage by using those marks to record and repeat lengthy speeches. However, the detailed operations of those marks remained a mystery to him, since (like most Cherokees before 1820) Sequoyah was illiterate and could neither speak nor read English. Because he was a blacksmith, Sequoyah began by devising an accounting system to help him keep track of his customers' debts. He drew a picture of each customer; then he drew circles and lines of various sizes to represent the amount of money owed.

Around 1810, Sequoyah decided to go on to design a system for writing the Cherokee language. He again began by drawing pictures, but gave them up as too complicated and too artistically demanding. He next started to invent separate signs for each word, and again became dissatisfied when he had coined thousands of signs and still needed more.

Finally, Sequoyah realized that words were made up of modest numbers of different sound bites that recurred in many different words—what we would call syllables. He initially devised 200 syllabic signs and gradually reduced them to 85, most of them for combinations of one consonant and one vowel.

As one source of the signs themselves, Sequoyah practiced copying the



The set of signs that Sequoyah devised to represent syllables of the Cherokee language.

letters from an English spelling book given to him by a schoolteacher. About two dozen of his Cherokee syllabic signs were taken directly from those letters, though of course with completely changed meanings, since Sequoyah did not know the English meanings. For example, he chose the shapes D, R, b, h to represent the Cherokee syllables *a, e, si,* and *ni,* respectively, while the shape of the numeral 4 was borrowed for the syllable *se.* He coined other signs by modifying English letters, such as designing the signs Ꮿ, Ꮜ, and Ꮎ to represent the syllables *yu, sa,* and *na,* respectively. Still other signs were entirely of his creation, such as Ꮀ, Ꮅ, and Ꮒ for *ho, li,* and *nu,* respectively. Sequoyah's syllabary is widely admired by professional linguists for its good fit to Cherokee sounds, and for the ease with which it can be learned. Within a short time, the Cherokees achieved almost 100 percent literacy in the syllabary, bought a printing press, had Sequoyah's signs cast as type, and began printing books and newspapers.

Cherokee writing remains one of the best-attested examples of a script that arose through idea diffusion. We know that Sequoyah received paper and other writing materials, the idea of a writing system, the idea of using separate marks, and the forms of several dozen marks. Since, however, he could neither read nor write English, he acquired no details or even principles from the existing scripts around him. Surrounded by alphabets he could not understand, he instead independently reinvented a syllabary, unaware that the Minoans of Crete had already invented another syllabary 3,500 years previously.

SEQUOYAH'S EXAMPLE CAN serve as a model for how idea diffusion probably led to many writing systems of ancient times as well. The han'gul alphabet devised by Korea's King Sejong in A.D. 1446 for the Korean language was evidently inspired by the block format of Chinese characters and by the alphabetic principle of Mongol or Tibetan Buddhist writing. However, King Sejong invented the forms of han'gul letters and several unique features of his alphabet, including the grouping of letters by syllables into square blocks, the use of related letter shapes to represent related vowel or consonant sounds, and shapes of consonant letters that depict the position in which the lips or tongue are held to pronounce that consonant. The ogham alphabet used in Ireland and parts of Celtic Britain from around the fourth century A.D. similarly adopted the alphabetic principle (in this case, from existing European alphabets) but again devised unique letter forms, apparently based on a five-finger system of hand signals.

We can confidently attribute the han'gul and ogham alphabets to idea diffusion rather than to independent invention in isolation, because we know that both societies were in close contact with societies possessing writing and because it is clear which foreign scripts furnished the inspiration. In contrast, we can confidently attribute Sumerian cuneiform and the earliest Mesoamerican writing to independent invention, because at the times of their first appearances there existed no other script in their respective hemispheres that could have inspired them. Still debatable are the origins of writing on Easter Island, in China, and in Egypt.

The Polynesians living on Easter Island, in the Pacific Ocean, had a unique script of which the earliest preserved examples date back only to about A.D. 1851, long after Europeans reached Easter in 1722. Perhaps writing arose independently on Easter before the arrival of Europeans, although no examples have survived. But the most straightforward interpretation is to take the facts at face value, and to assume that Easter

산 유 화

산에는 꽃피네
꽃이 피네
갈 봄 여름 없이
꽃이 피네

산에
산에
피는 꽃은
저만치 혼자서 피어있네

산에서 우는 작은 새요
꽃이 좋아
산에서
사노라네

산에는 꽃지네
꽃이 지네
갈 봄 여름 없이
꽃이 지네

김 소 월

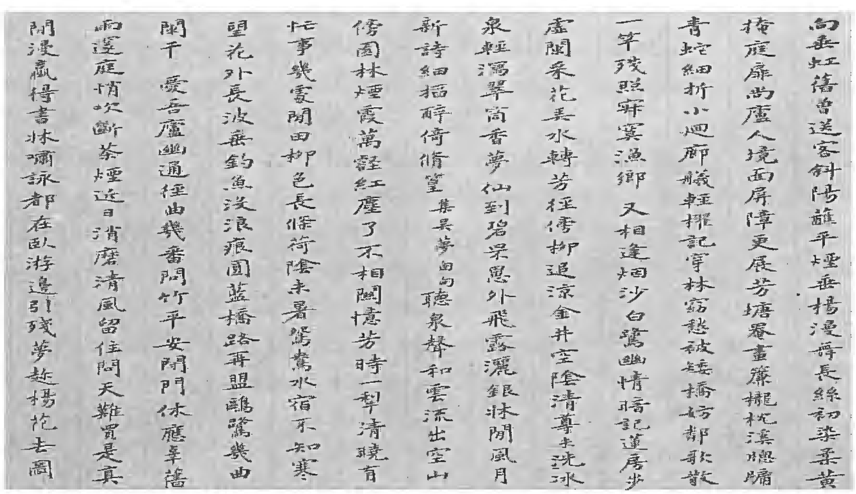
A Korean text (the poem "Flowers on the Hills" by So-Wol Kim), illustrating the remarkable Han'gul writing system. Each square block represents a syllable, but each component sign within the block represents a letter.

Islanders were stimulated to devise a script after seeing the written proclamation of annexation that a Spanish expedition handed to them in the year 1770.

As for Chinese writing, first attested around 1300 B.C. but with possible earlier precursors, it too has unique local signs and some unique principles, and most scholars assume that it evolved independently. Writing had developed before 3000 B.C. in Sumer, 4,000 miles west of early Chinese urban centers, and appeared by 2200 B.C. in the Indus Valley, 2,600 miles west, but no early writing systems are known from the whole area between the Indus Valley and China. Thus, there is no evidence that the earliest Chinese scribes could have had knowledge of any other writing system to inspire them.

Egyptian hieroglyphics, the most famous of all ancient writing systems, are also usually assumed to be the product of independent invention, but the alternative interpretation of idea diffusion is more feasible than in the case of Chinese writing. Hieroglyphic writing appeared rather suddenly, in nearly full-blown form, around 3000 B.C. Egypt lay only 800 miles west of Sumer, with which Egypt had trade contacts. I find it suspicious that no evidence of a gradual development of hieroglyphs has come down to us, even though Egypt's dry climate would have been favorable for preserving earlier experiments in writing, and though the similarly dry climate of Sumer has yielded abundant evidence of the development of Sumerian cuneiform for at least several centuries before 3000 B.C. Equally suspicious is the appearance of several other, apparently independently designed, writing systems in Iran, Crete, and Turkey (so-called proto-Elamite writing, Cretan pictographs, and Hieroglyphic Hittite, respectively), after the rise of Sumerian and Egyptian writing. Although each of those systems used distinctive sets of signs not borrowed from Egypt or Sumer, the peoples involved could hardly have been unaware of the writing of their neighboring trade partners.

It would be a remarkable coincidence if, after millions of years of human existence without writing, all those Mediterranean and Near Eastern societies had just happened to hit independently on the idea of writing within a few centuries of each other. Hence a possible interpretation seems to me idea diffusion, as in the case of Sequoyah's syllabary. That is, Egyptians and other peoples may have learned from Sumerians about the idea



An example of Chinese writing: a handscroll by Wu Li, from A.D. *1679.*

An example of Egyptian hieroglyphs: the funerary papyrus of Princess Entiu-ny.

of writing and possibly about some of the principles, and then devised other principles and all the specific forms of the letters for themselves.

LET US NOW return to the main question with which we began this chap ter: why did writing arise in and spread to some societies, but not to man others? Convenient starting points for our discussion are the limited capa bilities, uses, and users of early writing systems.

Early scripts were incomplete, ambiguous, or complex, or all three. Fo example, the oldest Sumerian cuneiform writing could not render normal prose but was a mere telegraphic shorthand, whose vocabulary was restricted to names, numerals, units of measure, words for objects counted, and a few adjectives. That's as if a modern American court clerk were forced to write "John 27 fat sheep," because English writing lacked the necessary words and grammar to write "We order John to deliver the 27 fat sheep that he owes to the government." Later Sumerian cuneiform did become capable of rendering prose, but it did so by the messy system that I've already described, with mixtures of logograms, phonetic signs, and unpronounced determinatives totaling hundreds of separate signs. Linear B, the writing of Mycenaean Greece, was at least simpler, being based on a syllabary of about 90 signs plus logograms. Offsetting that virtue, Linear B was quite ambiguous. It omitted any consonant at the end of a word, and it used the same sign for several related consonants (for instance, one sign for both *l* and *r*, another for *p* and *b* and *ph*, and still another for *g* and *k* and *kh*). We know how confusing we find it when native-born Japanese people speak English without distinguishing *l* and *r*: imagine the confusion if our alphabet did the same while similarly homogenizing the other consonants that I mentioned! It's as if we were to spell the words "rap," "lap," "lab," and "laugh" identically.

A related limitation is that few people ever learned to write these early scripts. Knowledge of writing was confined to professional scribes in the employ of the king or temple. For instance, there is no hint that Linear B was used or understood by any Mycenaean Greek beyond small cadres of palace bureaucrats. Since individual Linear B scribes can be distinguished by their handwriting on preserved documents, we can say that all preserved Linear B documents from the palaces of Knossos and Pylos are the work of a mere 75 and 40 scribes, respectively.

The uses of these telegraphic, clumsy, ambiguous early scripts were as restricted as the number of their users. Anyone hoping to discover how Sumerians of 3000 B.C. thought and felt is in for a disappointment. Instead, the first Sumerian texts are emotionless accounts of palace and temple bureaucrats. About 90 percent of the tablets in the earliest known Sumerian archives, from the city of Uruk, are clerical records of goods paid in, workers given rations, and agricultural products distributed. Only later, as Sumerians progressed beyond logograms to phonetic writing, did they begin to write prose narratives, such as propaganda and myths.

Mycenaean Greeks never even reached that propaganda-and-myths

stage. One-third of all Linear B tablets from the palace of Knossos are accountants' records of sheep and wool, while an inordinate proportion of writing at the palace of Pylos consists of records of flax. Linear B was inherently so ambiguous that it remained restricted to palace accounts, whose context and limited word choices made the interpretation clear. Not a trace of its use for literature has survived. The *Iliad* and *Odyssey* were composed and transmitted by nonliterate bards for nonliterate listeners, and not committed to writing until the development of the Greek alphabet hundreds of years later.

Similarly restricted uses characterize early Egyptian, Mesoamerican, and Chinese writing. Early Egyptian hieroglyphs recorded religious and state propaganda and bureaucratic accounts. Preserved Maya writing was similarly devoted to propaganda, births and accessions and victories of kings, and astronomical observations of priests. The oldest preserved Chinese writing of the late Shang Dynasty consists of religious divination about dynastic affairs, incised into so-called oracle bones. A sample Shang text: "The king, reading the meaning of the crack [in a bone cracked by heating], said: 'If the child is born on a keng day, it will be extremely auspicious.' "

To us today, it is tempting to ask why societies with early writing systems accepted the ambiguities that restricted writing to a few functions and a few scribes. But even to pose that question is to illustrate the gap between ancient perspectives and our own expectations of mass literacy. The *intended* restricted uses of early writing provided a positive disincentive for devising less ambiguous writing systems. The kings and priests of ancient Sumer wanted writing to be used by professional scribes to record numbers of sheep owed in taxes, not by the masses to write poetry and hatch plots. As the anthropologist Claude Lévi-Strauss put it, ancient writing's main function was "to facilitate the enslavement of other human beings." Personal uses of writing by nonprofessionals came only much later, as writing systems grew simpler and more expressive.

For instance, with the fall of Mycenaean Greek civilization, around 1200 B.C., Linear B disappeared, and Greece returned to an age of preliteracy. When writing finally returned to Greece, in the eighth century B.C., the new Greek writing, its users, and its uses were very different. The writing was no longer an ambiguous syllabary mixed with logograms but an alphabet borrowed from the Phoenician consonantal alphabet and improved by the Greek invention of vowels. In place of lists of sheep, legible only to scribes and read only in palaces, Greek alphabetic writing from the moment of its appearance was a vehicle of poetry and humor, to be read in private homes. For instance, the first preserved example of Greek alphabetic writing, scratched onto an Athenian wine jug of about 740 B.C., is a line of poetry announcing a dancing contest: "Whoever of all dancers performs most nimbly will win this vase as a prize." The next example is three lines of dactylic hexameter scratched onto a drinking cup: "I am Nestor's delicious drinking cup. Whoever drinks from this cup swiftly will the desire of fair-crowned Aphrodite seize him." The earliest preserved examples of the Etruscan and Roman alphabets are also inscriptions on drinking cups and wine containers. Only later did the alphabet's easily learned vehicle of private communication become co-opted for public or bureaucratic purposes. Thus, the developmental sequence of uses for alphabetic writing was the reverse of that for the earlier systems of logograms and syllabaries.

THE LIMITED USES and users of early writing suggest why writing appeared so late in human evolution. All of the likely or possible independent inventions of writing (in Sumer, Mexico, China, and Egypt), and all of the early adaptations of those invented systems (for example, those in Crete, Iran, Turkey, the Indus Valley, and the Maya area), involved socially stratified societies with complex and centralized political institutions, whose necessary relation to food production we shall explore in a later chapter. Early writing served the needs of those political institutions (such as record keeping and royal propaganda), and the users were full-time bureaucrats nourished by stored food surpluses grown by food-producing peasants. Writing was never developed or even adopted by hunter-gatherer societies, because they lacked both the institutional uses of early writing and the social and agricultural mechanisms for generating the food surpluses required to feed scribes.

Thus, food production and thousands of years of societal evolution following its adoption were as essential for the evolution of writing as for the evolution of microbes causing human epidemic diseases. Writing arose independently only in the Fertile Crescent, Mexico, and probably China precisely because those were the first areas where food production emerged in their respective hemispheres. Once writing had been invented by those

few societies, it then spread, by trade and conquest and religion, to other societies with similar economies and political organizations.

While food production was thus a necessary condition for the evolution or early adoption of writing, it was not a sufficient condition. At the beginning of this chapter, I mentioned the failure of some food-producing societies with complex political organization to develop or adopt writing before modern times. Those cases, initially so puzzling to us moderns accustomed to viewing writing as indispensable to a complex society, included one of the world's largest empires as of A.D. 1520, the Inca Empire of South America. They also included Tonga's maritime proto-empire, the Hawaiian state emerging in the late 18th century, all of the states and chiefdoms of subequatorial Africa and sub-Saharan West Africa before the arrival of Islam, and the largest native North American societies, those of the Mississippi Valley and its tributaries. Why did all those societies fail to acquire writing, despite their sharing prerequisites with societies that did do so?

Here we have to remind ourselves that the vast majority of societies with writing acquired it by borrowing it from neighbors or by being inspired by them to develop it, rather than by independently inventing it themselves. The societies without writing that I just mentioned are ones that got a later start on food production than did Sumer, Mexico, and China. (The only uncertainty in this statement concerns the relative dates for the onset of food production in Mexico and in the Andes, the eventual Inca realm.) Given enough time, the societies lacking writing might also have eventually developed it on their own. Had they been located nearer to Sumer, Mexico, and China, they might instead have acquired writing or the idea of writing from those centers, just as did India, the Maya, and most other societies with writing. But they were too far from the first centers of writing to have acquired it before modern times.

The importance of isolation is most obvious for Hawaii and Tonga, both of which were separated by at least 4,000 miles of ocean from the nearest societies with writing. The other societies illustrate the important point that distance as the crow flies is not an appropriate measure of isolation for humans. The Andes, West Africa's kingdoms, and the mouth of the Mississippi River lay only about 1,200, 1,500, and 700 miles, respectively, from societies with writing in Mexico, North Africa, and Mexico, respectively. These distances are considerably less than the distances the alphabet had to travel from its homeland on the eastern shores of the Mediterranean to reach Ireland, Ethiopia, and Southeast Asia within 2,000 years of its invention. But humans are slowed by ecological and water barriers that crows can fly over. The states of North Africa (with writing) and West Africa (without writing) were separated from each other by Saharan desert unsuitable for agriculture and cities. The deserts of northern Mexico similarly separated the urban centers of southern Mexico from the chiefdoms of the Mississippi Valley. Communication between southern Mexico and the Andes required either a sea voyage or else a long chain of overland contacts via the narrow, forested, never urbanized Isthmus of Darien. Hence the Andes, West Africa, and the Mississippi Valley were effectively rather isolated from societies with writing.

That's not to say that those societies without writing were *totally* isolated. West Africa eventually did receive Fertile Crescent domestic animals across the Sahara, and later accepted Islamic influence, including Arabic writing. Corn diffused from Mexico to the Andes and, more slowly, from Mexico to the Mississippi Valley. But we already saw in Chapter 10 that the north–south axes and ecological barriers within Africa and the Americas retarded the diffusion of crops and domestic animals. The history of writing illustrates strikingly the similar ways in which geography and ecology influenced the spread of human inventions.

CHAPTER 13

NECESSITY'S MOTHER

ON JULY 3, 1908, ARCHAEOLOGISTS EXCAVATING THE ancient Minoan palace at Phaistos, on the island of Crete, chanced upon one of the most remarkable objects in the history of technology. At first glance it seemed unprepossessing: just a small, flat, unpainted, circular disk of hard-baked clay, 6½ inches in diameter. Closer examination showed each side to be covered with writing, resting on a curved line that spiraled clockwise in five coils from the disk's rim to its center. A total of 241 signs or letters was neatly divided by etched vertical lines into groups of several signs, possibly constituting words. The writer must have planned and executed the disk with care, so as to start writing at the rim and fill up all the available space along the spiraling line, yet not run out of space on reaching the center (page 240).

Ever since it was unearthed, the disk has posed a mystery for historians of writing. The number of distinct signs (45) suggests a syllabary rather than an alphabet, but it is still undeciphered, and the forms of the signs are unlike those of any other known writing system. Not another scrap of the strange script has turned up in the 89 years since its discovery. Thus, it remains unknown whether it represents an indigenous Cretan script or a foreign import to Crete.

For historians of technology, the Phaistos disk is even more baffling; its

One side of the two-sided Phaistos Disk.

estimated date of 1700 B.C. makes it by far the earliest printed document in the world. Instead of being etched by hand, as were all texts of Crete's later Linear A and Linear B scripts, the disk's signs were punched into soft clay (subsequently baked hard) by stamps that bore a sign as raised type. The printer evidently had a set of at least 45 stamps, one for each sign appearing on the disk. Making these stamps must have entailed a great deal of work, and they surely weren't manufactured just to print this single document. Whoever used them was presumably doing a lot of writing. With those stamps, their owner could make copies much more quickly and neatly than if he or she had written out each of the script's complicated signs at each appearance.

The Phaistos disk anticipates humanity's next efforts at printing, which similarly used cut type or blocks but applied them to paper with ink, not

to clay without ink. However, those next efforts did not appear until 2,500 years later in China and 3,100 years later in medieval Europe. Why was the disk's precocious technology not widely adopted in Crete or elsewhere in the ancient Mediterranean? Why was its printing method invented around 1700 B.C. in Crete and not at some other time in Mesopotamia, Mexico, or any other ancient center of writing? Why did it then take thousands of years to add the ideas of ink and a press and arrive at a printing press? The disk thus constitutes a threatening challenge to historians. If inventions are as idiosyncratic and unpredictable as the disk seems to suggest, then efforts to generalize about the history of technology may be doomed from the outset.

Technology, in the form of weapons and transport, provides the direct means by which certain peoples have expanded their realms and conquered other peoples. That makes it the leading cause of history's broadest pattern. But why were Eurasians, rather than Native Americans or sub-Saharan Africans, the ones to invent firearms, oceangoing ships, and steel equipment? The differences extend to most other significant technological advances, from printing presses to glass and steam engines. Why were all those inventions Eurasian? Why were all New Guineans and Native Australians in A.D. 1800 still using stone tools like ones discarded thousands of years ago in Eurasia and most of Africa, even though some of the world's richest copper and iron deposits are in New Guinea and Australia, respectively? All those facts explain why so many laypeople assume that Eurasians are superior to other peoples in inventiveness and intelligence.

If, on the other hand, no such difference in human neurobiology exists to account for continental differences in technological development, wha does account for them? An alternative view rests on the heroic theory o invention. Technological advances seem to come disproportionately fron a few very rare geniuses, such as Johannes Gutenberg, James Watt Thomas Edison, and the Wright brothers. They were Europeans, o descendants of European emigrants to America. So were Archimedes an other rare geniuses of ancient times. Could such geniuses have equally we been born in Tasmania or Namibia? Does the history of technolog depend on nothing more than accidents of the birthplaces of a few inver tors?

Still another alternative view holds that it is a matter not of individu inventiveness but of the receptivity of whole societies to innovation. Son societies seem hopelessly conservative, inward looking, and hostile change. That's the impression of many Westerners who have attempted to help Third World peoples and ended up discouraged. The people seem perfectly intelligent as individuals; the problem seems instead to lie with their societies. How else can one explain why the Aborigines of northeastern Australia failed to adopt bows and arrows, which they saw being used by Torres Straits islanders with whom they traded? Might all the societies of an entire continent be unreceptive, thereby explaining technology's slow pace of development there? In this chapter we shall finally come to grips with a central problem of this book: the question of why technology did evolve at such different rates on different continents.

THE STARTING POINT for our discussion is the common view expressed in the saying "Necessity is the mother of invention." That is, inventions supposedly arise when a society has an unfulfilled need: some technology is widely recognized to be unsatisfactory or limiting. Would-be inventors, motivated by the prospect of money or fame, perceive the need and try to meet it. Some inventor finally comes up with a solution superior to the existing, unsatisfactory technology. Society adopts the solution if it is compatible with the society's values and other technologies.

Quite a few inventions do conform to this commonsense view of necessity as invention's mother. In 1942, in the middle of World War II, the U.S. government set up the Manhattan Project with the explicit goal of inventing the technology required to build an atomic bomb before Nazi Germany could do so. That project succeeded in three years, at a cost of $2 billion (equivalent to over $20 billion today). Other instances are Eli Whitney's 1794 invention of his cotton gin to replace laborious hand cleaning of cotton grown in the U.S. South, and James Watt's 1769 invention of his steam engine to solve the problem of pumping water out of British coal mines.

These familiar examples deceive us into assuming that other major inventions were also responses to perceived needs. In fact, many or most inventions were developed by people driven by curiosity or by a love of tinkering, in the absence of any initial demand for the product they had in mind. Once a device had been invented, the inventor then had to find an application for it. Only after it had been in use for a considerable time did consumers come to feel that they "needed" it. Still other devices, invented to serve one purpose, eventually found most of their use for other, unanticipated purposes. It may come as a surprise to learn that these inventions in search of a use include most of the major technological breakthroughs of modern times, ranging from the airplane and automobile, through the internal combustion engine and electric light bulb, to the phonograph and transistor. Thus, invention is often the mother of necessity, rather than vice versa.

A good example is the history of Thomas Edison's phonograph, the most original invention of the greatest inventor of modern times. When Edison built his first phonograph in 1877, he published an article proposing ten uses to which his invention might be put. They included preserving the last words of dying people, recording books for blind people to hear, announcing clock time, and teaching spelling. Reproduction of music was not high on Edison's list of priorities. A few years later Edison told his assistant that his invention had no commercial value. Within another few years he changed his mind and did enter business to sell phonographs—but for use as office dictating machines. When other entrepreneurs created jukeboxes by arranging for a phonograph to play popular music at the drop of a coin, Edison objected to this debasement, which apparently detracted from serious office use of his invention. Only after about 20 years did Edison reluctantly concede that the main use of his phonograph was to record and play music.

The motor vehicle is another invention whose uses seem obvious today. However, it was not invented in response to any demand. When Nikolaus Otto built his first gas engine, in 1866, horses had been supplying people's land transportation needs for nearly 6,000 years, supplemented increasingly by steam-powered railroads for several decades. There was no crisis in the availability of horses, no dissatisfaction with railroads.

Because Otto's engine was weak, heavy, and seven feet tall, it did not recommend itself over horses. Not until 1885 did engines improve to the point that Gottfried Daimler got around to installing one on a bicycle to create the first motorcycle; he waited until 1896 to build the first truck.

In 1905, motor vehicles were still expensive, unreliable toys for the rich. Public contentment with horses and railroads remained high until World War I, when the military concluded that it really did need trucks. Intensive postwar lobbying by truck manufacturers and armies finally convinced the public of its own needs and enabled trucks to begin to supplant horse-drawn wagons in industrialized countries. Even in the largest American cities, the changeover took 50 years.

Inventors often have to persist at their tinkering for a long time in the absence of public demand, because early models perform too poorly to be useful. The first cameras, typewriters, and television sets were as awful as Otto's seven-foot-tall gas engine. That makes it difficult for an inventor to foresee whether his or her awful prototype might eventually find a use and thus warrant more time and expense to develop it. Each year, the United States issues about 70,000 patents, only a few of which ultimately reach the stage of commercial production. For each great invention that ultimately found a use, there are countless others that did not. Even inventions that meet the need for which they were initially designed may later prove more valuable at meeting unforeseen needs. While James Watt designed his steam engine to pump water from mines, it soon was supplying power to cotton mills, then (with much greater profit) propelling locomotives and boats.

THUS, THE COMMONSENSE view of invention that served as our starting point reverses the usual roles of invention and need. It also overstates the importance of rare geniuses, such as Watt and Edison. That "heroic theory of invention," as it is termed, is encouraged by patent law, because an applicant for a patent must prove the novelty of the invention submitted. Inventors thereby have a financial incentive to denigrate or ignore previous work. From a patent lawyer's perspective, the ideal invention is one that arises without any precursors, like Athene springing fully formed from the forehead of Zeus.

In reality, even for the most famous and apparently decisive modern inventions, neglected precursors lurked behind the bald claim "X invented Y." For instance, we are regularly told, "James Watt invented the steam engine in 1769," supposedly inspired by watching steam rise from a tea-kettle's spout. Unfortunately for this splendid fiction, Watt actually got the idea for his particular steam engine while repairing a model of Thomas Newcomen's steam engine, which Newcomen had invented 57 years earlier and of which over a hundred had been manufactured in England by the time of Watt's repair work. Newcomen's engine, in turn, followed the steam engine that the Englishman Thomas Savery patented in 1698, which followed the steam engine that the Frenchman Denis Papin designed (but did not build) around 1680, which in turn had precursors in the ideas of

the Dutch scientist Christiaan Huygens and others. All this is not to deny that Watt greatly improved Newcomen's engine (by incorporating a separate steam condenser and a double-acting cylinder), just as Newcomen had greatly improved Savery's.

Similar histories can be related for all modern inventions that are adequately documented. The hero customarily credited with the invention followed previous inventors who had had similar aims and had already produced designs, working models, or (as in the case of the Newcomen steam engine) commercially successful models. Edison's famous "invention" of the incandescent light bulb on the night of October 21, 1879, improved on many other incandescent light bulbs patented by other inventors between 1841 and 1878. Similarly, the Wright brothers' manned powered airplane was preceded by the manned unpowered gliders of Otto Lilienthal and the unmanned powered airplane of Samuel Langley; Samuel Morse's telegraph was preceded by those of Joseph Henry, William Cooke, and Charles Wheatstone; and Eli Whitney's gin for cleaning short-staple (inland) cotton extended gins that had been cleaning long-staple (Sea Island) cotton for thousands of years.

All this is not to deny that Watt, Edison, the Wright brothers, Morse, and Whitney made big improvements and thereby increased or inaugurated commercial success. The form of the invention eventually adopted might have been somewhat different without the recognized inventor's contribution. But the question for our purposes is whether the broad pattern of world history would have been altered significantly if some genius inventor had not been born at a particular place and time. The answer is clear: there has never been any such person. All recognized famous inventors had capable predecessors and successors and made their improvements at a time when society was capable of using their product. As we shall see, the tragedy of the hero who perfected the stamps used for the Phaistos disk was that he or she devised something that the society of the time could not exploit on a large scale.

MY EXAMPLES SO far have been drawn from modern technologies because their histories are well known. My two main conclusions are that technology develops cumulatively, rather than in isolated heroic acts, and that it finds most of its uses after it has been invented, rather than being invented to meet a foreseen need. These conclusions surely apply with much greater force to the undocumented history of ancient technology. When Ice Age hunter-gatherers noticed burned sand and limestone residues in their hearths, it was impossible for them to foresee the long, serendipitous accumulation of discoveries that would lead to the first Roman glass windows (around A.D. 1), by way of the first objects with surface glazes (around 4000 B.C.), the first free-standing glass objects of Egypt and Mesopotamia (around 2500 B.C.), and the first glass vessels (around 1500 B.C.).

We know nothing about how those earliest known surface glazes themselves were developed. Nevertheless, we can infer the methods of prehistoric invention by watching technologically "primitive" people today, such as the New Guineans with whom I work. I already mentioned their knowledge of hundreds of local plant and animal species and each species' edibility, medical value, and other uses. New Guineans told me similarly about dozens of rock types in their environment and each type's hardness, color, behavior when struck or flaked, and uses. All of that knowledge is acquired by observation and by trial and error. I see that process of "invention" going on whenever I take New Guineans to work with me in an area away from their homes. They constantly pick up unfamiliar things in the forest, tinker with them, and occasionally find them useful enough to bring home. I see the same process when I am abandoning a campsite, and local people come to scavenge what is left. They play with my discarded objects and try to figure out whether they might be useful in New Guinea society. Discarded tin cans are easy: they end up reused as containers. Other objects are tested for purposes very different from the one for which they were manufactured. How would that yellow number 2 pencil look as an ornament, inserted through a pierced ear-lobe or nasal septum? Is that piece of broken glass sufficiently sharp and strong to be useful as a knife? Eureka!

The raw substances available to ancient peoples were natural materials such as stone, wood, bone, skins, fiber, clay, sand, limestone, and minerals, all existing in great variety. From those materials, people gradually learned to work particular types of stone, wood, and bone into tools; to convert particular clays into pottery and bricks; to convert certain mixtures of sand, limestone, and other "dirt" into glass; and to work available pure soft metals such as copper and gold, then to extract metals from ores, and finally to work hard metals such as bronze and iron.

A good illustration of the histories of trial and error involved is furnished by the development of gunpowder and gasoline from raw materials. Combustible natural products inevitably make themselves noticed, as when a resinous log explodes in a campfire. By 2000 B.C., Mesopotamians were extracting tons of petroleum by heating rock asphalt. Ancient Greeks discovered the uses of various mixtures of petroleum, pitch, resins, sulfur, and quicklime as incendiary weapons, delivered by catapults, arrows, firebombs, and ships. The expertise at distillation that medieval Islamic alchemists developed to produce alcohols and perfumes also let them distill petroleum into fractions, some of which proved to be even more powerful incendiaries. Delivered in grenades, rockets, and torpedoes, those incendiaries played a key role in Islam's eventual defeat of the Crusaders. By then, the Chinese had observed that a particular mixture of sulfur, charcoal, and saltpeter, which became known as gunpowder, was especially explosive. An Islamic chemical treatise of about A.D. 1100 describes seven gunpowder recipes, while a treatise from A.D. 1280 gives more than 70 recipes that had proved suitable for diverse purposes (one for rockets, another for cannons).

As for postmedieval petroleum distillation, 19th-century chemists found the middle distillate fraction useful as fuel for oil lamps. The chemists discarded the most volatile fraction (gasoline) as an unfortunate waste product—until it was found to be an ideal fuel for internal-combustion engines. Who today remembers that gasoline, the fuel of modern civilization, originated as yet another invention in search of a use?

ONCE AN INVENTOR has discovered a use for a new technology, the next step is to persuade society to adopt it. Merely having a bigger, faster, more powerful device for doing something is no guarantee of ready acceptance. Innumerable such technologies were either not adopted at all or adopted only after prolonged resistance. Notorious examples include the U.S. Congress's rejection of funds to develop a supersonic transport in 1971, the world's continued rejection of an efficiently designed typewriter keyboard, and Britain's long reluctance to adopt electric lighting. What is it that promotes an invention's acceptance by a society?

Let's begin by comparing the acceptability of different inventions within the same society. It turns out that at least four factors influence acceptance

The first and most obvious factor is relative economic advantage com pared with existing technology. While wheels are very useful in modern industrial societies, that has not been so in some other societies. Ancient Native Mexicans invented wheeled vehicles with axles for use as toys, but not for transport. That seems incredible to us, until we reflect that ancient Mexicans lacked domestic animals to hitch to their wheeled vehicles, which therefore offered no advantage over human porters.

A second consideration is social value and prestige, which can override economic benefit (or lack thereof). Millions of people today buy designer jeans for double the price of equally durable generic jeans—because the social cachet of the designer label counts for more than the extra cost. Similarly, Japan continues to use its horrendously cumbersome kanji writing system in preference to efficient alphabets or Japan's own efficient kana syllabary—because the prestige attached to kanji is so great.

Still another factor is compatibility with vested interests. This book, like probably every other typed document you have ever read, was typed with a QWERTY keyboard, named for the left-most six letters in its upper row. Unbelievable as it may now sound, that keyboard layout was designed in 1873 as a feat of anti-engineering. It employs a whole series of perverse tricks designed to force typists to type as slowly as possible, such as scattering the commonest letters over all keyboard rows and concentrating them on the left side (where right-handed people have to use their weaker hand). The reason behind all of those seemingly counterproductive features is that the typewriters of 1873 jammed if adjacent keys were struck in quick succession, so that manufacturers had to slow down typists. When improvements in typewriters eliminated the problem of jamming, trials in 1932 with an efficiently laid-out keyboard showed that it would let us double our typing speed and reduce our typing effort by 95 percent. But QWERTY keyboards were solidly entrenched by then. The vested interests of hundreds of millions of QWERTY typists, typing teachers, typewriter and computer salespeople, and manufacturers have crushed all moves toward keyboard efficiency for over 60-years.

While the story of the QWERTY keyboard may sound funny, many similar cases have involved much heavier economic consequences. Why does Japan now dominate the world market for transistorized electronic consumer products, to a degree that damages the United States's balance of payments with Japan, even though transistors were invented and patented in the United States? Because Sony bought transistor licensing rights from Western Electric at a time when the American electronics consumer industry was churning out vacuum tube models and reluctant to compete with its own products. Why were British cities still using gas street lighting into the 1920s, long after U.S. and German cities had converted to electric street lighting? Because British municipal governments had invested heavily in gas lighting and placed regulatory obstacles in the way of the competing electric light companies.

The remaining consideration affecting acceptance of new technologies is the ease with which their advantages can be observed. In A.D. 1340, when firearms had not yet reached most of Europe, England's earl of Derby and earl of Salisbury happened to be present in Spain at the battle of Tarifa, where Arabs used cannons against the Spaniards. Impressed by what they saw, the earls introduced cannons to the English army, which adopted them enthusiastically and already used them against French soldiers at the battle of Crécy six years later.

THUS, WHEELS, DESIGNER jeans, and QWERTY keyboards illustrate the varied reasons why the same society is not equally receptive to all inventions. Conversely, the same invention's reception also varies greatly among contemporary societies. We are all familiar with the supposed generalization that rural Third World societies are less receptive to innovation than are Westernized industrial societies. Even within the industrialized world, some areas are much more receptive than others. Such differences, if they existed on a continental scale, might explain why technology developed faster on some continents than on others. For instance, if all Aboriginal Australian societies were for some reason uniformly resistant to change, that might account for their continued use of stone tools after metal tools had appeared on every other continent. How do differences in receptivity among societies arise?

A laundry list of at least 14 explanatory factors has been proposed by historians of technology. One is long life expectancy, which in principle should give prospective inventors the years necessary to accumulate technical knowledge, as well as the patience and security to embark on long development programs yielding delayed rewards. Hence the greatly increased life expectancy brought by modern medicine may have contributed to the recently accelerating pace of invention.

The next five factors involve economics or the organization of society: (1) The availability of cheap slave labor in classical times supposedly discouraged innovation then, whereas high wages or labor scarcity now stimulate the search for technological solutions. For example, the prospect of changed immigration policies that would cut off the supply of cheap Mexican seasonal labor to Californian farms was the immediate incentive for the development of a machine-harvestable variety of tomatoes in California. (2) Patents and other property laws, protecting ownership rights of inventors, reward innovation in the modern West, while the lack of such protection discourages it in modern China. (3) Modern industrial societies provide extensive opportunities for technical training, as medieval Islam did and modern Zaire does not. (4) Modern capitalism is, and the ancient Roman economy was not, organized in a way that made it potentially rewarding to invest capital in technological development. (5) The strong individualism of U.S. society allows successful inventors to keep earnings for themselves, whereas strong family ties in New Guinea ensure that someone who begins to earn money will be joined by a dozen relatives expecting to move in and be fed and supported.

Another four suggested explanations are ideological, rather than economic or organizational: (1) Risk-taking behavior, essential for efforts at innovation, is more widespread in some societies than in others. (2) The scientific outlook is a unique feature of post-Renaissance European society that has contributed heavily to its modern technological preeminence. (3) Tolerance of diverse views and of heretics fosters innovation, whereas a strongly traditional outlook (as in China's emphasis on ancient Chinese classics) stifles it. (4) Religions vary greatly in their relation to technological innovation: some branches of Judaism and Christianity are claimed to be especially compatible with it, while some branches of Islam, Hinduism, and Brahmanism may be especially incompatible with it.

All ten of these hypotheses are plausible. But none of them has any necessary association with geography. If patent rights, capitalism, and certain religions do promote technology, what selected for those factors in postmedieval Europe but not in contemporary China or India?

At least the direction in which those ten factors influence technology seems clear. The remaining four proposed factors—war, centralized government, climate, and resource abundance—appear to act inconsistently: sometimes they stimulate technology, sometimes they inhibit it. (1) Throughout history, war has often been a leading stimulant of technological innovation. For instance, the enormous investments made in nuclear weapons during World War II and in airplanes and trucks during World

War I launched whole new fields of technology. But wars can also deal devastating setbacks to technological development. (2) Strong centralized government boosted technology in late-19th-century Germany and Japan, and crushed it in China after A.D. 1500. (3) Many northern Europeans assume that technology thrives in a rigorous climate where survival is impossible without technology, and withers in a benign climate where clothing is unnecessary and bananas supposedly fall off the trees. An opposite view is that benign environments leave people free from the constant struggle for existence, free to devote themselves to innovation. (4) There has also been debate over whether technology is stimulated by abundance or by scarcity of environmental resources. Abundant resources might stimulate the development of inventions utilizing those resources, such as water mill technology in rainy northern Europe, with its many rivers—but why didn't water mill technology progress more rapidly in even rainier New Guinea? The destruction of Britain's forests has been suggested as the reason behind its early lead in developing coal technology, but why didn't deforestation have the same effect in China?

This discussion does not exhaust the list of reasons proposed to explain why societies differ in their receptivity to new technology. Worse yet, all of these proximate explanations bypass the question of the ultimate factors behind them. This may seem like a discouraging setback in our attempt to understand the course of history, since technology has undoubtedly been one of history's strongest forces. However, I shall now argue that the diversity of independent factors behind technological innovation actually makes it easier, not harder, to understand history's broad pattern.

For the purposes of this book, the key question about the laundry list is whether such factors differed systematically from continent to continent and thereby led to continental differences in technological development. Most laypeople and many historians assume, expressly or tacitly, that the answer is yes. For example, it is widely believed that Australian Aborigines as a group shared ideological characteristics contributing to their technological backwardness: they were (or are) supposedly conservative, living in an imagined past Dreamtime of the world's creation, and not focused on practical ways to improve the present. A leading historian of Africa characterized Africans as inward looking and lacking Europeans' drive for expansion.

But all such claims are based on pure speculation. There has never been a study of many societies under similar socioeconomic conditions on each of two continents, demonstrating systematic ideological differences between the two continents' peoples. The usual reasoning is instead circular: because technological differences exist, the existence of corresponding ideological differences is inferred.

In reality, I regularly observe in New Guinea that native societies there differ greatly from each other in their prevalent outlooks. Just like industrialized Europe and America, traditional New Guinea has conservative societies that resist new ways, living side by side with innovative societies that selectively adopt new ways. The result, with the arrival of Western technology, is that the more entrepreneurial societies are now exploiting Western technology to overwhelm their conservative neighbors.

For example, when Europeans first reached the highlands of eastern New Guinea, in the 1930s, they "discovered" dozens of previously uncontacted Stone Age tribes, of which the Chimbu tribe proved especially aggressive in adopting Western technology. When Chimbus saw white settlers planting coffee, they began growing coffee themselves as a cash crop. In 1964 I met a 50-year-old Chimbu man, unable to read, wearing a traditional grass skirt, and born into a society still using stone tools, who had become rich by growing coffee, used his profits to buy a sawmill for $100,000 cash, and bought a fleet of trucks to transport his coffee and timber to market. In contrast, a neighboring highland people with whom I worked for eight years, the Daribi, are especially conservative and uninterested in new technology. When the first helicopter landed in the Daribi area, they briefly looked at it and just went back to what they had been doing; the Chimbus would have been bargaining to charter it. As a result, Chimbus are now moving into the Daribi area, taking it over for plantations, and reducing the Daribi to working for them.

On every other continent as well, certain native societies have proved very receptive, adopted foreign ways and technology selectively, and integrated them successfully into their own society. In Nigeria the Ibo people became the local entrepreneurial equivalent of New Guinea's Chimbus. Today the most numerous Native American tribe in the United States is the Navajo, who on European arrival were just one of several hundred tribes. But the Navajo proved especially resilient and able to deal selectively with innovation. They incorporated Western dyes into their weaving, became silversmiths and ranchers, and now drive trucks while continuing to live in traditional dwellings.

Among the supposedly conservative Aboriginal Australians as well, there are receptive societies along with conservative ones. At the one extreme, the Tasmanians continued to use stone tools superseded tens of thousands of years earlier in Europe and replaced in most of mainland Australia too. At the opposite extreme, some aboriginal fishing groups of southeastern Australia devised elaborate technologies for managing fish populations, including the construction of canals, weirs, and standing traps.

Thus, the development and reception of inventions vary enormously from society to society on the same continent. They also vary over time within the same society. Nowadays, Islamic societies in the Middle East are relatively conservative and not at the forefront of technology. But medieval Islam in the same region was technologically advanced and open to innovation. It achieved far higher literacy rates than contemporary Europe; it assimilated the legacy of classical Greek civilization to such a degree that many classical Greek books are now known to us only through Arabic copies; it invented or elaborated windmills, tidal mills, trigonometry, and lateen sails; it made major advances in metallurgy, mechanical and chemical engineering, and irrigation methods; and it adopted paper and gunpowder from China and transmitted them to Europe. In the Middle Ages the flow of technology was overwhelmingly from Islam to Europe, rather than from Europe to Islam as it is today. Only after around A.D. 1500 did the net direction of flow begin to reverse.

Innovation in China too fluctuated markedly with time. Until around A.D. 1450, China was technologically much more innovative and advanced than Europe, even more so than medieval Islam. The long list of Chinese inventions includes canal lock gates, cast iron, deep drilling, efficient animal harnesses, gunpowder, kites, magnetic compasses, movable type, paper, porcelain, printing (except for the Phaistos disk), sternpost rudders, and wheelbarrows. China then ceased to be innovative for reasons about which we shall speculate in the Epilogue. Conversely, we think of western Europe and its derived North American societies as leading the modern world in technological innovation, but technology was less advanced in western Europe than in any other "civilized" area of the Old World until the late Middle Ages.