EDWIN DANSON

WEIGHING THE WORLD

THE QUEST TO MEASURE THE EARTH

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The Quest to Measure the Earth

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For he hath weighed the world in the balance.
By measure hath he measured the times,
And by number hath he numbered the times.

Second Book of Esdras, ch. IV, vs. 36–37

He had bought a large map representing the sea,
Without the least vestige of land:
And the crew were much pleased when they found it to be
A map they could all understand.

Lewis Carroll, “The Hunting of the Snark”

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Preface

It was an age of reason; it was an age of enlightenment. It was an age of philosophical and scientific revolution, a fleeting period in history sandwiched between two momentous political revolutions: the bloodless English revolution of 1688 and the very bloody French Revolution of 1789.

The golden age began with the sowing of the mechanical seeds that grew to become the Industrial Revolution. The opening decade of the eighteenth century saw the world's first wheezing steam plant, and by 1712 Thomas Newcomen's steam-powered pumping engine was sucking prodigious amounts of water from a coal mine in Derbyshire. When the century began, manufacturing throughout the Western world was a cottage industry; 80 years later Sir Richard Arkwright had set in motion the "factory revolution" and was employing over 5,000 workers in his dark, but not yet "satanic," textile mills.

It was the age of Swift and Johnson, of political radicals such as Wilkes, and of philosophers like Rousseau and Voltaire. Mozart was born and died in this century, the genius of Beethoven flourished, and Handel wrote music sublime to entertain kings. And there were the poets, such as Pope, Goldsmith, and Cowper, who captured the essence of change that was sweeping across Europe. "Whereas in France the hurricane of revolution swept the country," reflected Engels in his socialist review of the eighteenth century, "there passed through England a quieter, but no less powerful upheaval. Steam and the new mechanical tools changed mill-working into modern heavy industry, thereby revolutionising the whole basis of middle class society. The sleepy evolution of the period of manufacture was turned into a veritable storm . . . of production."[1]

It was a turbulent age, a time of nearly continuous conflict by armies and navies increasingly furnished with scientific wonders to improve the means of waging war in ever more terrible, more destructive, and more devastating ways. The first decade of the century saw the union of Scotland with England and the beginnings of worldwide political unrest. Across the Atlantic Ocean, Britain's colonies in America grew and flourished, competing in affluence and power with their French and Spanish neighbors. The settlers of the eastern seaboard were already beginning to wonder why they needed the old country at all.

The great European conflict of 1755, known as the Seven Years' War, was kindled in the backwoods of America. It was the first world war and was fought across North America, up and down the coasts of India, and amid the tropical islands of the East Indies. It was fought across Europe and on the high seas, along the Africa coasts, and among the sugar islands of the West Indies. The victor's spoils would be the foundation of empire.

The great American sage Benjamin Franklin and other enlightened men on both sides of the Atlantic suddenly recognized a unique instant in world history, an opportunity for a "wider British Empire,"[2] one that offered horizons of influence and commerce undreamed of. But it was not to be; the opportunity was cast away for the selfish interests and narrow perspectives of a wealthy few.

Not yet an empire, not yet a nation so divided by the evils of the Industrial Revolution as to be without a humanist core, Britain had nevertheless taken the first steps toward a new and disturbing form of class segregation. For 700 years, its common people had lived the legacy of the Norman invasion, dominated by a Norman-French aristocracy that was wealthy almost beyond reason. Now the inventive and exploitative merchant classes, with their "new money," were adding new layers to the social hierarchy in fulfillment of their own special labor needs. The eighteenth century, then, in its later years saw the rise of a disadvantaged proletariat and a hardening of the ubiquitous British class system, with its rigid, illogical, and slightly ridiculous (but ever entertaining) social divides.

Across Europe, the art of thinking was undergoing a revolution equally as profound as that in artillery or politics. Freethinking intellectuals, the first of their genre, were employing reason and science to challenge traditional values, question conventional ideas, and contest long-held beliefs. In Britain, writers like Jonathan Swift were using "the artillery of words" to electrify the newly emergent, affluent, and literate middle classes and revolutionize the accepted wisdom of a thousand years. The eighteenth century, unlike its successor, represented an almost unique period in history, when bright young boys of the humblest birth might become rich merchants, great military men, or famous scientists.

For scientific advance, the eighteenth century saw the culmination of the slow transition of the ancient "sciences" such as alchemy and astrology into the "new" sciences of chemistry, physics, and astronomy. Issac Newton, in the previous century, wrote significantly more on alchemy and the harmony of nature than on his gravity theories. Astrology was still a respectable pursuit, and many of the great astronomers of the age were astrologers. With the thirst for learning, so new sciences evolved, particularly that of geography, geology, and mineralogy as mankind's curiosity and the demands for raw minerals to fuel the Industrial Revolution awakened latent intellects.

Before Engels's veritable storm could unleash its full fury, the obstacles to its passage, and to that of trade itself, had to undergo their own quiet revolution. Commerce was hampered by a lack of good roads; communications throughout the developing world were much as they had been in the Middle Ages. The economies of the trading nations of Europe were increasingly dependent on foreign trade to fuel their growth and pay their armies. Cargoes were ever at the mercy of the sea and the backward state of navigation, exacerbated by the inadequacy and inaccuracy of sea charts.

National jealousies and commercial and political rivalry were, as ever, the underlying causes for many of the century's wars, but war also provided the stimulus for much commercial effort and scientific innovation. Armies equipped with the latest weaponry marched about the countryside, led by generals with only the vaguest of maps at their disposal. At the start of the eighteenth century there were no maps, in the modern sense of the word, anywhere in the world. Indeed, there were plenty of atlases and sketch maps of countries, regions, and districts, but with few exceptions, they were imperfect renditions of nature. Vast gaps in knowledge were filled with speculation and fantastic imagery, as Swift wittily observed:

> So geographers, in Afric maps,
> With savage pictures fill their gaps,
> And o'er unhabitable downs,
> Place elephants for want of towns.[3]

For eighteenth-century sailors aboard the fast-growing fleets of merchantmen and naval ships, the problem of navigating the treacherous seas was compounded by the fact that no one knew how to determine the all-important longitude precisely enough to ensure a safe passage and a welcome landfall. No one knew, with any certainty, the shape of the earth or what lay beneath its surface. Was it hollow or was it solid? Were the Andes the highest mountains on earth or was it the peak of Tenerife? Was the earth a perfect sphere or was it slightly squashed, as Sir Isaac Newton prophesied? Just how did you accurately measure the planet?

The answers to these and a plethora of questions about the nature of the earth, answers we now take for granted, were a complete mystery. Yet, without the answers, maps and sea charts were of dubious value other than at the most provincial level, and provincialism was not in the vocabulary of the politicians, generals, philosophers, scientists, and businessmen of the bustling eighteenth century.

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1

I CANNOT BE WRONG

As the sun rose at the dawn of the sixteenth century, it shone upon a world mostly uncharted, warming newly discovered lands as yet unexplored. Beyond purple horizons, unknown countries and tropical paradises lay slumbering in happy ignorance of the coming storm. In the Old World of the West, the paucity of geographic knowledge had not deterred men from making maps of the World. On the contrary: there was a vast library of maps and atlases, many of which were wildly inaccurate and frequently farcical, showing beautifully engraved continents that did not exist and vague, vast landscapes populated with monsters and cannibalistic savages.

Serene seaways promised wide passages through what were impassable icy wastes that, the cosmographers insisted, led to the riches and spices of the Indies. No one knew from where precisely the spices came, nor did they particularly care. In fact, the strange berries and nuts were grown in the glades of remote East Indian islands and shipped by sea to the coasts of India, from where Moghul traders carried them to Arabia. Arab traders then hauled the baggage overland by camel train through burning deserts to the coasts of the Levant, where Genoese, Italian, French, and English sea traders imported the expensive and shriveled goods into the greedy markets of Europe.

The rich had been satisfied to purchase their spices and exotic goods from the last man in a long chain of traders, that is, until the Ottoman Turks expanded their empire from the east in the fifteenth century, capturing a swath of land stretching from Athens to the Crimea. With Sultan Bayezid II's horde of warriors and warlords controling access to the Danube, Europe's great trade river, and dominating all of eastern Europe, exacting high tolls on goods and traffic, the flow of spices from Asia dwindled. At this juncture, an ancient, much copied map of the world suddenly became very important.

The map was from the *Geographia* of Claudius Ptolemy (fl. 150 A.D.) made at the library of Alexandria during the second century. Much "improved" by Italian cartographers, the map suggested to a young Italian navigator by the name of Christopher Columbus (1451–1506) that there might be a sea route to Cathay and its exotic spices. Columbus reasoned that, the earth being round, he could bypass the Turkish obstruction simply by sailing west until he reached the exotic East.

When Columbus first spied the New World from his flagship, *Santa Maria,* he knew exactly where he was because he had a sea chart. He had discovered, he was certain, the eastern outliers of fabled Japan, gateway to the spice lands. Unfortunately, his chart was hopelessly wrong. The size of the world on which it was based was wrong; his estimate of the distance from Spain to Japan was wrong; the landmasses marked on his chart were wrong. The people he encountered were also wrong—at least, wrong as far as their race was concerned. The natives he met were the cannibal Caribs and their plat du jour, the gentle Arawaks; they were definitely not Japanese or even Chinese. But Columbus did not know this, and there is no reason why he should have. As far as he was concerned, he had been proved right and had found Japan at the very eastern limits of the spice-rich East.

Paolo Toscanelli, a Florentine cosmographer, is supposed to have provided both inspiration and the chart Columbus took with him on his first voyage of discovery. It was based, for the most part, on Ptolemy's ancient map of the world, embellished by the salty tales of coastal traders, fishermen, and an "unknown pilot" who had supposedly seen the fabled lands. Ptolemy's world was the Greek world and was a perfectly round, spherical world. Toscanelli, Columbus, and the natural philosophers of the day accepted this fact almost without question.

From this certain knowledge of a round world, and equipped with the great map, Columbus calculated that his sailing distance west to Japan would be a mere 2,760 miles (4,440 km).[1] In 1492, as his little fleet sailed further and further westward, with no sight of the promised land, Columbus grew increasingly worried, yet he kept his thoughts to himself, confident in his own abilities and having faith in his Florentine map. The crew was frightened and the men were becoming mutinous when, on 12 October (after 36 days at sea), young Juan Rodriguez Ber Mejo saw land from the prow of the *Pinta.*

When Columbus totted up his sailing distance, he realized that they had gone about 4,500 sea miles (8,230 km), considerably further than his original 2,760 miles; the only conclusion the navigator could infer was that the earth appeared to be a lot larger than everyone thought. A few years later, on his third voyage to the Indies (1498–1500), Columbus made an even stranger discovery.

He was observing the latitude by sighting the Pole Star with his quadrant when something very odd occurred. He was certain he knew where he was from his previous voyages, but the latitude observations appeared to be all wrong.

> I found that there between these two straits [the seas between Trinidad and Venezuela], which I have said face each other in a line from north to south, it is twenty six leagues from the one to the other, and I cannot be wrong in this because the calculation was made with a quadrant. In that on the south, which I named la Boca de la Sierpe, I found that at nightfall I had the pole star at nearly five degrees elevation, and in the other on the north, which I named la Boca del Drago, it was at almost seven.[2]

The difference of nearly 2 degrees of latitude for two locations fewer than 70 miles apart could only be explained if the earth, instead of being a perfectly round sphere, had somehow or other manifested some sort of bump near the equator: it was, according to Columbus, deformed.

We might now suggest that the strange anomaly was probably in part the result of his dubious navigational skills and in part to what we would call "atmospheric aberration." But, in 1498, neither Columbus nor any philosopher of the day was aware that the atmosphere behaves like a giant lens, bending light rays. When we watch a big red sun dipping below the horizon on a summer's evening it has, in reality, already set. We see it still because the atmospheric lens bends the light above the horizon. To illustrate the point, if you put a stick in a pond, that part beneath the water appears to be at an odd angle, as the water behaves like a lens, bending the light.

Whatever the cause for Columbus's disconcerting discovery, his thoughts that the earth could be anything other than perfectly round flew in the face of divine perfection; it flaunted the Aristotelian dogma of the church of Rome and challenged the received wisdom of a thousand years. On that starry night in the Caribbean Sea were sown the first heretical seeds of doubt.

2

THE TITAN KING

IN THE 170 YEARS that followed Columbus's discovery of the Americas, a vast library of knowledge about the earth accumulated. Explorers on land and sea, fur and spice traders, and the new merchant companies brought back information on new lands, strange new peoples, and of course, made maps of their discoveries. By the dawn of the eighteenth century, much was known about the shape and size of the earth.

The idea that the world could be a cosmic entity and possess a particular shape and size was a revolutionary Greek concept, and by the fifth century B.C., the world was believed by many philosophers to be round. The Greeks held to the perfection of the mysterious circle with an almost religious zeal; therefore, it was reasoned, the form of the earth had to be a circle that rotated to form a perfect sphere. Although their estimates varied widely and their notion of universal scale was problematic—Anaxagorus of Clazomenae (500–428 B.C.) believed the sun to be very distant, soaring as high above the planet as the Mediterranean was wide—the Greeks were the first to attempt to measure the size of the earth. In the third century B.C., Eratosthenes made the first "scientific" measurement.

Born about the year 276 B.C. in Cyrene, Libya, Eratosthenes, who had been educated at Athens, became librarian of the famous library at Alexandria in 240 B.C. A great scholar and the first "geographer," his wide reading and geographical research led to an interesting discovery. Tradition has it that he learned that near Syene (modern Aswan) was a deep well where the sun at midsummer was reflected in its dark waters. Syene lies very close to the Tropic of Cancer, the northernmost limit of the sun's biannual migration across the equator. Eratosthenes also knew that the distance from Alexandria to Syene, according to official Egyptian "pacers" and from the accounts of camel drivers, was 5,300 stadia (an ancient Greek measure estimated to be between 500 and 607 ft, or 152 and 185 m). Adjusting for the fact that Alexandria was not due north of Syene, he corrected the distance to 5,000 stadia. He then reasoned that if he could measure the angle of the midsummer sun's shadow at Alexandria, by simple trigonometry he could calculate the size of the spherical earth.

One tradition holds that he used an obelisk in the grounds of the library, where he found that the angle cast by the sun at the summer solstice was 7.2°. By dividing this angle into the 360° of a full circle, he calculated that the angular distance from Alexandria to Syene was one-fiftieth of the circumference of the earth. Multiplying the ground distance of 5,000 stadia by 50 gave Eratosthenes a circumference for the earth of 250,000 stadia, or (depending on which definition of the stadion one uses), approximately 24,855 miles, or 40,000 kilometers, a result remarkably close to the modern equatorial circumference of 24,901 miles, or 40,075 kilometers. Modern scholarship[1] suggests that Eratosthenes's work was in actuality far more complex and far more thorough than suggested here; he may even have used an accurate instrument called a *skiotheron,* or shadow catcher, similar to a modern surveyor's transit.

Some years later, another Greek geographer, Posidonius, thought Eratosthenes's circumference was too great and, from his own calculations, deduced a circumference for the earth of about 17,750 miles (28,960 km). It would appear that Posidonius's estimate was the one used by Ptolemy* for his great map of the world, which understated the planet's size by nearly 30 percent. Just why the great cosmographer used such an unreliable figure, when the evidence of his own time pointed to a larger earth, no one is certain. What is certain is that in the 1,400 years after Ptolemy, no one thought it necessary to remeasure physically the size of the planet.

For some 2,200 years, the learned of the West were satisfied that the earth was a perfectly round body. Then, in 1687, the English scientist Isaac Newton postulated that, almost certainly, the earth had to be slightly squashed because of the effects of its daily rotation. Incredibly, in his *Principia,* Newton even calculated the size of the distortion, using the distance between Paris and Amiens, measured by the French scientist Jean Picard.

Among the many physical problems with which the new men of science and philosophy were struggling were the exact dimensions of the earth and whether it was a solid ball or a hollow shell, wherein, some were certain, lay Satan's fiery realm. The more ardent interpreters of Holy Scripture still vigorously defended the process and chronology of the biblical Creation, but slowly and cautiously the accepted dogma of the Catholic Church was probed and tested. There was, of course, no doubt about the age of the world. James Ussher (1581–1656), the

*In his *Geographic hyphegesis,* Ptolemy accepts 1° of latitude as the equal of 500 stadia.

bishop of Armagh and a leading expert in his field, accurately calculated the very date of Creation from biblical records. Ussher set the event as having occurred precisely at six o'clock in the evening of 23 October 4004 B.C.[2] There was no evidence or reason to challenge this date as being anything other than a self-evident truth, as many still believe it to be.

Whatever the date for Creation, and despite popular misconceptions, the church never believed the earth to be flat, with Jerusalem at its center. Aristotle, the "virtuous Heathen," had declared it to be round, and round it was. Neither was it any longer believed, although not so generally expressed, that the earth stood at the center of Creation; instead, it traveled around the sun, as stated by the heretic Nicholas Copernicus (1473–1543).

Perhaps we should be thankful that Greek literature and ancient Greek learning was at the very center of Europe's post-Renaissance science. It was fortunate, too, that it had been the ancient Greeks who made the earliest recorded attempts to estimate earth's dimensions. It was even more fortunate that infidel Saracens had the wisdom to preserve what the West, during the Dark Ages, forgot. Had science been based on biblical texts alone, we would have had a narrower pot for science to grow in and might still be dreaming of how we could reach the moon.

With the arrival of the eighteenth century, the thirst for knowledge that had epitomized the previous century exploded. Until Newton's theories about the shape and form of the earth, it was assumed that our planet was perfectly spherical and of a uniform density. A plumb bob suspended above such a perfect world would point directly toward the center of the planet. However, the earth is not perfectly spherical, as Newton postulated, and as we shall see, there is no particular center to where the plumb bob can point.

New theories about the shape and form of the earth abounded and raised many intriguing questions. Newton's laws of gravity set out in his *Principia* were contentious, obscure, and hotly debated, and by no means did everyone agree with the great scientist. If everything, every atom and every particle, created its own gravity, some asked, how large would an object have to be before its effects became apparent? For example, would the mass of a mountain be sufficient to generate its own local gravity? And would it matter anyway?

Some philosophers suggested that an effect caused by mountains, if it existed, might be strong enough to cause a plumb line to be deflected toward the mountain. If so, if the effect were strong enough, it would result in serious errors when measuring the apparent position of the stars. Newton was convinced that the effect did exist but doubted that an instrument could ever be built accurate and sensitive enough to detect the tiny force that became known as "the attraction of mountains." In the event, the effect would turn out to be all too real and lead to some very surprising consequences.

The attraction of mountains, obscure and peculiar as it is, does exist and can be measured, and as we shall see later, it does matter—it matters a great deal. Its greatest effect occurs near the largest mountains, such as the Andes, but even modest-sized mountains can generate enough independent gravity to cause errors. Any instrument that uses the direction of gravity as its reference, such as a surveyor's theodolite or an astronomical observatory's telescopes, will be in error by the amount of the deflection. The most critical measurement affected is latitude.

Even a modest-sized mountain will cause an error of tens of seconds of arc. Now, 1 second of arc in latitude is the equivalent of approximately 100 feet (30 m) on the surface of the earth, so an error of 10 seconds will cause an error of over 1,000 feet (304.8 m). Near giant mountains, the deflection can exceed 1 minute of arc, or 60 seconds, equivalent to more than 6,000 feet (1,829 m) over the ground. Ignoring such errors would lead to inaccurate maps and sea charts. In short, it would lead to the sort of inaccurate maps that led Columbus to discover the New World by chance and many others to become forever lost at sea.

However, at this point in the story, the phenomenon of the attraction of mountains was nothing more than a curious theory and of little consequence. Most maps of the time, that is, all accurate renditions of the earth at a scale sufficient to show useful detail, were surveyed and presented after the Roman model, employing the so-called "Christian topography," and as if the earth were flat. The Romans were practical warmongers and their maps were equally practical. Just because the earth was round was no reason for making things more complicated than necessary.

Mapmaking is an art at least equally as old as writing and probably much older. At Catal Hoyuk, a prehistoric site in Anatolia, a wall painting dated to the seventh millennium B.C. clearly shows a small township and an erupting volcano in recognizable map form. The Babylonians, Egyptians, and Assyrians have left examples of their cartographic skills engraved on clay tablets or picked out on papyrus. Strabo of Alexandria (fl. 20 B.C.) wrote that Anaximander of Miletus compiled the first map of the world in the early part of the sixth century B.C. Even at such early dates, philosophers were struggling to comprehend the shape and size of the world; some followed the Homeric school and believed the world to be disk-shaped; others followed Pythagoras's idea that the earth was spherical.

Much knowledge was lost when Rome fell to the barbarians and religious fanaticism replaced reason and learning in the West. The church descended into a brooding period of dark, cosmic dogmatism that was to develop in a sinister way and persist until the Age of Reason. Fortunately, when western Europe plunged enthusiastically into the Dark Ages, the wisdom of Ptolemy found newer and eager disciples among the thinkers and scholars of Islam.

These Muslim scholars were crucial in transforming the arithmetic of the ancients into modern mathematics. The dissemination, though not the idea, of the rather abstract concept of having a number represent zero is Islamic, as is our "Arabic" numbering system. So enthusiastic and progressive was Islam that places of learning were established. For example, in the ninth century, al'-Mansur, the caliph of Baghdad, founded the House of Wisdom. In its cloisters and gardens, mathematicians like Omar Khayyam developed the processes of calculation called *algebra;* the very word is Arabic. And it was these Arab philosophers who kept alive the learning and perspicacity of the ancients and who added their own new learning and new observations of the cosmos.

Arab scholars also advanced the Greek concept of latitude and longitude, and tenth-century mathematicians such as Abdul Wafa deduced the geometrical principles. The Islamic mathematician and astronomer al'Biruni, a far-sighted individual who believed the earth was not stationary but rotated about its own axis, even made accurate calculations of latitude and longitude for many places in the known world. In 1154, proving that science and learning transcended ideological divides, the Islamic cosmographer al'Idrisi constructed a world map for the Christian crusader King Roger of Sicily.

As the West awoke from its dark slumbers in the fourteenth and fifteenth centuries, it was the Muslim and Moorish Arab scholars who provided the libraries and replenished the lost repository of learning and who passed on their map skills, mathematics, and astronomical knowledge to Renaissance Europe.

However, Europe had not entirely abandoned its mapmaking. In the Middle Ages some magnificent manuscript maps were made in England and France. These works of art were probably produced in some quantity to meet the demands of enthusiastic crusaders who needed to know the way from London to Palestine. Such are the maps of Matthew Paris, a monk of Saint Alban's abbey, drawn about the year 1250, as well as the famous *Mappa Mundi* of about 1300, preserved in Hereford Cathedral. This must have been a most useful map, showing, as it does, the whereabouts of Jerusalem at the center of the world; and almost certainly the beautiful map adorned the hall of a great lord.

Ptolemy's *Geographia* and its world map reappeared in European cosmography circles sometime after 1430. Variations on the map based on Italian models became more widely available with the invention of the printing press in 1450. It was about this time that Europe found that its traditional source of spices and goods from the East via Constantinople (Istanbul) was unexpectedly closed to traffic by the Ottoman Empire. Suddenly, the trade in precious metals, fancy goods, and the all-important spices, so necessary to disguise the flavor of decaying meat, dried up. This event, probably more than any other, stimulated European interest in looking westward as a means of going east and spawned a flurry of exploration.

In what became the age of discovery, the Portuguese set out to explore the coast of Africa, Columbus discovered America, Cabot traversed the bleak shores of Labrador, and Magellan circumnavigated the entire globe. The knowledge these adventurers brought back with them stimulated overheated imaginations and led to the myths of the existence of Northwest and Northeast passages and fabulous shortcuts to the riches of Cathay. What all the explorers agreed on was that the earth seemed to be a lot bigger than previously thought.

Depicting the round earth on a flat piece of parchment was an ancient skill and employed to great effect by cosmographers such as Ptolemy. However, the first scientific method of map rendition came in 1569 when a cosmographer by the name of Gerard de Cramer, or Geradus Mercator,* as he is better known, produced a map of the world whose construction was mathematically sound. Mercator's genius was in employing a device of his own invention (which became known as Mercator's projection) that transposed in a mathematical relationship the roundness of the earth onto the flat plane of a piece of paper.

Mercator (1512–1594) was the eighth child of a poor cobbler in Gangelt, a German border town. While he was still young, his parents died and his elder brother Gisbert, a Catholic priest living in Rupelmonde, Flanders (now Belgium), brought him up. At the age of 16, Gisbert secured Mercator a place as a scholar at the University of Louvain, where he studied the teachings of Aristotle. It was at Louvain that his sympathies for Protestantism first became apparent and where he began to feel that the views of Aristotle, whose teaching was enshrined in Catholic dogma, were misconstrued. However, such thoughts in the early years of the Reformation were distinctly and dangerously heretical, and he kept them to himself.

After a short period of European travel, in 1534 Mercator returned to Louvain to study mathematics and cosmography under the celebrated Dutch astronomer and mathematician Gemma Frisius (1508–1555). In 1537, he produced his first major map, of Palestine, and 3 years later he made a map of Flanders that he constructed from a survey he personally supervised.

Then, in 1544, in a wave of arrests, Mercator and many of his friends and acquaintances were charged with heresy. After 7 months' incarceration in the dis-

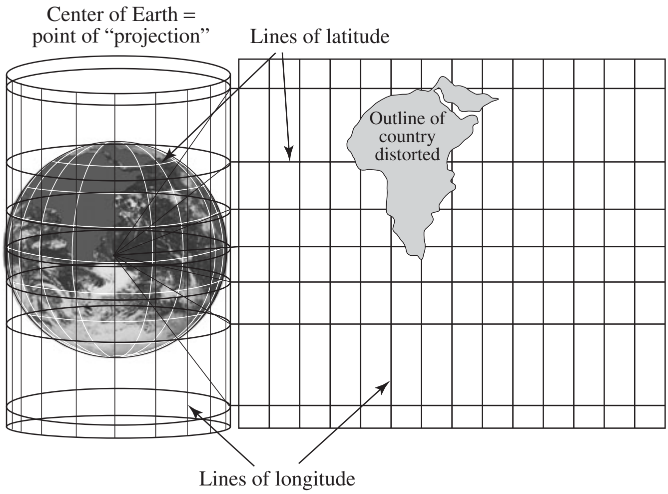
*Cramer = Dutch for "merchant," which, Latinized = *Mercator.*

Geraldus Mercator. Courtesy Library of Congress.

mal cells of Louvain castle, he was released without charge; many of his associates were less fortunate. The women were buried alive; the men were burned at the stake or beheaded.[3] It was a frightening lesson: Mercator learned that these were dangerous times for mapmakers who flirted with concepts that could so easily be interpreted as devilish. Impoverished and desperate, Mercator and his family fled to Duisburg in the Duchy of Cleves, a progressive Calvinist town where attitudes were a little more liberal.

In 1552, Mercator set himself up in business, making globes, atlases, and “large-scale” maps of Europe, including the British Isles. It was in his shop at Duisburg that he perfected his mathematical projection for the earth and where he produced his famous world map. Duisberg was also where he coined the first known use of the word “atlas” to describe very small-scale maps of countries, “to honour,” he wrote, “the Titan, Atlas, King of Mauritania, a learned philosopher, mathematician, and astronomer.”[4]

Mercator’s mathematical projection of the world revolutionized mapping and for the first time allowed the accurate construction of maps and charts. Fortunately, it is not necessary to understand the mathematics to see how his projection works. It is easily visualized as a piece of photographic paper wrapped as a cylinder around the equator of a glass globe, one that has engraved on it the lines of latitude and longitude. If a light is placed at the center of the globe, the lines of latitude and longitude are “projected” onto the paper. When the paper is unwrapped and developed, the curved lines of latitude and longitude appear



Mercator's projection of the earth.

on the flat paper as straight lines. The spacing between the latitude lines increases toward the poles, which is a drawback to this sort of device, and Mercator's projection runs out of steam in the high latitudes. But this would not be a problem until explorers ventured to the icy polar wastes many years in the future.

The latter part of the sixteenth century witnessed an extraordinary increase in the number of maps and atlases in production, spurred by the new discoveries and the demands of sea traders and merchants. The worldly imaginings of Ptolemy finally faded away in 1570, when Abraham Ortelius, geographer to Phillip II of Spain and a close friend of Mercator, published *Theatrum Orbis Terrarum,* an atlas of the world composed (almost) entirely from contemporary explorers' knowledge and observations.

Fifteen years later, Mercator's mighty map of the world, his *Atlas in Three Parts,* was published in Amsterdam. It was, at the time, the most accurate rendition of the earth ever made. Many errors of earlier times were corrected and the latest discoveries included. For the first time, the width of the Mediterranean Sea was shown close to its modern value, 10 degrees of latitude less than on Ptolemy's map.

Between 1572 and 1618 Braun and Hogenberg, in the Rhineland, produced plans of over 500 towns. In England, Christopher Saxton began his survey of England and Wales, publishing his *Atlas* in 1579, a work unsurpassed in accuracy and quality for nearly 200 years. The cartographer John Speed published his *Atlas* in 1611, which contained superlatively detailed town plans, the first of their kind, and the boundaries of the ancient administrative sections called "hundreds" and "lathes." With various amendments and additions, Speed's maps remained popular until the close of the eighteenth century.

In 1675, the cartographer John Ogilby published *Britannia,* the first atlas of Britain to show the main postal roads. Yet only the atlases that depicted large areas of a country or a continent employed Mercator's projection as a means of preserving accuracy by rendering the curved surface of the earth on to paper. All other maps were drawn as if the world was flat. But, for accurate mapmaking of large areas at anything greater than atlas scales, removing or allowing for the distortions caused by the roundness of the earth was a prerequisite.

Mercator's projection made it easy for maps and charts to be drawn very accurately, but the instruments to measure the all-important latitudes and longitudes in the first place had not similarly advanced. Navigating at sea and determining an accurate geographical position on land depended entirely, as it had for thousands of years, on observing the stars. Apart from the Pole Star, very few star positions were accurately known for anything but the most basic sort of navigation. It was a sort of Catch 22: latitudes depended on knowing the positions of the stars, but knowing the position of the stars depended on making accurate observations of their locations from the earth in the first place.

To overcome this difficulty and address the paucity of data, well-equipped and properly staffed astronomical observatories were needed to measure precisely the places of the stars and to follow the motions of the planets and the sun and moon. The first modern telescopic observatory charged with charting accurately the night sky was built in Paris in 1667. Britain followed suit in 1675 with its Greenwich Royal Observatory.

Of the two critical geographical measurements, latitude was relatively easy to determine by using a primitive quadrant or astrolabe to observe the "altitude" of a star. Longitude, on the other hand, was totally abstract; it required an origin, a physical place, from where it could be counted. The French naturally counted from Paris, the British from Greenwich, and the Spanish from the Canary Islands. Unlike the astronomical nature of latitude, finding the longitude required a "mechanical" solution. Stimulated by a large cash prize, the problem was eventually solved by the British clockmaker John Harrison with his remarkable invention of the chronometer. However, prizes for solving the longitude problem had a long history that well demonstrates the commercial and military importance that merchants, politicians, and scientists placed upon it.

The maritime nations of Spain and Portugal were among the first to recognize the importance of longitude for the safety of their shipping and, in particular, mapmaking and exploration. Toward the end of the fifteenth century, these two neighbors were in dispute over their overlapping exploration and commercial interests. In 1493, the year Columbus brought back news of his discovery of "Japan," Pope Alexander VI (a Spaniard) issued a Bull of Demarcation to settle the argument.

Alexander, a notable pope but less so a cartographer, drew a line of longitude on a sea chart 100 leagues (400 Roman miles) west of the Azores. Everything undiscovered to the west (including the New World) he bequeathed to Spain, and everything to the east went to Portugal. In the pope's mind, and in the minds of his advisors, the solution was simple and expedient. What they failed to realize was that it was almost impossible to implement the bull with even the remotest degree of accuracy and that their line of longitude would cross the poles and run down the other side of the world.

In 1567, King Philip II of Spain announced a cash prize for the first person to solve the longitude problem; in 1598, his successor, Philip III, raised the stakes further. Nearly 60 years earlier, in 1530, the Dutch mathematician Gemma Frisius, who had taught Mercator, had put forward his method of finding the longitude by using a clock. His suggestion was that a clock would be set ticking at the point of departure, and "while we are on our journey," wrote Frisius, "we should see to it that our clock never stops. When we have completed a journey of 15 or 20 miles, it may please us to learn the difference of longitude between where we have reached and our place of departure. We must wait until the hand of our clock exactly touches the point of an hour and at the same moment by means of an astrolabe . . . we must find out the time of the place we now find ourselves."[5]

Observations with an astrolabe, an ancient device for measuring the altitude of a heavenly body above the horizon, were commonly used to determine local apparent time; in theory, his proposal could have worked but for two facts. First, astrolabes were not particularly accurate, and second, seeing "that our clock never stops" was hopelessly optimistic. There was not a clock in the whole world that was either accurate enough or reliable enough. Despite the absence of the technology, Frisius's method did, in the end, triumph but only after 230 years.

The Spanish longitude prize was worth an incredible 6,000 gold ducats plus a pension of 2,000 ducats for life to the discoverer. One early respondent was the Italian astronomical genius Galileo, who wrote to the Spanish court in 1616 with a clever plan. Instead of relying on the fallibility of man-made mechanics, Galileo proposed using the regular and predictable heavenly mechanics of the moons of Jupiter, which he had discovered in 1610 and for whose motion he had compiled tables. In essence, Jupiter's tiny moons replaced the hands of Frisius's clock; in all other respects the solution was the same.

For 16 years, Galileo tried in vain to persuade the Spaniards of the excellence of his scheme. Then, in 1636, the States General of the United Provinces of the Netherlands joined the longitude race and offered a prize of its own. Galileo, ever on the lookout for cash, quickly turned his attention from the reticent Spanish to the enterprising Dutch. The States General set up a commission to investigate his proposal, but by then the great Italian was under house arrest by the Inquisition for his heretical belief in Copernicus's theory of a sun-centered universe.

3

A Calm and Gentle Character

One of Galileo's vehement detractors was the astrologer Jean-Baptiste Morin (1583–1656), a wan-looking man with a shock of wild hair; his broad forehead ranged above a pair of troubled eyes. Morin passionately believed the earth to be fixed firmly in space, as befitted the church's Aristotelian ideal, and he renounced any philosopher who challenged him.

Morin was a delightfully arrogant and self-opinionated person: "I am excessively inclined to consider myself superior to others on account of my intellectual endowments and scientific attainment,"[1] he wrote of himself. He had been born into a wealthy family of Villefranche and educated in philosophy and medicine. At the age of 30, he was sent on an investigative trip to Germany and Transylvania to study the mines and minerals of the area for the bishop of Boulogne. This was an interesting journey and stimulated within Morin a curiosity for the mechanical sciences and an overdeveloped opinion of his own righteousness. In 1630, he became a professor of mathematics at the College Royale in Paris, where he embarked on a distinguished astrological career.[2]

In the seventeenth century, the gap separating astrology from astronomy was narrow to the point of nonexistence; it is no surprise, then, that Morin contributed so much to the junior science while being a master of the senior. In 1634 he approached Cardinal Richelieu (1585–1642), King Louis XIII's chief minister, with a method for finding the elusive longitude. His proposals were an advance on the earlier work of the Nuremberg cosmographer Johann Werner (1468–1522), whose idea in 1514 was to observe "the distance between the Moon and one of the fixed stars which diverges little or nothing from the ecliptic."[3] King Louis's advisors set up a royal commission of eminent scientists, including the celebrated mathematicians Etienne Pascal and Clause Mydorge, to study Morin's proposals.

Like Werner, Morin's idea for finding the longitude was to take advantage of the moon's passage across the celestial sphere. Morin claimed that by observing the angular distance of the moon from the sun or from certain charted stars, he could use this information to derive a longitude difference. Where he differed most from old Werner was that Morin included corrections for atmospheric refraction and for the "lunar parallax," the difference in angle made by the moon when viewed from different points on the earth. Werner's proposal, known widely as the "lunar distance method" would, in the distant future of Morin's time, rank as important a solution to the problem as John Harrison's chronometer. Morin had little faith in clocks, recalling the mechanical ideas of Frisius: "I do not know if the Devil will succeed in making a longitude timekeeper, it would be folly for man to try."[4]

Instead, Morin proposed taking advantage of the recent improvements in optical instruments to make his lunar method a practical one for simple seafarers. He even suggested erecting an observatory to determine accurately the necessary lunar data. For 5 years, the committee met on and off to discuss and evaluate Morin's proposal. For 5 years Morin argued with the committee; he even argued with the great philosopher René Descartes. But the mathematics of the solution were far too complex for seafarers to solve, and the data on the moon's erratic movements, vital for the theory to work, were too difficult to measure or predict.

Eventually the scientific community in France could stand Morin's bickering and argumentative ways no longer and sent him away to spend his declining years in isolation, a scientific pariah, absorbed in his astrological studies. His original benefactor, Cardinal Richelieu, died in 1642, but his successor, Cardinal Mazarin, ultimately awarded the old astrologer his 2,000 livres longitude prize, even though his ideas had been set aside.

The lunar distance method was shelved, and no further progress on the longitude problem was made in France until 1661, when King Louis XIV appointed the far-sighted Jean-Baptiste Colbert his minister for home affairs. Colbert recognized that what was needed, not just for the longitude but also for a range of scientific advances, was a college or foundation made up of all the greatest minds in Europe. In 1666, he founded the Académie Royale des Sciences and persuaded the king to fund it from the royal purse. The society had a wide remit to study all things scientific and to provide philosophical advice to the government. Its most important directive was, however, to give France better maps and sea charts and to improve the dangerous business of navigation.

Colbert was totally committed to his new society and offered large remuneration to any scientist willing to dedicate himself to its work. The greatest brains of the day were invited to join, including Gottfried Leibniz, Ehrenfried Tschirnhaus, and Isaac Newton. The Dutch physicist, astronomer, philosopher, and