CHAPTER 1

HISTORY OF GEODESY

Ever since man evolved into a thinking creature, he has been interested in learning about the earth. The various natural phenomena he observed around him, often with awe or fear, were frequently responsible for his behaviour and gave rise to various superstitions, rites, and cults. These, in turn, encouraged a better comprehension of events which resulted in many early cultures and civilizations acquiring a surprisingly deep understanding of some of the natural phenomena, left to us in such obvious forms as monuments (like Stonehenge in Wiltshire, southern England and the Egyptian pyramids), temples and towns (built by Central American Indians), calendars, etc. Such natural phenomena are often intimately related to the size, shape, gravity field of the earth, and their time changes, and to understand them requires a certain knowledge of geodesy.

For many centuries, the only way to learn about the geometry of the earth was through the observations of the sun, moon, planets, and stars, i.e., through astronomy. Hence the first achievements of geodesy went hand in hand with the development of astronomy. Together with astronomy, geodesy is among the oldest sciences; it is doubtless the oldest geoscience.

Little documentation of the geodetic accomplishments of the oldest civilizations—Sumerian, Egyptian, Chinese, Indian—has survived. There are many indications [TOMPKINS, 1971], however, that they must have had some very accurate observations, if not an understanding, of at least the basic motions of the earth. Our outline of geodetic history begins with the first positively documented concepts of the Greek era. Inevitably, the story we present is very subjective, with the historical flavour being emphasized rather than the historical accuracy. For the facts and dates not referenced in the text, the source is ASIMOV [1972]. Throughout this chapter we use modern terminology which, from the historical point of view, may at times be misleading. To do otherwise would have required more space than this presentation warrants.

This chapter is divided into four chronological sections. The first section covers the period from Thales till the end of the Roman Empire. The second section treats the Middle Ages, the Renaissance, and the beginning of the era of rationalism till about the mid-eighteenth century marked by the acceptance of Newton's theory of gravitation. The third section deals with the next 200 years, ending with the Second World War, and marked by the acceptance of Einstein's theory of gravitation. The last section describes the most recent developments of approximately the past 40 years. It was our deliberate decision to avoid references to living scientists, with a few notable exceptions.

1.1. Historical beginnings of geodesy

During the Greek era, geodesy was considered to be one of the most challenging disciplines and, consequently, some of the best intellects of that period devoted their energies to it. The first documented ideas about geodesy date back to Thales of Miletus (c. 625–c. 547 B.C.), commonly recognized as the founder of trigonometry. His concept of the earth was that of a disk-like body floating on an infinite ocean; our own interpretation of this idea is shown in FIG. 1.

Anaximander of Miletus (c. 611–c. 545 B.C.), Thales's contemporary, had a slightly different idea; he taught that the earth was cylindrical—see FIG. 2—with the axis oriented in the east–west direction [ASIMOV, 1972]. He was the first to discourse on a celestial sphere. This idea has permeated centuries of astronomical thinking and still remains a useful idealization in position astronomy (see §15.1). Anaximenes, Anaximander's pupil, modified Thales's vision somewhat by maintaining that the earth floated on a finite, circumferential ocean and was held in space by compressed air [BROWN, 1949]. This is interpreted in FIG. 3.

The school of Pythagoras (c. 580–c. 500 B.C.) was the first to believe in a spherical earth—a view that prevailed for well over two millenia. The work of this school was later compiled by Philolaus (flourished mid-fifth century B.C.) who was also the first to propose a non-geocentric universe centred on Hestia (the central fire). As the sun (and all the other bodies) moved in circular orbits round this fire, it cannot be called a heliocentric system [DIJKSTERHUIS, 1950]. Around the end of the sixth century B.C., Hecataeus of Miletus compiled one of the first known maps of the world, represented here in FIG. 4 (after BUNBURY [1883]). It rather vividly illustrates the limited knowledge and the prejudices the ancient Greeks had about the world. Yet,

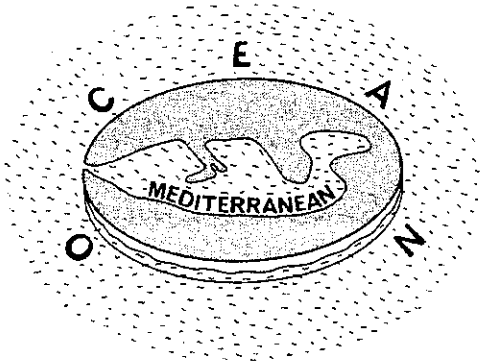

FIG. 1.1. Authors' interpretation of Thales's concept of the earth.

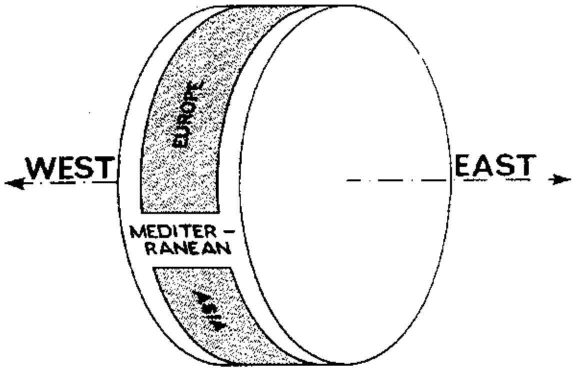

FIG. 1.2. Authors' interpretation of Asimov's description of the figure of the earth according to Anaximander.

at about this time, a Phoenician by the name of Hanno (born c. 530 B.C. in Carthage) may have circumnavigated Africa [WELLS, 1961]. As with the reports and findings of so many explorers throughout the ages, his were disbelieved and forgotten for another 2000 years.

Astronomy, often based not on observations but on philosophical views of the world, continued to develop. Anaxagoras (c. 500–428 B.C.) was the first to recognize the spherical form of the moon and explain the diurnal motions of the sun and the moon. The first star map was prepared by Eudoxus (c. 408–c. 355 B.C.) who also knew the length of the solar year almost exactly: 365.25 days, a figure probably learned from the Egyptians. Heracleides (c. 388–c. 315 B.C.) proposed that at least the earth, Mercury, and Venus moved round the sun, thus modifying Philolaus's century old notion. He also taught that the earth spins round its own axis.

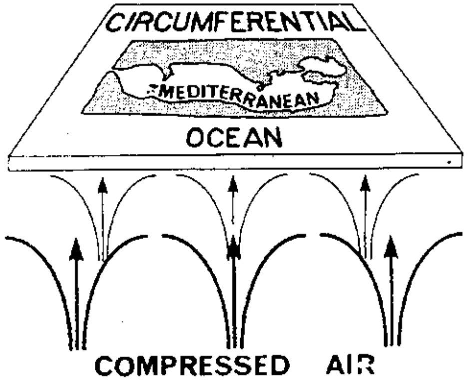

FIG. 1.3. Authors' modification of Brown's interpretation of Anaximenes's earth.

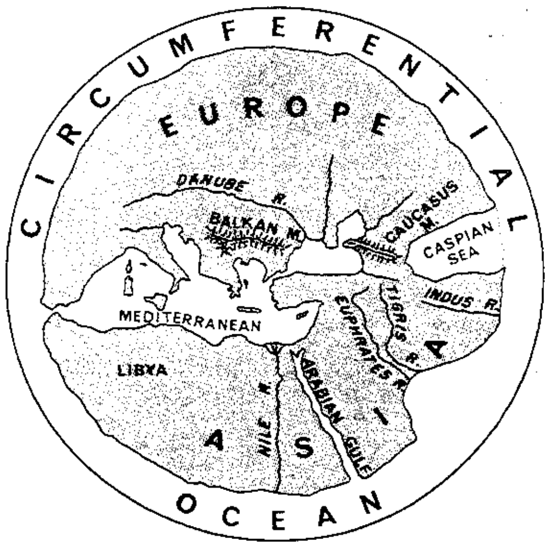

FIG. 1.4. Hecataeus's map of the world.

The first hint at the possibility of gravity is due to Aristotle (384–322 B.C.) who, in addition, formulated the first plausible argument for the sphericity of the earth, which survives till the modern day. Aristotle's interest in gravity was taken up by Strato (born c. 340 B.C.) after whom further breakthroughs had to wait till the Renaissance. Pytheas (born c. 300 B.C.) suspected the celestial bodies were responsible for the sea tide (see §8.1) but had insufficient knowledge to link this to gravitational attraction.

With the idea of the sphericity of the earth becoming acceptable, it was only a matter of time before spherical (angular) coordinates were introduced. This was finally done by Dicaearchus (died c. 285 B.C.) around the end of the third century B.C. He also compiled an updated map of the world containing information about south Asia gained during Alexander the Great's military expeditions. Shortly afterward, Pytheas determined the first relatively accurate latitude (for Marseilles).

Further progress in astronomy is associated with Aristarchus (c. 310–c. 250 B.C.) who attempted to determine the dimensions and distances of the moon and the sun. About half a century later, Eratosthenes (276–194 B.C.) introduced the notion of the obliquity of the earth's spin axis. Hipparchus (c. 190–c. 120 B.C.) gave us the first accurate star maps drawn in an angular system of coordinates, known now as the right ascension system (see §15.1). He subscribed to the idea of a precessing earth (see §5.2) but never accepted the heliocentric hypothesis of Heracleides, Aristarchus, and Seleucus, a Babylonian astronomer and contemporary of Hipparchus. It would be 1700 years before anyone again taught the heliocentric motion of the earth.

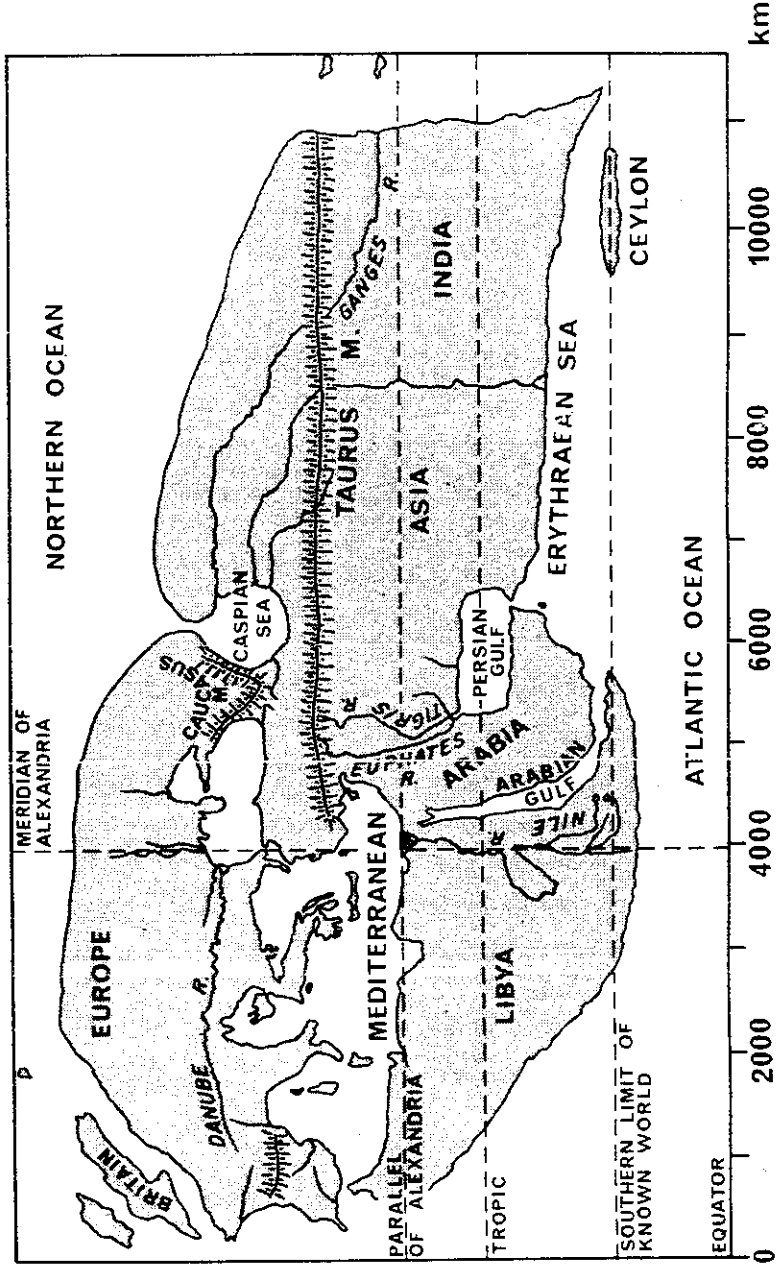

FIG. 1.5. The world according to Eratosthenes.

Let us return to Eratosthenes who, from the geodetic point of view, is the most interesting of all the aforementioned. Eratosthenes, holder of the prestigious position of librarian of the famous Alexandrian Museum (an institution approximating today's university), can be called the proper founder of geodesy. The result of his determination of the size of the (then thought of as spherical) earth, in his celebrated measurement of latitude difference between Alexandria and Aswan [GROUEFF, 1974], is discussed in §7.3 in the context of some of the more modern results. A later attempt by Poseidonius (c. 135–c. 50 B.C.), who considered the effect of air refraction (see §9.2), is now known to be considerably inferior to that of Eratosthenes. Along with some of his predecessors, Eratosthenes believed in the existence of one interconnected ocean which belief had to wait for confirmation for 17 centuries. His vision of the earth's surface is shown in FIG. 5 (after BUNBURY [1883]).

With Poseidonius there ended the era of original thinkers and experimenters. Thereafter, for some one and a half millenia, geodesy remained static, except for an occasional compilation or synthesis of the Greek achievements. The only notable exception during the Roman Empire was probably the implementation of the (Julian) calendar, commissioned of Sosigenes by Julius Caesar in the middle of the first century B.C. [DURANT, 1944]. This calendar, except for the small Gregorian reform in 1582 [PANNEKOEK, 1951], has survived till today.

As the Greek era drew to a close, some very important compilatory works were carried out by the Greek astronomer Claudius Ptolemy (c. 75–151). Ptolemy published a monumental compilation of astronomy and geodesy as developed at Alexandria, which is known under its Arabic name of *Almagest*. In an equally important work, the *Geography* published in 150, Ptolemy produced a new map of the world unsurpassed for some fourteen centuries. It is shown here in FIG. 6, according to THOMSON [1966]. It clearly represents no substantial improvement over the 300 year old map of Eratosthenes. In one respect it is worse: Ptolemy used the inferior figure of Poseidonius for his size of the earth at the expense of Eratosthenes's. An illustration of the intrinsic conservatism of the science of that period is the fact that Ptolemy never accepted the heliocentric hypothesis believed in by several astronomers before him. He also paid little heed to the traveller Strabo's (born c. 63 B.C.) suggestions that some continents could exist as yet unknown to man.

1.2. Scientific beginnings of geodesy

The ancients had been held back from expanding their knowledge of the material world by their philosophical and religious beliefs. In the centuries following the fall of the Roman Empire, i.e., during the Middle Ages, geodesy, along with so many other sciences, came more and more within the detrimental embrace of theology. The Greek teachings survived this dark period chiefly in Arabic versions that in the twelfth century found their way to Europe through Spain and were translated into Latin, then the language of European intellectuals. An example of the influence the Scriptures had on scientific thought in the European Middle Ages is shown in FIG. 7 (after BROWN [1949]), which is the navigator Cosmas's idea of the world of 548.

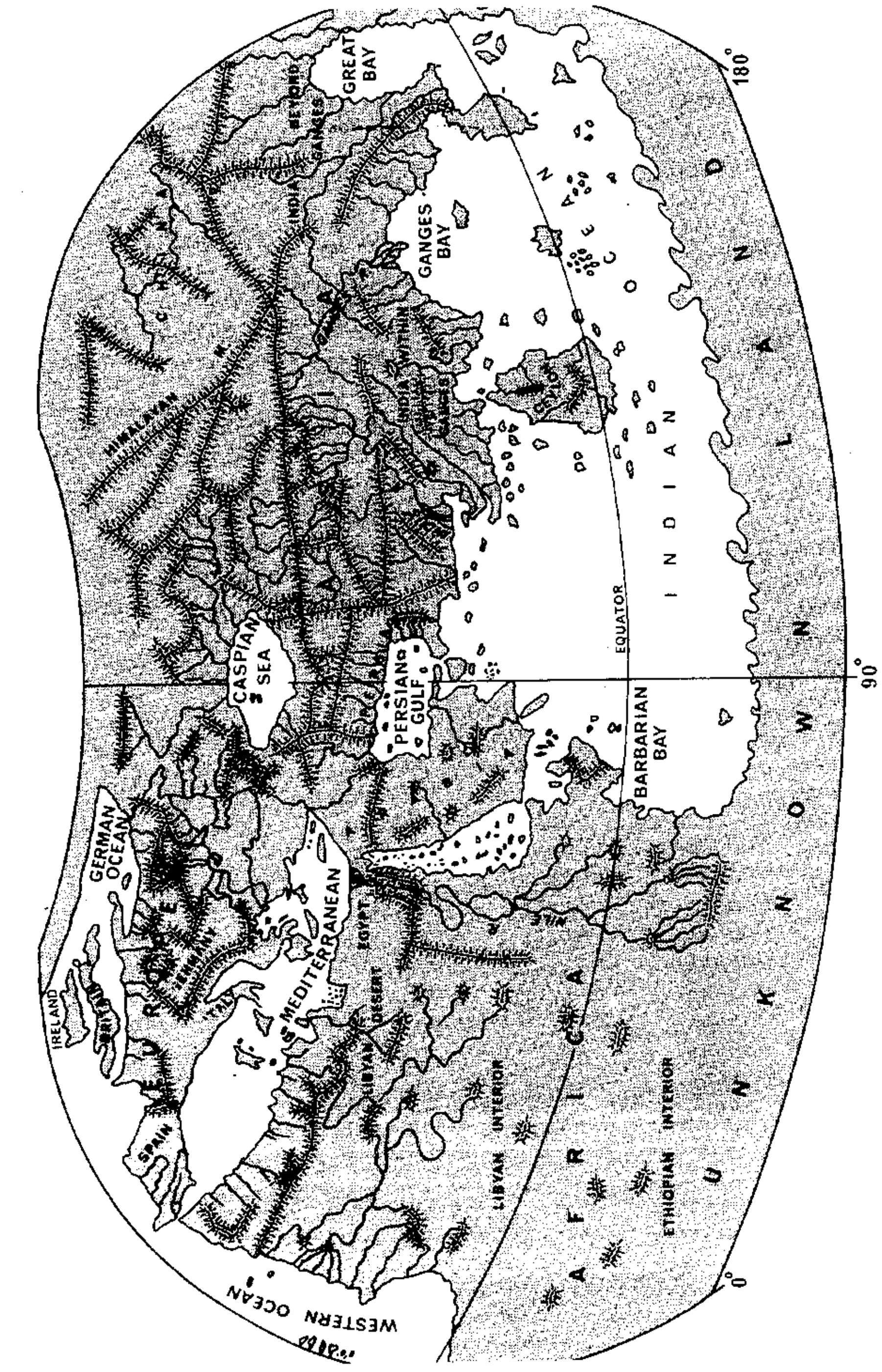

FIG. 1.6. The world according to Ptolemy.

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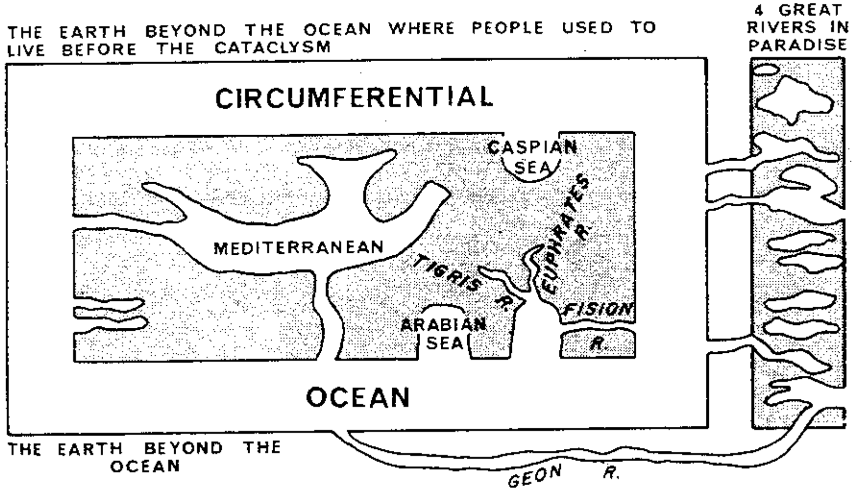

FIG. 1.7. Cosmas's vision of the world.

As will be seen from the following, the occasional glimpses of light during the Middle Ages were rare and far from overwhelming. The Persian Kharazmi (born c. 780), after whose Arabic name, Al-Khwarizmi, comes the word 'algorithm', redetermined the size of the earth. The result was about 1.6 times too large—no match for Eratosthenes's. Al-Khwarizmi, who also published a map of the world not very different from Ptolemy's, earns a permanent place in history by introducing Hindu numerals, 1, 2, ..., 9, into Arabic mathematics. The Arabic astronomer Albategnius (c. 858–929) knew the length of the year more accurately than Sosigenes did nine and a half centuries earlier. So did the Englishman Roger Bacon (c. 1210–92), who advocated reforming the Julian calendar to include one extra day every 128 years.

Things started coming to a head in the mid-fourteenth century, characterized by renewed curiosity and growing boldness. The age of great explorations was approaching, and the quest for uncorrupted truth grew. A new vision of the world, doubtless influenced by the exploits of Marco Polo (in the period 1271–95), was offered by Toscanelli (1397–1482) and is shown here in FIG. 8 (after HAPGOOD [1966]). It was reputedly this map and Bacon's estimate of the short distance from Europe to the east coast of Asia that tempted Columbus to sail west to find the new, only 5000 km long, way to India [DURANT, 1944].

The major explorations got under way at the end of the fifteenth century with Columbus crossing the Atlantic in 1492, Vasco da Gama circumnavigating Africa in 1497, and Magellan's expedition circumnavigating the world between 1519 and 1522. The expanding geographical knowledge prompted the growth of a new profession: map-making, or cartography. Cartography is the art of displaying the final product of geodesy, so mention must be made of a few of the more famous map-makers in

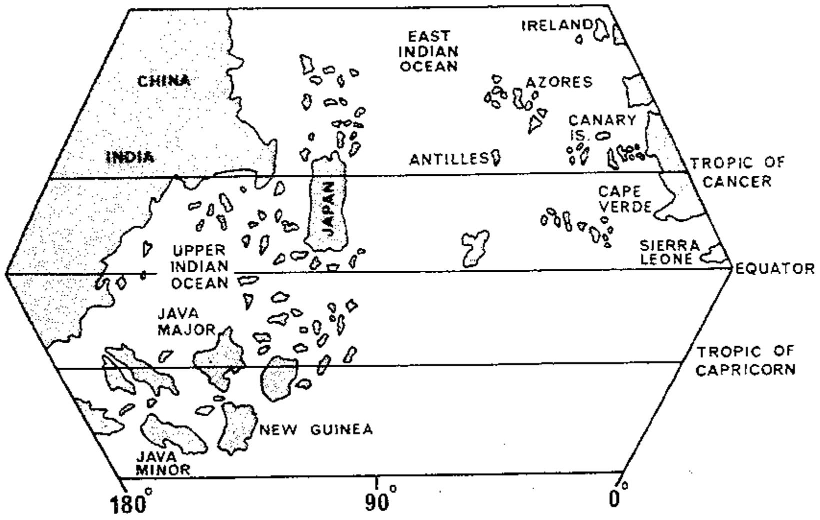

FIG. 1.8. Toscanelli's idea of the western hemisphere.

history. Among the best known is the Italian Amerigo Vespucci (1451–1512) who gave us the first maps of the North American Pacific coast and provided a name for the continent. Another well-known map-maker, often considered to be the father of modern cartography, is the Flemish Mercator (1512–94). He very successfully responded to the demands of navigators for maps with the least distortions (see §16.3). FIG. 9 (after FITE AND FREEMAN [1926]) shows one of his world maps which reflects the tremendous improvement, during the Renaissance, in mankind's knowledge of the earth's surface. Although Eratosthenes's figure for the size of the earth was finally accepted after it had been confirmed by Magellan's expedition, old customs die hard, and maps like the one shown in FIG. 10 (after NORDENSKJÖLD [1889]) were still being printed in the mid-sixteenth century.

Indications of an impending revival of geodesy can be found in the mid-fifteenth century when there arose a series of thinkers who paved the way for Copernicus and Kepler. Among the better known were the German cardinal Nicolaus of Cusa (1401–64), who wrote about the diurnal motion for the earth and introduced the idea of an infinite universe, and the Italian artist Leonardo da Vinci (1452–1519) who suggested the probability of isostasy (see §8.2) [DURANT, 1944]. Finally, about 1530 the Polish clergyman Copernicus (1473–1543) published his heliocentric theory which, for the first time, included all the planets.

The battle of reason against theology though was not over. In 1600 the Italian astronomer Bruno (1548–1600) died at the stake for, among other heresies, maintaining basically the same views that Nicolaus of Cusa and Copernicus had held before him. The story of Galileo's forced recant [WELLS, 1961] (an apology finally being issued by Pope John Paul II in November, 1979) of heliocentricity is well

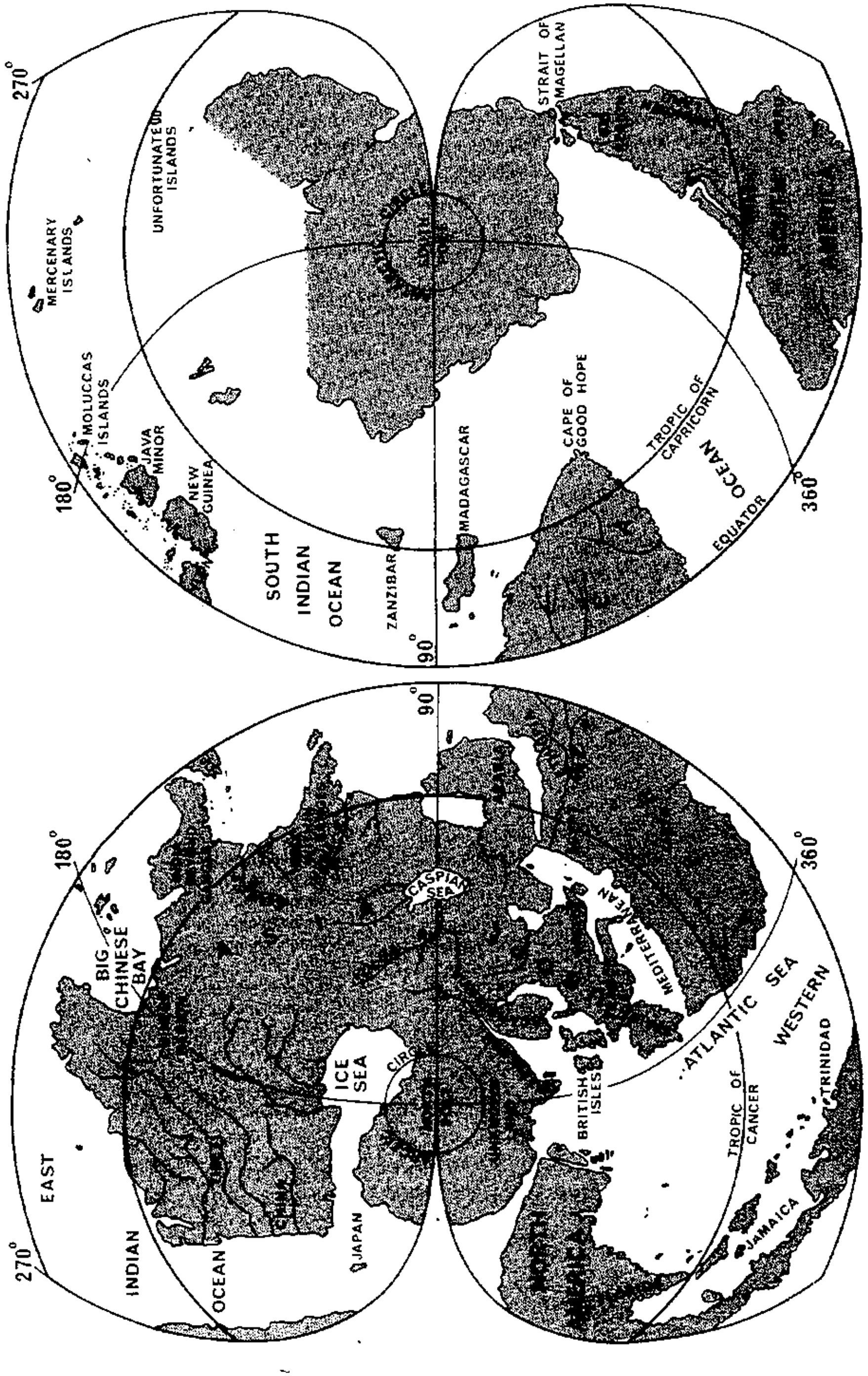

Fig. 1.9. Mercator's map of the world.

Fig. 1.10. Apianus's map of the world.

known. The observational evidence, collected chiefly by the Danish astronomer Tycho Brahe (1546–1601); improvements of the experimental methods, due mainly to the Italian Galileo (1564–1642); progress in theory, associated with the German Kepler (1571–1630); and superior instrumentation (such as the telescope) should have combined to render the theologically based views untenable. But in Catholic countries the Inquisition banned the books of Copernicus, Kepler, Galileo and others advocating heliocentricity until 1822 when they were finally removed from the *Index* [DREYER, 1905].

In the meantime for geodesy, this fermentation of ideas brings the beginning of real scientific enquiry into gravity in terms of the Dutchman Stevin's (1548–1620) experiment showing the equivalence of gravity attraction for disparate bodies, and Galileo's formulation of the first mechanical laws. Nevertheless, Newton's idea of gravity as a force was still far away. In 1615, the Dutchman Snell (1591–1626) carried out the first accurate triangulation [BÖHM, 1972] and made the first rigorous study of refraction. The French clergyman Picard, in 1670, made the first modern measurement of the size of the earth. His result of 6275 km [GROUEFF, 1974] for the radius of the earth is the first improvement on Eratosthenes in 19 centuries. The technique Picard used is outlined in §7.3.

The scene was set for the most important discovery of this era: the (Newton's) law of universal gravitational attraction in 1687 (see §6.1), for which the works of the Italian Borelli (1608–79) and the Englishman Horrox (1619–41) can be seen as precursors. The mathematical tools needed had been prepared by Descartes (1596–1650), Leibnitz (1646–1716), and Newton (1642–1727) himself who, among other

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things, was a professor of mathematics at the University of Cambridge. Progress in the understanding of gravity brought about two somewhat related discoveries. Towards the end of the seventeenth century, the Dutchman Huygens invented the first accurate time keeping mechanism based on the use of a pendulum; the Englishman Bradley (1693–1762) discovered nutation (see §5.2).

Newton's theory of gravitation was not accepted overnight. Its most renowned opponent was Newton's French counterpart, the royal astronomer of Italian origin, Cassini (1625–1712). While Newton's new theory predicted that the earth should be oblate—because of the centrifugal force caused by the spin (cf. §6.1)—Cassini maintained that it should be prolate. This he did in spite of the observational discovery by the Frenchman Richer in 1671 that gravity was weaker at the equator, as required by Newton's theory.

As the theory of gravitation gained acceptance, a resolution of the deadlock between Newton and Cassini was required. In the years 1735–43, the French Academy of Science organized two survey expeditions to measure two meridian arcs—and the corresponding latitude differences—one at the equator, the other closer to the pole. The equatorial expedition, under the leadership of Bouguer, went to Peru (now Ecuador). The other, led by Maupertuis (1698–1759) and including the young Clairaut (1713–65), went to Lapland. The results of the two expeditions confirmed the validity of Newton's theory. In addition, it was Clairaut who, as a by-product of his theory of rotating fluid bodies, later derived the simple relationship between the gravity change along a meridian and the flattening of the earth (cf. §7.4).

1.3. Geodesy in the service of mapping

The pioneering work done by Snell, Picard, and the two French expeditions showed that terrestrial geodetic measurements (angles and distances) are viable tools for the task of relative positioning. Networks of points whose horizontal positions were determined from the measurements of angles and occasional distances (see §7.1), known as triangulation networks, started to spring up in all parts of Europe in support of mapping programmes of various kinds. Accurate mapping for military as well as civilian purposes became feasible because it was suddenly possible to cover the land with triangulation points the positions of which were obtainable with relative ease. The instruments needed for triangulation, i.e., theodolites and base line measuring devices like wires and tapes, became more precise, easier to operate, and more portable. The techniques of triangulation, astronomical determination of positions and azimuths, as well as levelling, have been perfected (cf. Part IV). Between 1750 and 1950, the determination of positions from terrestrial and astronomical observations were the daily bread of geodesists. So much so that even today many people view geodesy as being merely a synonym for this task.

At times, these geodetic tasks presented an intellectual challenge to the best brains of the era, arousing an interest equal to that which geodesy stirred at the dawn of our civilization. Thus we find, for instance, J. K. F. Gauss (1777–1855), acknowledged as the greatest mathematician of the early nineteenth century, inventing the heliotrope, a device that uses reflected solar rays for signalization of geodetic points, and measuring a geodetic network in the kingdom of Hannover. In America, with its smaller population density and larger distances, unique techniques had to be used by surveyors (like George Washington) to meet the more challenging problem of positioning. The first satisfactory map of British and French North America became available in 1755 [BOORSTIN, 1958].

Hand in hand with developments in geodetic positioning went discoveries in other aspects of geodesy. In 1798 the Englishman Cavendish, using Michell's torsion balance, succeeded in 'weighing the earth'. The French mathematician Laplace (1749–1827) laid the foundations for modern celestial mechanics and the theory of tides; he also devoted a considerable effort to the development of probability theory. The German astronomer Bessel (1784–1846) determined the first accurate figure of the flattening of the earth (see §7.3) from existing knowledge of geodetic positions. Gauss defined the geoid (see §6.3) and invented the least-squares method (see Chapter 12), though concurrently with Legendre. His work on the theoretical foundations of geodesy has caused some geodesists to claim him as the father of geodesy. He did usher geodesy into its mature age, but he was equally eminent in other branches of science.

The end of the eighteenth and the whole of the nineteenth centuries were enormously fruitful in the realm of mathematics. Most of the tools of applied mathematics used in geodesy today were invented then. Thus mention should be made of a few great mathematicians who contributed the most toward building up the geodetic 'arsenal'. These are: the Swiss Euler (1707–83), with his work on mechanics of physical bodies; the French-Italian Lagrange (1736–1813), the creator of analytical mechanics who, among other contributions, helped to introduce the metric system in France in 1795. Another Frenchman, Fourier (1768–1830), is remembered for his work on potential, Gauss and the German Riemann (1826–66) for their work on differential geometry, and the Irishman Hamilton (1805–65) who put the finishing touches to analytical mechanics.

Naturally, in this period of rationalization, other fields akin to geodesy underwent equally fast development. To name a few: geophysics began with the Scottish geologist Hutton's (1726–97) theory of evolution of the earth's surface, the German polyhistor Humboldt's (1769–1859) studies of various physical aspects of the earth, and the German geophysicist Wegener's (1880–1930) theory of continental drift (see §8.3). The elevation determined by Humboldt of Chimborazo in South America [BOTTING, 1973] remained the highest known until the measurements in the Himalayas started by Everest, the Surveyor General of India. Oceanography progressed from the first soundings carried out by the English explorer Cook (1728–79), to the American oceanographer Maury's (1806–73) mapping of the sea bottom and the currents, to the Swiss explorer Piccard's (1884–1962) observations from submersibles. Propagation of electromagnetic waves was theoretically described by the Scottish physicist Maxwell (1831–79), and its velocity first measured in a laboratory by the Frenchman Fizeau (1819–96). The application of electromagnetic waves to long distance measurements was carried out by the German-American physicist

Michelson (1852–1931) who first determined a geodetic distance to a relative accuracy better than 10^{-6}.

All these developments had a stimulating effect on geodesy, and discoveries in the realm of geodesy proper followed. The French physicist Coriolis (1792–1843) explained the total acceleration of bodies moving on the earth's surface. The mid-nineteenth century saw the first measurements of the deflections of the vertical (see §6.4) and the first attempts by two English physicists, Airy and Pratt, to quantify isostasy (§8.2). At about the same time, the French physicist Foucault demonstrated that the earth is spinning and invented the gyroscope, later to be adapted into a gyrocompass (see §16.1) by the American Sperry (1860–1930). The year 1880 saw the first serious attempt to synthesize and formalize the mathematical and physical foundations of geodesy by the German geodesist Helmert in his book *Mathematical and Physical Theory of Geodesy*. In 1883, the English physicist Stokes published the solution of the geodetic boundary value problem (see §22.1) in closed form. The Scot Kelvin (1824–1907), the Englishman Darwin (1845–1912, son of Charles Darwin), and the Frenchman Poincaré (1854–1912) developed the theory of the earth tides (see §8.1), and the Canadian astronomer Newcomb (1835–1909) studied the wobble of the earth's spin axis (see §5.4).

The beginning of the twentieth century saw a major change in the thinking of physicists affected by Minkowski's space–time and, of course, by Einstein's special and general theory of relativity [CLARK, 1971], a further generalization of Newton's theory of gravitation. The idea that "...gravity is geometry—the geometry of space and time..." [DAVIES, 1979] soon permeated physics and, though not directly applicable to most geodetic problems, had an effect on geodesy in due course. It has certainly affected at least the philosophical outlook of the authors of this book.

In the first half of the twentieth century, the Hungarian physicist Eötvös studied gravity gradients, and the Dutch geophysicist Vening Meinesz significantly improved the theory of isostasy. The English geophysicist Jeffreys introduced the concept of the telluroid (see §7.4) that started a new trend in geodesy culminating in the Russian physicist Molodenskij's more rigorous solution to the geodetic boundary value problem (see §22.2). Finally, the work of the Italian mathematicians, Pizzeti and Somigliana, on the theory of the normal gravity field (see §20.3) must be mentioned.

1.4. Geodesy of the modern era

The mid-twentieth century saw the dawning of the technological revolution. Prompted by weapons and defence requirements during the Second World War, the invention of a 'radio detection and ranging' system, commonly known as radar, has had a deep effect on the philosophy behind geodetic instruments. At about the same time, the first practical electronic computers appeared, opening up horizons for numerical mathematics unimaginable in the past. The introduction of computers not only sped up geodetic computations but revolutionized the thinking of geodesists: solutions to tasks, previously out of the question because of the sheer volume of the calculations involved, became not only feasible but even easy.

For centuries, horizontal angles, measurable to a much higher accuracy ~~with~~ intrinsic ease, had been preferred to distances. Shortly after the war, sufficiently accurate electromagnetic distance measuring devices became commercially available for geodetic uses. These instruments, first using polarized light then radiowaves and finally lasers, eventually changed the pattern of geodetic positioning.

The forerunners to the turbulent development of extraterrestrial methods were the first experiments in radio-astronomy that culminated in the discovery of pulsars and quasars. These new distant radio-objects emit signals with high frequential stability and are now being used in the fast developing techniques of radio-interferometry (see §16.1).

The launching of the first artificial satellites was another giant leap for geodesy. For the first time, geodesists could use extraterrestrial objects, passive or active, for accurate positioning of points the intervisibility between which was no longer a constraint. The low altitude of the satellites offered the opportunity of studying the geometry of the earth's gravity field by means of direct observations of the satellite response (motion) to the field (cf. Chapter 23). Satellites also brought about a new project for geodesy: the mapping of the gravity field above the earth to predict satellite orbits. Once again, the major customers for this kind of information were the military who needed to know the gravity field geometry for computing missile trajectories.

Another spin-off of the space programme is the inertial navigation and positioning systems (see §16.1). These technologically complex systems were made possible by vast improvements in the accuracy of acceleration sensing and direction seeking devices. The spectacular development of microelectronics was probably the single most important contributor here.

The increased ease and accuracy with which geodesists could determine positions, as well as the gravity field parameters, led to new applications, but also to new problems. Suddenly, effects that had always been considered negligible started showing up, and the 'noise' these effects caused had to be accounted for. "One man's noise being the other man's signal...", other disciplines became interested in geodetic techniques, as well as results, to study the phenomena relating to their own fields. Prime examples of such (symbiotic) relations are those of geodesy with geophysics, space science, astronomy, and oceanography (see §2.2).

The relation with geophysics has been particularly fruitful because of another fact: in the late 1960s the hypothesis of plate tectonics finally gained almost universal acceptance. In some parts of the world (cf. §8.3), the rate of relative tectonic movement is so fast that it is directly measurable by geodetic means. Geodesy, therefore, became the major supplier of geometrical information on these movements. This successful deployment of geodesy in tectonic investigations has led to further applications of geodetic techniques in other branches of geodynamics.

The last important development of geodesy that must be mentioned here concerns the sea. Expansion into the marine environment, characterized by exploration and