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Growth of cartography, the science.

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Thesis

GROWTH OF CARTOGRAPHY, THE SCIENCE

by

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Introduction

Cartography has been defined as the science and art of expressing graphically by means of maps and charts, our knowledge of the earth's surface features and cultural relationships. As the art of map-making it is perhaps the oldest variety of primitive art, because from the very beginning it was art with a purpose. It is the scientific phase of cartography with which this thesis concerns itself. Tracing the growth of cartography the science limits this study to the observation and classification of facts.

The means for collecting and observing facts related to cartography were easily found, but the means for classifying these facts presented a problem. The answer to this was found in the basic purpose of cartography—the construction of the projection or graticule. The fundamental elements of a projection being: the shape of the earth, latitude, longitude and again the eventual result, the projection.

The growth of scientific cartography as presented in this thesis has been classified and developed about these facts. Chapter I considers the earth and how its true shape and dimensions were learned. Chapter II traces the realization and measurement of latitude. Chapter III presents the more complex evolution of longitude and its co-partner, the chronometer.
Finally, Chapter IV focuses these elements on to a plane to reveal the various projections which result.
Chapter I

The Earth

The first concern of cartography, like that of geodesy, was the determination of the size and shape of the earth through the application of mathematics and astronomy in the then practical field of surveying. This information about the earth occupied the attention of astronomers and others for centuries following the generally accepted opinion by leading thinkers that the earth was flat.

Previously, the earth, according to Homer and his disciples was a plane disc surrounded by a constantly moving ocean river, "Oceanus". Resting on the rim of the earth's disc was the high vault of heaven, an inverted hemisphere. In need of additional support, the skies were supposedly propped up by a series of tall invisible pillars, whose structural safety was in the care of Atlas. Strabo called Homer the founder of the science of Geography, but his concept was a far cry from the true shape of the earth which we now know to be almost a perfect sphere. The perfect sphere being an axiomatic tool of cartographers.

The first tentative approach to the truth concerning the shape of the earth came about 523 B. C. A great name in the history of science, Phytagoras is credited with several important scientific hypotheses which turned out to be correct. Perhaps his most important theory was that the earth, instead of
being flat or disc-shaped, was spherical.

To Aristotle (384-322 B.C.) is given the distinction of founding scientific geography. He demonstrated the theory of a spherical earth although his idea is credited to Thales who preceded him by several centuries. The latter was probably the first who looked for a physical origin of the earth instead of relying upon mythology.

One of the earliest known scientists who made a serious attempt at determining the circumference of the earth was Eratosthenes, (276-196 B.C.), the keeper of the famous library at Alexandria, Egypt. His method consisted in comparing the length of a north-and-south arc in linear units with the angular equivalent determined from a difference in latitude. His result is stated to have been remarkably accurate, but unfortunately it was not accepted by later geographers. This method of using meridional arcs was employed until about the middle of the nineteenth century when the invention of telegraphy made possible the determination of differences in longitude with an accuracy comparable to that of difference in latitude and thus removed the necessity of confining geodetic operations to arcs of the meridian.

It was Hipparchus (160-120 B.C.) who added much to mathematical cartography. He was a noted mathematician and the founder of scientific astronomy, which he placed on a firmer basis and applied astronomic methods in determining points on the earth's surface. Mathematical cartography has, therefore a
direct appeal as being one of the pioneers of science.

Although Strabo (50 B.C.–24 A.C.) in a way set the pattern for geographers to follow, it is to Ptolemy, however, that we are indebted more than anyone else for having concentrated in his *Geographia* the sum of all geographic learning. We know that he received much of his knowledge from Marinus, the Phoenician of Tyre who closely preceded him. Ptolemy is the one outstanding figure in early map-making. He devoted much of his *Geographia* to the principles for the scientific construction of maps. He devised a scientific system of parallels and meridians.

The gnomon and its telltale shadow revealed the equinoxes and eventually the equinoctial line which we now know as the equatorial line. The second and third parallels laid down on the spherical earth were closely related to the equatorial or equinoctial line, and were literally parallel to it. Strabo and his contemporaries called them, logically, the Summer Tropic and the Winter Tropic, because they marked the two extremes of the sun's annual course and corresponded to the summer and winter seasons of Strabo's habitable world. The Summer Tropic later was named the Tropic of Cancer, because on the day of the solstice the Crab (Cancer), the fourth sign of the Zodiac, made its first appearance in the sky. The Winter Tropic became the Tropic of Capricorn because the He-Coat (Capricorn), the tenth sign of the Zodiac, first made its appearance on the horizon.

Early Greek astronomers used the term "arctic" not in
connection with the frigid zones of the earth near the poles, but with reference to a celestial circle. In this case the arctic circle varied according to the position of the observer and his horizon. Pytheos seems to have brought the arctic circle down to earth in his first reference to Thule. In referring to its latitude he said it was the most uninhabited region and that at Thule the arctic circle corresponds with the Summer Tropic (Tropic of Cancer), which is to say that the height of the polestar at Thule is the same as the angular height of the Summer Tropic about the equator, or, about 24°, approximately the location of the Arctic Circle from the North Pole. In other words, if Pytheos, like Eratosthenes and Strabo, placed the Summer Tropic at 24° north of the equator, the latitude of Thule would be 66°, the complement of the Summer Tropic.

The modern compass is a combination of the ancient rose of the winds a magnetized needle. The wind rose evolved separately, and was no more than a convenient way of partitioning the circular horizon. Names of winds were used to express direction instead of numerals or degrees of arc. The naming of the winds was as natural and elementary as the naming of the stars. It was likewise natural that the wind rose should eventually be used in connection with the greatest of all instruments for determining direction--the compass needle.

The identity of the inventor of the magnetic compass is hidden in the ages. The subject of direction upon the seas was
a popular one when the amazing properties of the lodestone be-
came known. In 1260 A. D. Roger Bacon mentions the stone to
which iron fastened itself. A needle were rubbed with
the stone and then floated on straw, it would always point
towards the star. The box compass invented and described by
Peregrinus had a pivoted needle revolving around a graduated
disc similar to an astrolabe, but about forty years later, the
wind rose and the pivoted needle were used in combination on
the coastal chart of Petrus Vesconti. In fact, 1302 is the tra-
ditional date of the "invention" of the mariners' compass by an
unknown navigator of Amalfi.

When Columbus made his first voyage of discovery, popular
belief maintained that the earth was flat, though the scholars
of the time recognized its spherical form. In 1736 Pierre
Bouguer proved independently that the earth had the form of an
oblate spheroid with a considerable flattening at either pole.
It was several decades later before the first fairly accurate
dimensions of the earth were derived and more than a century
before the computation of the Bessel Spheroid of 1841 and the
Clarke spheroid of 1866, which have since been used at various
times in many countries.

Modern geodesists and cartographers have proven and accept-
ed as a fact that the earth is an oblate spheroid. As it is
flattened at the poles, it is not a perfect sphere, nor even a
perfect ellipsoid, but a ball with slight irregularities of
surface. Its longest diameter is 7,926.6 miles and its shortest
7,899.6 miles. The circumference is approximately 24,000 miles. But to the cartographer, the earth is assumed to be a perfect sphere. A sphere divided equally and evenly by degrees of latitude and longitude enable the map-makers to standardize their projections.

The axis of rotation of the earth is its shortest diameter. The ends of the axis point to opposite parts of the sky, and these, called the poles of the heavens, seem to stand still while the rotation of the earth causes an apparent revolution of the sky from east to west. The system for determining position and direction is established on the earth's rotation and revolution. The great circle midway between the poles is the equator. Great circles extending north and south through the poles are meridians. Distance from the equator toward either pole is called latitude, and is measured along a meridian.

Just how latitude evolved out of necessity and the progress of science, will be discussed in the next chapter.
Chapter II

Latitude

The discovery that the earth was spherical in shape and that an equatorial line existed, presented the scientists and astronomers with a starting point for their next problem—the locating of places and the measuring of distances on the earth's surface.

The ancients, instead of designating the position of a place by means of measurement by latitude, used the earth's climatic zones—the climate being the slope of the plane of the celestial equator, which is the complement of the latitude. Many of the Egyptian obelisks were erected primarily for use as gnomons and were used for that purpose.

It was the geographers of the fifth and early fourth centuries B.C. who taught that the ecumene—the habitable world—was more or less oblong in shape, twice as long from east to west as from north to south. From this conception are the terms "latitude" and "longitude" derived.

The method of determining and the naming of latitude was introduced by Ptolemy. His work had two main faults: by his method of measurement and choice of the Canary Islands for his prime meridian he greatly overestimated the length of the land surface eastward from this line, and consequently reduced the gap, presumed to be water, lying between Europe and Asia.

Eratosthenes' contribution was a map showing certain prin-
cipal parallels and meridians in which he was attacked by Hipparchus, who advocated an even system of parallels and meridians dividing the circle into $360^\circ$, as we still use it at the present time.

The ancient Greeks established a co-ordinate system dividing the arc between the equator and poles into $90^\circ$ in parallel circles which get larger nearer the equator. Similarly the equator was divided into 360 parts and through the division points and the two poles are 180 semicircles or meridians.

The ancients had few or no instruments for measuring latitude. They were, however, able to make a very respectable approximation by means of the simplest of all astronomical instruments, the gnomon. This was merely a vertical shaft or column of known height erected on a perfectly horizontal plane; and the observation consisted in noting the length of the shadow cast at noon at certain times of the year. It was easy to compute the sun's zenith distance when farthest north and south; and, since the sun travels equal distances north and south of the celestial equator, the mean of the two results gave the angular distance between the equator and zenith.

By the middle of the sixteenth century there were two established methods for finding latitude on land and at sea. The first was to determine the height of the sun above the horizon at the place of observation; the second was to determine the height of the polestar. Both methods required the use of angle-measuring instruments; and in each case, having determined the
observed height of the celestial bodies, the observer had to make certain corrections, aided by mathematical tables computed for the purpose. The theoretical requirements, both as to instruments and mathematical tables, were fully appreciated by the ancients and the only scientific contributions to the subject in the next 2,000 years were improvements.

The sextants, quadrants and octants that were to be developed throughout the following centuries, were merely parts of the ancient astrolabe. These were improved and adapted to meet the special requirements of surveyors and navigators. The Nautical Almanac, as we know it today, was the product of ancient astrology, refined and perfected with astronomical instruments.

The astrolabe was described in some detail by the geographer, Martin Cartez, in 1551. It was made of copper or tin, about ¼ inch thick and 6 or 7 inches in diameter. It was circular except at a place on the limb where a projection (shoulder) was provided for a hole and ring by which the astrolabe was suspended. One half of the copper circle was graduated in degree. A plumb line extended from the point of suspension to the opposite side marked the vertical line, and from it the horizontal line and center were derived.

There was no limit to the size of the astrolabes. Many were of iron and brass, and installed on permanent foundations in central towns or cities. On some ships of the 16th century the entire poop deck was given over to a mammoth astrolabe for
use by the navigator.

João de Barros, the historian, reported that when Vasco da Gama reached the bay of St Helena on his first voyage around the Cape of Good Hope in 1471, he went ashore and set up a large astrolabe of wood to get his bearings. He had been unable to get a trustworthy meridian altitude of the sun from the deck of his ship with his portable instrument.

Developing along with the astrolabe was the cross-staff and later the back-staff. The cross-staff was an instrument used by ancient astronomers for determining latitudes and the angle between the stars; it was later adopted by mariners for measuring altitude at sea. Its simplicity suggests that it may have antedated the astrolabe as a device for measuring angles. The earliest known description of the cross-staff was written by Levi ben Gerson, a learned Jew of Benolas in Catalonia in 1342. It was an instrument whose origin was lost, but over a period of years with improvements and refinements, became the modern sextant.

The cross-staff in its simplest form consisted of five parts: the staff, the cross and three sights. The staff was simply a stick of wood about 1 1/2 inches square and of varying length. One was described about 27 inches long. The cross "transom" or "transversary" was usually about 1 1/2 inches thick and 2 1/3 inches wide.

It was fitted with three sights; one at either end of the transom and one on the near end of the staff. The problem was
The cross-staff as shown above was used for centuries to measure the height of the sun.
to face the sun, and then line up the three sights simultaneously. The transom could be moved back and forth on the staff. After an observation was made the instrument was laid on a table or sheet of paper and the resultant angle traced on the paper.

The great and obvious defect of this instrument and the astrolabe was the necessity of peering directly into the sun when making an observation. Many centuries past before an ingenious mariner, John Davis of Devonshire, England, decided to eliminate this defect by developing the back-staff.

The original consisted of a staff and transom, the latter in the form of a "halfe crosse", riding as it were, on top of the yard. The functioning of the instrument, Davis point out, was contrary to that of the cross-staff, because the observer worked with his back to the sun, sighting the horizon through a horizontal slit at the far end.

From these—the astrolabe, the cross-staff and the back-staff—grew the English quadrant. It was developed by John Davis, probably with the help of Edward Wright of Cambridge, England, who was also applying his mathematical skill to the improvement of navigational charts. The improved instrument was a divided quadrant or quarter circle, actually the old back-staff with refinements. The sector transom, originally on a slide, was moved to the near end of the staff and fastened there. A second staff or brace was added to make it rigid. The straight upper transom of the old back-staff was replaced by a second sector transom; this too, was reinforced and fastened at the far
The back-staff as pictured above enabled the observer to work with his back to the sun.
end of the staff as before, and two on slides, one on each of two sectors. Now, instead of sliding the transoms back and forth, the pinnule sights were moved up and down on their sectors to make the necessary angle adjustments. The angular height of the sun or star observation would be equal to the sum of the angles indicated on the two sectors.

The first refinement in the English quadrant came from France. Two years before the Englishman, John Hadley described the first quadrant, a Frenchman named Pierre Bouguer, professor of Hydrography at Croissic submitted a paper which fitted the two quadrant sights with convex lenses and a reflector which focused the star and horizon. These two refinements gave us first the quadrant, then the octant and finally the sextant. During the gradual evolution of the modern sextant, better and more suitable metals replaced the once useful wooden sections. This led to finer graduations on the arc of metal, and naturally, to greater accuracy in measuring angles. Also augmenting the accuracy of the instrument was the addition of the vernier adjustment.

From these modern instruments were derived the facts concerning latitude as we know it today. Latitude we know as the distance from the equator measured along a meridian and expressed in degrees (minutes and seconds).

In all these considerations the earth is regarded as a perfect sphere. As the exact form of the earth is more nearly a rotational ellipsoid, the degrees of latitude are slightly
The early English quadrant was a logical refinement of the back-staff and the forerunner of the modern sextant.
smaller near the equator, 68.7 miles, and larger near the poles, 69.2 miles.

There are six methods of determining latitude. (1) The Circumpolar makes use of the polestar located directly, or nearly directly over the pole. A direct observation of it reveals the latitude. (2) The Meridian Altitude or Zenith Distance of a Body of Known Declination, this method utilizes tables to assume any celestial body as a polestar. (3) By Circum-meridian Altitudes, here the time must be known to utilize the time of meridian passage. (4) The Zenith Telescope Method makes use of a pair of stars, one north of the zenith and one south. (5) By the Prime Vertical Instrument, a known star is observed on the eastern and then western side of the prime vertical (6) By the Gnomon—a simple vertical shaft and its telltale shadow.

The measurement of latitude came early and easily to man, but the story of longitude which follows next taxed the genius and technology of man to the utmost. The problem involved the intricacies of time and its mechanisms.
Chapter III

Longitude

The geographers of the fifth and fourth centuries B.C. were concerned with both latitude and longitude. To them, latitude and longitude were real, definitive entities, but their actual solution of measurement came much later.

The term "longitude" like "latitude" came from these early geographers who taught that the ecumene was more or less oblong in shape, twice as long from east to west as from north to south. Our terms are derived from this conception.

Hipparchus and Ptolemy realized the need for locating each place on earth scientifically according to its latitude and longitude. Hipparchus had worked out the difference between a solar day and sidereal day (the interval between two successive returns of a fixed star to the meridian), and had plotted a list of 44 stars scattered across the sky at intervals of right ascension equal to exactly one hour, so that one or more of them would be on the meridian at the beginning of every sidereal hour. He had gone a step further and adopted a meridian line through Rhodes, suggesting that longitude of other places could be determined with reference to his prime meridian by the simultaneous observation of the moon's eclipses. Hipparchus's suggestion for the establishment of a prime meridian was an important step in the solution of longitude. His selection of the meridian that passed through Rhodes was the first of many.
In the past, numerous prime meridians have been used in cartographic work which has led to much confusion. Ptolemy used the legendary Fortunate Islands, which may be the Canary Islands as we know them today. They were the western limit of the then known world. As the explorers moved further west so did the selection of the Prime Meridian. Dutch and English cartographers of the seventeenth century used either the Azores or the Cape Verde Islands as Prime Meridians. In 1498 the Pope established a line of demarcation which cut Brazil in half. This was done to decide the conflicting claims of the Spanish and Portuguese Empires in the new world. The king of France ordered his cartographer to use Ferro, the westernmost island of the Canaries for his prime meridian; this was supposed to be just 20 degrees west of the Paris Observatory, but in reality is one minute less. As the major nations grew in wealth, each stressed their respective capital as being ideal for the prime meridian. London, Lisbon, Madrid, Paris and even Philadelphia and Washington were used as prime meridians. The British Admiralty reckoned longitudes from the Greenwich Observatory in London because England was the home of the marine chronometer and a possessor of a great merchant fleet. At present the Greenwich meridian is accepted by all nations.

It was necessity that prodded the scientists, geographers and navigators to seek an early solution to the problem of longitude. The countries of the thirteenth century entered into a period of maritime exploration. This meant the acquisi-
tion of distant colonies and the increase of maritime commerce, and commerce that flourished as it stripped the newly acquired possessions of their native wealth. Much of this wealth was lost on ships that failed to make port; failed because they lacked an accurate means of locating themselves. Latitude was calculated fairly accurately, but longitude depended on reckoning the way of the ship, which on long voyages was unsatisfactory. Any information concerning the determining of longitude of the times was far from the reach of the practical geographer or navigator. Pigafetta who sailed with Magellan, said that the great explorer spent many hours studying the problem of longitude, "but", he wrote, "the pilots content themselves with the knowledge of the latitude, and are so proud, they will not hear speak of the longitude".

A great conflict arose in 1493, less than two months after Columbus returned to Spain, between the two foremost maritime nations of that time—Spain and Portugal. A Bull of Demarcation was issued by Pope Alexander VI, the Holy See at Rome. This Bull established a line of longitude on a chart of the Western Ocean one hundred leagues from the Azores. Here again was another necessity for the solution for determining longitude.

Governments realizing the great importance for a means of measuring longitude dug down into their coffers to make the problem more attractive. In 1598, Philip III of Spain offered a perpetual pension of 6000 ducats, together with a life pension of 2000 ducats and an additional gratuity of 1000 more to
the "discoverer of longitude". Portugal and Venice posted rewards, and drew the same motley array of talent, and the same results as Spain. Holland offered a prize of 30,000 scude to the inventor of a reliable method of finding longitude at sea.

In 1636, Galileo made an attempt to reap the reward of 30,000 scude offered by Holland. With the aid of his telescope he had discovered what might be a remarkable celestial time-keeper-Jupiter. He recognized the true relationship between the terrestrial sphere and the celestial sphere. The relationship was one of time-solar time and sidereal time. For two years he continuously observed, through his telescope, the movements of selected celestial bodies. He had drawn up tables, plotting the positions of the satellites at various positions at night. These, he found, could be drawn up several months in advance and used to determine mean time at two different places at once. This method, too advanced for the times, was ignored by scientists and governments alike.

Scientific as well as modern cartography dates from the longitudes measurements of the French Academy about 1680. About 80 longitudes were accurately measured by simultaneous observations of the accumulations of the satellites of Jupiter, as chronometers were not yet available. The results of these measurements were laid down on a polar map, covering the floor of the Paris Observatory, by Jean Cassini. French cartographers of the 18th century excelled in fine, accurate work, critical, scientific attitude, and less inclination for decoration. Some
of the outstanding men of the period were Guillaume Delisle, Jean Baptiste Bourgerignon d'Anville, Gilbs and Didier Robert de Vaugondy.

In the two thousand year search for a solution of the longitude problem it was never a foregone conclusion that the key lay in the transportation of timekeepers. In addition to discovering Jupiter's satellites, Galileo made a second important contribution to the solution of longitude by his studies of the pendulum and its behavior, for the application of the mechanism of a clock was the first step towards the development of an accurate timekeeper.

The pendulum clock was developed by Christian Huygens, Dutch Physicist and astronomer, the son of Constantine Huygens. He built the first one in 1656 in order to increase the accuracy of his astronomical observations, and later presented it to the States General of Holland on the 16th of June, 1657. The following year he published a full description of the principles involved in the mechanism of his timekeeper and the physical laws governing the pendulum.

It was the resident members of the Académie Royale des Sciences in France who solved mechanical and physical problems connected with the pendulum and the effect of gravity on it. The Académie had been established by one Jean Baptiste Colbert in 1666, with the good wishes of Louis XIV. It was founded to correct and improve maps and sailing charts to aid France in its growth as a maritime nation. The members realized the solution
of the major problems of chronology, geography and navigation, whose practical importance was incontestable, lay in the further study and application of astronomy.

The Académie under the able direction of Jean Dominque Cassini made great contributions to the science of cartography. Their remeasurement in 1676 of the diameter of the earth resulted in a value of 7801 miles, a remarkable close result. He organized expeditions bearing two time-keepers, one for mean time and one for sidereal or star time. These expeditions went to distant lands to record the longitude. One of the longest and most difficult expeditions sailed to the island of Gorée and the West Indies.

It was England, the growing monarch of the Seven Seas, who saw the increasing importance of discovering "longitude". Parliament passed a bill (1714) "for providing a public reward for such person or persons as shall discover the Longitude". It was the largest reward ever offered:

- £10,000 for any device that would determine longitude within 1 degree.
- £15,000 for any device that would determine the longitude with 40 minutes.
- £20,000 for any device that would determine the longitude within 30 minutes (2 minutes of time or 34 miles).

The solution to determine longitude was discovered by a ticking machine in a box, the invention of an uneducated Yorkshire carpenter named John Harrison. The device was the marine chronometer. John Harrison had many obstacles to overcome in
creating his precision timekeeper. One of the biggest hurdles
he cleared, but the envy and intrigue that he encountered with
the government officials was heartbreaking, but finally, with
the aid of the king himself, he was given the reward.

With the creation of the chronometer came the solution to
the problem of determining longitude accurately. A solution
that gave us longitude as we know it today. The longitude of
a place on the earth, as defined today, is the angle at the
pole between the meridian of Greenwich (Prime Meridian) and
the meridian passing through the observer's position; or it is
the arc of the equator intercepted between these meridians; or,
since this arc is measured by the time required for the earth
to turn sufficiently to bring the second meridian into the same
position held by the first, it is simply the difference of their
local times, usually reckoned in hours, minutes and seconds in-
stead of degrees. Since it is easy for the observer to find
his own local time by the methods which have been given, the
problem is really this: being at any place, find the corres-
ponding local time at Greenwich without going there.

There are three principal methods of determining longi-
tude. (1) Finding Longitude by Means of Signals Simultaneous-
ly Observable at the Places between which the Differences of
Longitude is Found. This method makes use of an Lunar Eclipse
or Eclipses of the satellites of Jupiter. The value of the
latter is in its more frequent occurrence. In both cases the
times at Greenwich and the observers position is simultaneously noted. (2) Finding Longitude by Regarding the Moon. A position is predicted for every hour of every Greenwich day three years in advance in the Nautical Almanac. The Almanac position is at the center of the earth, so the observation must be corrected for parallax. (3) Finding Longitude by Mechanical Methods. By the chronometer which itself must be corrected for local time and instrument error of rate and run. Another means—mechanical—is by telegraphy. Signals are sent at specified times from one station to another with the use of the chronograph which records and helps to coordinate the signals.
Chapter IV

Projections

Although the primitive peoples lacked any definite knowledge concerning the shape of the earth, latitude or longitude, they were able to draw maps of large areas in a simple vertical projection without any difficulty. The Eskimos, the Indians and the nomads of Asia and Africa, and the South Sea Islanders were and are excellent map makers. The oldest maps which have survived through the centuries were made by the ancient Babylonians, but records also indicate that the Egyptians, Persians and Phoenicians made maps, few of which have survived.

As revealed in the previous chapters, it was the early Greeks who established cartography as a science. In the 5th and 6th centuries B.C. the cartographers projected the earth in the form of a disc. Geographers of the 4th century B.C. depicted the oblong shaped world, hence our expressions of latitude and longitude. Gradually, about that time, emerged the concept of a spherical shaped earth. The 3rd century B.C. found Eratosthenes measuring the obliquity of the earth's ecliptic and describing the earth as a sphere revolving on its own axis. The measurement of the earth's circumference he computed to be 28,000 miles, an error less than 14 per cent. This measurement was accepted by Ptolemy and influenced Paolo dal Pozza Toscanelli and Columbus. About this time Eratosthenes constructed a map showing certain principal parallels and meridians dividing the
circle into 360 degrees, which is as we know it today.

Hipparchus, a mathematician and the founder of scientific astronomy, (160-120 B.C.), made great progress in the field of mathematical cartography. Such progress resulted from his invention of trigonometry and creation of the stereographic and orthographic projections. He used astronomic means to mark the position of places on the earth's surface. Here was one of the first solutions for the projection of the earth's curved surface on to a plane.

The only Greek map which survived was an atlas of Ptolemy who lived about 150 A.D. Much of his material was based on the Phoenician, Marinus of Tyre. This atlas consisted of 27 detailed maps of the Greek Empire and a map of the then known world. Until the 18th century his atlas had an immense influence upon cartography when some of his mistakes were discovered.

Claudius Ptolemy disagreed with Marinus' method of using straight lines equidistant from one another for both his parallels of latitude and meridians of longitude. He proposed a compromise which plan or projections would retain a semblance of the earth's spherical proportions on a flat map. The meridians he wanted drawn as straight lines equidistant at the equator and converging at a common point at either pole. The parallels of latitude, however, would be arcs of circles having a common center at the pole. He insisted that the Island of Rhodes be the Prime Meridian because so many distances had been determined in relation to it that it had become a standard
This was one of the first simple conic projections and Ptolemy realized its faults. He next proceeded to develop a plan for a modified spherical projection which was a momentous step forward for the science of cartography. It was a mathematical plan of a sphere projected onto a plane, subsequently known as an "orthographic projection". The results and process of this projection were revealed in his work, *Analemma*. Another work of Ptolemy's, *Planesphaerium* described a projection in which the eye, being at the pole, projected a sphere on the equator. This was the view which became the forerunner of the "stereographic projection".

The contributions of the Roman civilization to cartography were negligible. They chose a more pragmatic approach rather than scientific in their development of maps. In construction and application it was a simple map, and was used primarily for administrative and military purposes. Most of their projections or graticules were based on the disk-shaped earth of the early Greeks, and their official atlas, the *Orbis Terrarum*, became the standard map of the civilized world for 13 centuries.

It was the Roman *Orbis Terrarum* that established the crude map making of the Middle Ages, consequently little or no progress was made in the field of cartography. The task of advancing the science of cartography was left to the Arabs. For their schools they created atlases of a highly diagramatic nature. The measurements of the earth they recalculated with
much greater accuracy. As leaders in the field of astronomy they compiled new tables of latitude and longitude which aided the navigators and scientists of the time.

About 1300 the Portolan Charts were created and perfected. These charts lacked parallels and meridians, and apparently were laid down without any particular projection in mind. They were laid down against a background of wind roses connected by intersecting rhumb lines, which formed a basic grid on which the copyist could work and along which the navigator could approximate his course. The eight principal winds and rhumb lines were drawn in black, the half-winds in green and the quarter-winds in red. A marked similarity between the outline of these charts and the Mercator chart has been pointed out.

The introduction of the compass and improved sailing vessels made possible the voyages of Columbus, Magellan and others. The great discoveries of these explorers caused the major maritime nations of Europe to think in terms of New World expansion. This thriving era of expansion caused a greater demand for more and better charts and maps.

Another discovery which did much to advance the science of map-making was the invention of printing and engraving. Hitherto, maps were manuscript and reproduced by hand. This new invention reduced the cost of printing maps and charts, and the flow of new data and information was facilitated. About the end of the 15th century woodcuts were common, but gradually copper engraving became the generally used method.
During the year 1410 the works of Claudius Ptolemy were translated into Latin, and the rediscovery of his cartographic fundamentals again became important. The map creations of Ptolemy survived chiefly through the exacting work of the scholars of Arabia. So great was the authority of Ptolemy that Waldseemüller replaced the good outline of the Mediterranean of the Portalan charts with the inferior outline of Ptolemy. On the other hand, many of his atlases and maps were the prototypes of modern map-making. The legends and conventional signs which he originated are still with us in modified forms. The practice of orienting a map with the north pole at the top and the east to the right started with Ptolemy. The listing of place names accompanied by their latitude and longitude reading was first with him also.

Martin Waldseemüller, a famous cartographer of the early sixteenth century, prepared the first map clearly separating North and South America. It was a huge map (4½ by 8 feet) displaying the detailed workmanship of the Renaissance. Its interesting feature was the projection on which it was constructed. It was a new one and it resembled the Bonne projection which will be discussed later on in this chapter.

The mariners of the late sixteenth century needed and demanded better charts. A chart maker of Antwerp, Michiel Coignet, stated the chief problem when he pointed out in 1581, that under existing conditions and with the map projections then available, there was no sense in laying off a course on a chart according
to the compass direction as it appeared on the chart. The problem was finally solved by Gerardus Mercator.

Mercator, called the father of Dutch cartography, had studied under Gemma Frisius, the noted cosmographer. Although Mercator was chiefly a maker of globes and instruments, he soon took up map-making. He understood the problem as Coignet stated it, and settled down to provide a chart that would show the navigator true direction and true distance in relation to the established longitude and latitude of the chart. The result of his work was a system of horizontal parallels and vertical meridians where the relation between the two is true on any part of the chart. Because the lines of compass directions appear straight, it was well adapted for navigation. The ship’s course or rhumb line, in reality a curved line, became a straight one on Mercator’s chart.

The Bonne projection for map construction was designed by Rigobert Bonne (1727-1795), a French cartographer. It has a straight central meridian which is crossed by a circular standard parallel. The central meridian is divided truly, and all parallels are concentric with the standard one. Every small quadrangle in the Bonne projection has both base and height true to scale and, therefore, the system is equal-area.

The eighteenth century ushered in the new concept of nationalism and the modern era of cartography. This new spirit of national consciousness manifested itself in the field of cartography with a demand for national surveys and maps of
greater accuracy. Maps were no longer decorated with monsters, elephants, lions and swash lines; a cartouche about the title was the only decoration. This was the Age of Reason, and its spirit appeared on maps, too. The new cartography was based on new instruments. The old cross-staff and back-staff were replaced by the octant and the sextant. Navigators no longer feared the higher mathematics in determining longitude with Harrison's chronometer on hand.

Cartography became the exact science with the introduction of accurate longitude measurements by the French Academy at the end of the seventeenth century. These longitudes were measured by simultaneous observations of the occultations of Jupiter's satellites at various places all over the world. The result was a new map of the world, which was laid out by Jean D. Cassini on the floor of the Paris Observatory in 1682—-one of the fundamental maps of history.

Triangulation perfected by the Dutchman, William Blaeu, came into importance in 1750 when country after country began detailed topographic surveys. A systematic survey consisted of several steps. First, a number of points are astronomically determined. Then a base line is measured for triangulation. This is a straight line of 10 to 20 miles in length, from the two ends of which other points are obtained by intersection. Further points are similarly determined by a system of triangles. Cesar F. Cassini in 1744 conducted the first triangulation of France which produced the first accurate map of France. It was
finished in 1779, and was composed of 182 sheets on the scale of 11
1:86,400.

The nineteenth century, the period of the industrial revolution, saw tremendous strides made in the field of cartography. It was the development of lithography, wax engraving, photogravure, and color printing that profoundly affected cartography. Maps became cheaper and more abundant than ever. Near the end of the nineteenth century, cartography received a new stimulus from the introduction of airplane photography. This eliminated the costly and laborious triangulation, and made possible the mapping of heretofore inaccessible places.

The projection as defined by most cartographers today is any orderly network of parallels and meridians upon which a map can be drawn. In its general sense, the term projection signifies the representation of the form of a given figure upon a given surface by means of a pencil of visual light, or other rays in such a manner that the figure in the projection corresponds point by point to the given figure.

The spherical surface of a globe cannot be flattened into a map without stretching or tearing. If only a small part of the Earth's surface is shown, as on large-scale maps, distortion is negligible, but on medium-scale maps, and especially small-scale maps of the whole Earth, considerable distortion is necessary.

Several geometrical methods were tried. If the globe is enveloped into a cylinder and the surface is projected upon
Cylindrical Projection

Conical Projection

Azimuthal Projection
this surface and then the cylinder is cut open and laid flat, we have a cylindrical projection. Similarly, if we cap the globe with a conical hat, project upon the cone, split open the cone along one of its elements and lay it out flat, we have a conical projection. Also, if the surface of the globe is projected upon a tangent board from some eye point at a selected distance, we have an azimuthal projection.

As the problem of flattening spherical surfaces is impossible, there can be no perfect projection. We can choose from dozens of imperfect solutions the one which is most suitable for our particular purpose.
Conclusions

The growth of cartography as a science is indebted to a few individuals. They were usually men of great persistence and intellect who had to overcome the superstitions and fallacies that accompanied all the learning of the times. The instruments that existed were crude and inaccurate. If they desired a particular tool or instrument, they had to create it. The ideas and principles that resulted from their efforts could not be ignored, because those were the trials and errors that go to make up the scientific process itself. It was far better to have believed the earth disc-shaped than not to have thought about it at all.

The terms "latitude" and "longitude" are hangovers from the period of Claudius Ptolemy when the earth was believed to be oblong in shape. Now that we know the earth to be--for most purposespherical, maybe new terms are in order. So much confusion arises when authors use the terms "latitude" and "parallels" interchangeably, and likewise "longitude" and "meridian". Some readily speak of "parallels of longitude" and "parallels of latitude". Especially is this confusion noted when the teacher attempts to convey the concepts of latitude and longitude to the student. Probably any new terms would make the understanding of these concepts easier.

The field of cartography has produced a definitive science. The purpose of cartography is to collect and analyze data and
measurements of the various patterns of the earth and to repre-
sent them graphically on such a reduced scale that the elements
of this pattern can be made clearly visible—Kaiser. Although
it touches on such varied studies as history, mathematics and
art, it stands alone, without infringing upon the other branches
of geographical science.
In tracing the growth of cartography the science, four basic elements were selected to assemble and organize the data collected. Those elements were: the shape of the earth, latitude, longitude and the projection.

The earth, its shape and dimensions were described in early Greek Mythology. Then, it was believed to be an inverted disc supported by a series of pillars in the care of Atlas. About 523 B.C. Pythagoras pointed out to the scientific world that the earth was spherical in shape. It was left to Aristotle in 370 B.C. to prove that the earth was truly a sphere. Eratosthenes, the keeper of the famous library at Alexandria, Egypt, made a serious attempt to determine the earth's circumference. His result was stated to have been remarkably accurate, but unfortunately it was not accepted by later geographers.

Hipparchus who in 140 B.C. advanced mathematical cartography with his discovery of scientific astronomy and trigonometry. The work of Strabo who set the pattern for geographers appeared in Ptolemy's Geographia—the sum of all geographic learning. The gnomon and its telltale shadow revealed the equatorial line to the astronomers and geographers of the day. From these the Tropic of Cancer and the Tropic of Capricorn were next calculated. The compass combined the ancient wind rose and a magnetized needle. This led to world wide exploration and
the discovery that the world was a sphere. In 1736 Pierre Bouguer proved independently that the earth had the form of an oblate sphere with a considerable flattening at either pole.

Such is the true shape of the earth with its longest diameter 7,926.6 miles and its shortest 7,899.6 miles as geographers accept it today.

The discovery of latitude followed closely that of the equinoxes and Tropics of Cancer and Capricorn. Because the ecumene was believed to be more or less oblong in shape, twice as long from east to west as from north to south, the terms "latitude" and "longitude" were derived. These terms were coined by Ptolemy. Instruments for measuring angles and determining latitude consisted of the gnomon and the astrolabe. Both were crude and inaccurate, but they were advances. To supplement these instruments the sixteenth century saw the compilation of tables which predicted the positions of various satellites. The quadrant, octant and sextant that developed throughout the following centuries were merely improvements on the ancient astrolabe and gnomon. Close on the heels of the astrolabe was the discovery of the cross-staff and the backstaff, also forebears of the modern sextant.

The refinement of the English sextant produced the means for determining accurately the latitude of any point on the earth's surface. Latitude is the distance from the equator measured along a meridian and expressed in degrees, (minutes and seconds). As the exact form of the earth is more nearly a rotational
ellipsoid, the degrees of latitude are slightly smaller near the equator, 58.7 miles, and larger near the poles, 69.2 miles.

The solution to the problem of determining longitude proved more difficult than that of latitude. The difficulty centered about the understanding and measurement of time. Hipparchus started the solution with the discovery that there was a solar day and a sidereal day (the interval between two successive returns of a fixed star to the meridian). He further plotted the positions of 44 stars so that one or more of them would be on the meridian at the beginning of every sidereal hour. He also planned that the meridian line through Rhodes be the starting point, or the Prime Meridian. The Prime Meridian has varied from Rhodes to Philadelphia with a final resting place at Greenwich, England.

The nations of the thirteenth century bent on exploiting their overseas colonies, offered huge rewards for a solution to longitude. Their ships with valuable cargoes were being lost, and the Pope at Rome had established a line of demarcation which caused much confusion.

Galileo in 1636 recognized the true time relationship between the terrestrial sphere and the celestial sphere. He had drawn up tables plotting the positions of the various satellites in an effort to determine the mean time. His second important contribution to the problem of longitude was his study of the pendulum.

In 1656, with aid of the pendulum, Christian Huygens, a
Dutch physicist and astronomer built the first timekeeper. This he made to increase the accuracy of his astronomical observations.

The Académie des Sciences of France founded by Jean Baptiste Colbert in 1666 did much to solve mechanical and physical problems connected to the pendulum and gravity. Under the able direction of Jean Dominique, made great contributions to the science of cartography. The diameter of the earth they computed to be 7,801 miles.

The solution to longitude was discovered by an invention of John Harrison of England. It was the first marine chronometer. After overcoming the envy and intrigue that he encountered with government officials, he received the generous reward that England had offered for the solution to longitude.

In the projection as we know it, is incorporated the shape of the earth, latitude and longitude. The graticle or grid of the projection was described by Eratosthanes in the third century, B.C. His measurement of the earth’s circumference had an error less than 14%. He constructed a map showing certain principal parallels and meridians dividing the circle into 360 degrees.

Hipparchus about 140 B.C. gave much to the field of mathematical cartography, and he devised the stereographic and orthographic projections for maps.

A plan for a modified spherical projection was recorded in Ptolemy's Analemma. This was a gnomonic projection subsequently
known as an orthographic projection. His *Planesphaerium* presented the stereographic projection.

The great civilization of Rome contributed the *Orbis Terrarum* to the science of cartography. Most of these projections were based on a disc-shaped earth of the early Greeks and did little to advance cartography.

With the introduction of the compass and the invention of printing and engraving, map making made great strides. The need for marine charts was met by Gerard Mercator in the late sixteenth century. He developed the Mercator projection which gave the navigator true direction as related to his given lines of latitude and longitude.

The seventeenth and eighteenth centuries saw the Dutch, French and English making great strides in the science of cartography. Topographical charts became important.

Modern cartographers realized that the spherical surface of a globe cannot be flattened onto a plane without stretching or tearing. Because of this distortion three basic geometrical projections were developed each to have its particular advantages and disadvantages. The three being: the cylindrical projection, the conical projection and the azimuthal projection.
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