The Origin and Development of Cartography

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Cartography, the science of drawing maps and charts, is inextricably bound up with our knowledge of the configuration and surface features of the earth. Its origin may therefore be traced to the very dawn of history, when man first started moving from one place to another and tried to record what he had seen on his travels in some more or less permanent pictorial form. Some writers seem to think that man's ability to draw maps antedates his efforts to read and to write. They point to the fact that primitive peoples in all parts of the world are generally able to produce some kind of topographical representation, however crude, of the places with which they are familiar. The Eskimoes of Eastern Greenland, for instance, often use wooden models to show the relative positions of the coastline and neighbouring islands and are known to have prepared a map of an archipelago in Hudson Bay over 100 miles in length, which agrees remarkably well with the present day British Admiralty chart of the same area. In 1908 Haddon, in the course of a scientific edition to the Torres Straits, between Queensland and New Guinea, found that the inhabitants of Mer used a number of stones to indicate the relative positions of various islands in the vicinity. And of course, the primitive cartographical efforts of some nomad races in drawing on the ground or in the sand such details of topography as are of immediate interest are well known. Perhaps the most striking example of crude map making can be seen in the sailing charts made by the Marshall Islanders. These charts consist of a number of shells attached to a framework made of the midribs of palm leaves. It is thought that the straight parts of the framework represent the open sea, the curved lines the position of the wave front, and the shells the individual islands. Although more than forty examples of these charts are extant, none is drawn even approximately correct to scale, and so the fact that they were sometimes used for voyages of nearly 600 miles probably indicates that greater tribute is due to the Marshall Islanders' navigation than to their cartographic skill.

One of the oldest known maps is a clay tablet about three inches square found in the excavations of the ancient city of Ga Sur, about 200 miles north of Babylon. It shows a river flowing between two ranges of hills through a delta into a sea or a lake. At the top and at the sides are minute characters inscribed within small circles to indicate the cardinal points of the compass. The whole tablet is still in a remarkably good state of preservation considering that it is about 4,300 years old. From this and many other similar tablets housed in the British Museum, it has been possible to obtain some idea of the cartographic knowledge possessed by the early Babylonians. In some respects, their ideas were crude. For instance, their conception of the universe was that of a *disc-shaped earth floating in a vast ocean, with the vault of heaven arching above it, and the firmament over all*. On the other hand, certain Greek and Roman writers have explicitly stated that the Chaldeans were able to determine the dimensions of the earth, a statement which, if true, could hardly have failed to attract the attention of their neighbours, the Babylonians.

By contrast with the relatively large number of clay tablet maps which have survived from Babylonian days, there are few records of maps of any kind in existence today from which a reasonably clear picture of the geographical and cosmological ideas of the ancient Egyptians can be formed. Sir Gaston Maspero, by piecing together what meagre information he could get from various monuments and papyri, came to the conclusion that the early Egyptians envisaged the universe as a kind of four posted bed. The whole earth with Egypt at the centre occupied the base, while around the sides and ends were lofty ranges of mountains which supported at each corner a sky cover thought to be made of iron. What gave rise to this strange conception is now obscure. It may have resulted from an observation of the fall of a meteorite because it is significant that the Egyptian name for iron is Bia-n-pet or metal of heaven.

Now although the Egyptians, Chaldeans and Babylonians were isolated peoples, who developed independently of each other largely because of their aversion to the sea, they probably had a common influence on the Greeks, through the Phoenicians who acted as intermediaries in passing the arts of civilisation from one country to another. In spite of this, they seem to have passed on very little knowledge of a geographical character, probably because of the jealousy with which they naturally regarded information about their trading activities. So that whatever influence the Egyptians and Babylonians exerted on the geographical conceptions of the Greeks arose from tradition and various myths associated with religion.

One of the commonest of such myths was the fiction of a river Oceanus which flowed around the world and was the source of all smaller rivers. Hesiod, for example, in his Theogony gave a list of rivers which he regarded as being the offspring of Oceanus - a list which included the Nile, the Eridanus (the river Po), the Phasis (a river of mythical celebrity, but in fact an insignificant river in the Caucasus flowing into the Black Sea) and the Ister (Danube), while Homer conceived the earth as being a plane of circular shape surrounded by a river-ocean which he regarded as a vast continuous stream for ever flowing around the earth.

Another myth concerned the nature of the sky. As mentioned previously, the ancient Egyptians thought that the sky was made of iron - a concept which was probably transmitted to the Greeks in the course of time, for Homer speaks quite clearly of the vault of heaven as being *brazen* or *of iron* and he then supposing it to be in need of some material form of support refers in the Odyssey to *the wizard Atlas, who knows the depths of every sea, and himself upholds the tall pillars which keep earth and sky asunder*.

It was not until the latter half of the seventh century BC that these mythological concepts about the earth gradually disappeared and gave place to knowledge of a scientific character. Thales of Miletus (640-550BC), one of the seven wise men of Greece, is regarded as the first person to have suggested a scientific explanation of the universe. According to Herodotus, he correctly predicted an eclipse of the sun which occurred in 585BC, and later authorities credit him with the correct explanation of both lunar and solar eclipses. Unfortunately, he left nothing in writing and so we have to rely on later historians for an appraisal of the extent of his scientific knowledge. For instance, it is often claimed that he was the first to discover the spherical form of the earth, but as the source of this information is Plutarch who used the expression *Thales, Pythagoras and his disciples . . .*, it is not clear to whom the credit really belongs. An equally vague expression was used by Aristotle who attributed the discovery to *the Pythagoreans*. More important to us today than the name of the discoverer is the method by which the result was deduced. In the first instance, it appears to have been little more than an arbitrary assumption based upon the belief that a sphere was naturally the most perfect of all forms. Subsequently it became one of the fundamental doctrines of the Pythagorean school of philosophy and finally it found general acceptance when Aristotle advanced several arguments for it. He argued first that a sphere was the natural result of matter gravitating towards a centre and since observation showed that matter did gravitate towards the centre, the earth was spherical. Secondly, he argued, that during an eclipse of the moon the shadow of the earth appeared to be circular. While these were cogent arguments, less convincing was his deduction that since one of the heavenly bodies, namely the moon, was spherical, all others would be also. But against this, a further deduction that the distance of the stars was very much greater than the dimensions of the earth has since proved to be remarkably accurate. A third argument in favour of a spherical earth, based upon the disappearance of an object moving out to sea, was not given until Strabo (circa 63BC-19AD) in his Geography said *It is obviously the curvature of the sea that prevents sailors from seeing distant lights at an elevation equal to that of the eye….*

To the pupil and successor of Thales, Anaximander (610- 547BC) is given the credit for the first Greek map of the world. There is, unfortunately, no detailed description of the map itself but it was no doubt based on the Homeric conception of the disc-shaped form of the earth surrounded by the river-ocean - an idea which found favour even among the philosophers of the Ionic School. According to one writer, the map was drawn with Greece at the centre and it extended from the Caspian Sea to the Cassiterides. Very little else is known about it except that it must have been extremely crude, being based neither on reference lines nor on lines of latitude and longitude. It was probably a copy of this map engraved on a bronze tablet, which Aristogoras, tyrant of Miletus, produced when trying to persuade Cleomenes, King of the Spartans, to assist the Ionians in the revolt which they were planning against the Persians. Herodotus said that this map had engraved upon it *the circumference of the whole earth, the whole sea, and all the rivers*.

The next three centuries saw the further gradual disappearance of some of the poetic fictions and inaccurate philosophical concepts which had for so long militated against the advancement of knowledge of either a geographical or geodetic character among the early Greeks. Men of learning were no longer prepared either to accept the idea of a vast river-ocean for ever flowing around the world or to consider seriously the doctrines of the Epicurean School of Philosophy which wilfully denied the spherical form of the earth in the face of so much evidence to the contrary. They were in fact entering upon the dawn of true scientific knowledge, heralded by such revolutionary ideas as those of Aristarchus (circa 310-230BC) who not only believed that the earth rotated upon its axis but also that it revolved around the sun in a circular orbit.

Eratosthenes was born at Cyrene in the year 275BC. At the age of 35, he was invited by Ptolemy III, King of Egypt, to become the head of the great Library at Alexandria, an appointment which he filled with distinction until his death in 194BC. His claim to immortality rests largely upon the accomplishment of two great works, the first scientific determination of the dimensions of the earth and the consummation of what Strabo called his avowed object *to make a complete revision of the early geographical map* by basing it upon sound geographical principles. Although he produced a number of works, some of which were scientific and others purely literary, there is, unfortunately, no longer any complete record of his original treatise in three volumes on geography and most of the information about his work must be inferred from the generally adverse criticisms of Strabo.

The method which Eratosthenes adopted for determining the circumference of the earth was theoretically sound in principle and is in some respects the same as used today. He determined the arc of meridian between Alexandria and Syene (now called Aswan) as one fiftieth of the circumference of a circle and knowing that the distance between the two places was 5,000 stadia, he calculated at once the circumference of the earth as 250,000 stadia, to which he then arbitrarily added another 2,000 stadia to obtain a round figure of one degree equal to 700 stadia. This result was about 17% greater than the true value.

A recent analysis by Dr John Ball, a mathematician and surveyor, who spent 34 years of his life in the field and in the office on the maps of the Egyptian Survey, has shown that although there were numerous defects in Eratosthenes' work, they were for the most part of an insignificant character with the exception of the incorrect assumption that Alexandria and Syene were on the same meridian and a faulty estimate of the distance between the two towns. In fact, so serious were these two defects in comparison with the general standard of the rest of the work that a number of modern writers have concluded that Eratosthenes must have used a stadium of a length different from that generally supposed. Let us consider the evidence available today. Herodotus (Historia, Book II, ch.149) said that one stadium was equal to 100 Orgyiae, each of which was equal to six feet (Greek). Now the length of the Greek foot is known from the measurements of the Hecatompedon in the Parthenon at Athens, which was supposed to have been 225 Greek feet in length and 100 Greek feet in width. According to the measurements of Revett (circa 1750) and Penrose (1889), the mean length of a Greek foot is 1.01257 English feet. Converting the latter unit to International metres in accordance with the relation given in the Weights and Measures Act, 1922, we find that one stadium is equal to 185.18 metres. A check on this result may be obtained through the Roman units of measurement as follows. Strabo tells us (Geography, 7.7.4) that one stadium is equal to an eighth of a Roman mile which in turn was known to be equal to 5,000 Roman feet. Again, it has been found possible to determine the length of the Roman foot in terms of modern units of measurement as follows. In 1639 Greaves, who was then Gresham Professor of Geometry and who subsequently became Savilian Professor of Astronomy, went to Rome with the express purpose of ascertaining the length of the Roman foot. In the Vatican gardens he found a monument constructed in the first century AD by Statilius Aper which included in relief a Roman foot measure of a length which Greaves reported as containing *1,944 such parts as the English foot contains 2,000*. The result obtained from these values is that one stadium is equal to 185.17 metres, which agrees well with the previous one.

However, many learned writers on the subject have decided. otherwise. In 1822 Jomard came to the conclusion that Eratosthenes' final result could not have differed over much from the true value and that he must therefore have used a stadium equal to the seven-hundredth part of a degree or 158.3 metres, while Tannery, some seventy years later thought that he used an Egyptian stadium of 300 royal cubits or 157.5 metres, a result also accepted by Berthelot in 1932, who based his conclusion on the supposition that despite the round figure of 5,000 stadia used, it was not a rough estimate made by travellers but the official value given to Eratosthenes by the Egyptian surveyors. And Crone, the librarian and map curator of the Royal Geographical Society, in a book published two years ago, speaking about Eratosthenes' classical measurements. said : *The figure he arrived at for the circumference of the earth was 252,000 stadia, which, assuming he employed the short stadium was the equivalent of 24,662 miles, a result only some fifty miles short of the reality*.

These are weighty opinions arrived at in many cases after years of painstaking study of the subject. Nevertheless, a very significant fact seems to have been overlooked. If Eratosthenes had used a short stadium in measuring the distance between Alexandria and Syene, he would undoubtedly have used the same unit when making other measurements of the same kind. If these results are then consistently either bigger or smaller than the true values, then the case for the short stadium may be considered decisive. Let us examine the evidence. Strabo (Geography, Book XVII, Ch. I) gives us the following information : *And here too I must set forth the declarations of Eratosthenes. Now according to him the Nile…is similar in shape to the letter N reversed ; for after flowing, he says, from Meroe towards the north about 2,700 stadia, it turns back towards the south and the winter sunset about 3,700 stadia, and after almost reaching the same parallel as that of the region of Meroe . . . and making the second turn flows towards the north 5,300 stadia to the great cataract turning aside slightly towards the east and then 1,200 stadia to the smaller cataract at Syene and then 5,300 more to the sea*. All the salient points mentioned in this passage are easily identified today and the corresponding distances readily ascertained from the present records of the Survey of Egypt. These values in the same order as the above and using the relation 1 stadium equal to 185.17 metres, are 1,780, 1,700, 3,297, 1,883 and 6,503 stadia. Of these, the first three are considerably less and the remaining two considerably greater than Eratosthenes' values. In this case, therefore, the evidence gives no support whatever to the supposition of a short stadium and on balance it would appear that we must be content that Eratosthenes' value for the distance between Alexandria and Syene is no more than an estimate.

We proceed now to an examination of Eratosthenes' famous map of the world. In the first place, we notice that no attempt was made to show all the surface features of the earth but only those of the *oecumene*, or habitable portion of the earth, which at that time was thought to include only North Africa, Southern and Central Europe and Western Asia as far as India. The possibility of the existence of other lands was not excluded, but if so they were thought to be either too hot or too cold to support human life. The main reference line of the map was drawn from west to east roughly through the middle of the Mediterranean Sea. On this parallel he put the Sacred Promontory (Cape St. Vincent) which he erroneously regarded as the westernmost point of Europe, the Strait of the Columns (Gibraltar), the Strait of Sicily, Athens, the Island of Rhodes and the Gulf of Issus at the eastern end of the Mediterranean. He then continued this line through Asia along what he called the Taurus Mountains until it ran into the Northern Ocean, just north of the River Ganges in India. The whole length of the Mediterranean from the Straits of Gibraltar to the Gulf of Issus, he made equal to 26,500 stadia which is about 6,500 stadia more than the true value. This exaggeration of the length of the Mediterranean continued for close on 2,000 years, for as recently as 1668, Sanson published a map in which the length was nearly 30% greater than the true value. It is also of interest to note that the total length of his main reference line for the *oecumene* was given as 77,800 stadia compared with about 200,000 stadia for the whole circumference in this latitude, which led him to speculate about the possibility of circumnavigating the globe, with these words *…if the immensity of the Atlantic Sea did not prevent, we could sail from Iberia to India along one and the same parallel over the remainder of the circle….*

In addition to his main parallel of latitude, Eratosthenes also drew parallels through Thule (probably one of the Shetland Islands), Alexandria, Syene and Meroe while he regarded the southern, limit of the habitable world as passing through Ethiopia. For his central meridian he took the line passing through Meroe, Syene, Alexandria, Rhodes and Byzantium and he draw other meridians through the Sacred Promontory, the Straits of Gibraltar, Carthage, the mouth of the Persian Gulf and the delta of the Ganges River.

Generally speaking, his map gave a fairly accurate representation of the Mediterranean basin, with the exception of the coast of North Africa which was drawn in almost as a straight line. The worst feature of the map was his representation of the southern coast of Asia while the outline of India hardly bore any relationship at all to that shown on a modern map.

The main reason for the inaccuracies of maps such as that of Eratosthenes was of course the almost complete lack of trustworthy observations of latitude and longitude. It is true that the ancient Greeks had an instrument for determining the latitude, the scaphe or gnomon, which was capable of giving a fairly reliable result in the hands of one skilled in its use, but this unfortunately excluded the majority of travellers. Another method used for determining latitude was that based on an estimate of the length of the longest or shortest day at the place concerned. At best, this was only a rough method and the lack of a reliable instrument for measuring diurnal time made it wholly unsatisfactory. The determination of longitude was even more unsatisfactory. Hipparchus had suggested that observations of eclipses could be used for determining longitude, but here again the lack of an accurate measurement of time made his suggestion a purely academic one. In practice, longitude was generally determined by estimating distance and direction to a place from another whose position was known.

Although in a sense Strabo's treatise on Geography in seventeen volumes is the most important work on geography that has come to us from antiquity, it is also a most disappointing work. He himself tells us that during his lifetime (63BC-24AD) he travelled widely - from Armenia to the Tyrrhenian Sea and from the Euxine to Ethiopia - but in spite of this his actual knowledge of the places which he visited is in some cases very scanty. In other cases, he seems to have relied largely on the stories of travellers for his information. In addition, his mathematical knowledge was decidedly inferior to both that of Eratosthenes and Posidonius, so that he was obliged to take much of their work for granted. While he adopted Eratosthenes' value for the dimensions of the earth, he criticised him strongly in regard to the extent of the habitabilis. In his map he therefore reduced this to an area of 70,000 stadia by 30,000 stadia. There were also so many glaring mistakes in his work, that it seems today that the extent and accuracy of geographical knowledge actually diminished in his hands.

Of considerable interest are his instructions on how to draw a map. He said that in the first instance it could only be satisfactorily done by starting with a globe not less than ten feet in diameter, but then realizing that the means for making such a globe was not always readily available and moreover that the habitabilis was only a small portion of the globe, a representation on a plane surface would generally suffice. In this case, he thought that the map should be at least seven feet in length. He proposed drawing the meridians and parallels as a series of mutually perpendicular straight lines and although he realized that this would not allow him to represent adequately their intrinsic curvature, he dismissed the matter by saying that the error would *not make much difference*. Later on, he changed his opinion slightly by suggesting that the meridian lines might be drawn *a little inclined towards one another*, although he did not really think that it mattered very much. Such were the puerile efforts of Strabo in the field of map projections.

The climax of cartographical as distinct from geographical achievement among the Greeks was undoubtedly reached with the work of Claudius Ptolemaeus, who was born in Upper Egypt about the year 90AD and lived until 168AD. Ptolemy (to use his more familiar name) was more of a mathematician and astronomer than a geographer, his work in the latter field having been done mainly with the object of supplementing his astronomical work, known today as the Almagest. Originally, this work was called *The Mathematical Construction* but later it became known as the *Megiste Syntaxis* or great construction, after which it was completely lost to European culture. Fortunately, at least one copy of it reached Arabia, where it was translated into Arabic by Nairizi several centuries later. Later it was retranslated by Thait b. Qurra (died 813AD) one of the official translators appointed by Harun-al-Raschid to the Great Translation Bureau in Baghdad. Here Ptolemy's astronomical treatise was known as *Al-Majisti* which subsequently became *The Almagest*, when it was translated back to Greek in the fifteenth century.

Of more interest to us was the *Geographike Hyphegesis* or introduction to map making which was published about 150AD. Written in Greek, it consisted of twenty-seven maps and eight books of text of which the first volume consisted of mathematical geography and his theory of map projections, the next six a list containing the latitudes and longitudes of all places shown on his maps, as scaled from the maps themselves and the last a set of tables giving the calculated lengths of the longest day of the year at the more important places considered.

For his maps, he used two main projections which were similar to what would be called today the simple conical projection with one standard parallel, and Bonne's projection.

In his first projection, he assumed that the habitabilis extended from Thule (latitude 63° North) to a line as far south of the equator as Meroe lay to the north of it, namely 16° 25', while in the east-west direction it extended for 90° on either side of a meridian through Alexandria. He then chose 36°N as the latitude of his standard parallel which, like Eratosthenes, he assumed to pass through the Straits of Gibraltar, the Island of Rhodes and the *centre line* of the Mediterranean. On the map, he drew this parallel as an arc of a circle of radius equal to the length of the side of the tangent cone of length equal to the true value on the scale of the map. The remaining circles of parallel he drew in as arcs of concentric circles spaced at their true distances apart. He now divided his standard parallel true to scale, and connected the points of division to the apex of the developed cone by means of straight lines. The graticule south of the equator was, however, constructed in an odd manner. He divided the circle of parallel at the southern limit of his map exactly the same as he divided the parallel through Meroe and joined these points of division to the corresponding points on the equator, with the result that all the meridians with the exception of the central meridian, were bent sharply as they crossed the equator. It was a crude projection but nevertheless it conformed strictly to the modern definition of a map projection.

For his second projection he became far more ambitious. He imagined an observer looking vertically down over a point situated at the intersection of the northern tropic and the meridian through Alexandria. On the map he drew a straight line through this point and marked off on it distances east and west, corresponding to angular distances of 90° on the globe. Southwards from the same point he marked off a length to correspond to an angular distance of 23° 50' on the globe, which was supposed to be the obliquity of the ecliptic. Through the three points thus obtained, he drew a circular arc to represent the equator. (This construction may easily be shown to be equivalent to the drawing of a standard parallel in latitude 19° 26'.) The remaining circles of parallel he then drew in as concentric circles spaced at their true distances apart. Each circle of parallel was then divided true to scale and the corresponding points of division connected by smooth circular curves. This was undoubtedly how Ptolemy intended his projection to be constructed, but owing to an unfortunate mistake, he plotted the centre of the circles of parallel from the southern limit of the habitabilis instead of from the equator, thus completely destroying its value as a map projection. Unfortunately, too, he used a value for the radius of the earth corresponding to 1° equal to 500 stadia as determined by Posidonius. Had he used a value of 1° equal to 600 stadia, the mean of Posidonius' and Eratosthenes' values, his projection would have been practically correct. Of course, we cannot blame Ptolemy for this mistake; we simply note that the scale of his map is far from what it was intended to be.

As far as the detail on his map was concerned, he plotted the positions of those places whose geographical coordinates he knew and the positions of all other places by measuring off the distances from points already known, making whatever adjustments he considered necessary. Finally, to guard against the loss of his maps, he scaled off the positions of about eight thousand places and tabulated the results in the form of an index.

In the above brief survey of the origin of map making, we have seen how the Ancient Greeks were responsible for lifting cartography above the illusions of superstition and mythology to the status and dignity of a science. They had determined the shape and dimensions of the earth, devised methods for finding geographical positions, invented a number of map projections and applied their knowledge to the construction of maps of the world. It might be expected, therefore, that their successors, the Romans, would in turn have developed it still further. While it is true that there was almost incessant warfare from the founding of Rome in 753BC to the death of Julius Caesar in 44BC, the advent of Augustus, the first Roman emperor ushered in an era of peace, order and good government. And while the Romans were consolidating their empire and disseminating their civilization, they had every opportunity for studying the geography of their colonies which now extended from Syria to Spain and from Cyrenaica to Germany. Moreover, the aim of a complete statistical survey prior to the imposition of a universal tax, should have at least provided the incentive for the construction of an accurate map of the whole empire. But in spite of this there is no evidence of a single Roman writer of note emerging to extend the frontiers of cartographical knowledge. Although Pliny dealt with the subject of geography in his 37 volume work on Natural History he did little more than edit the work of others often without a real understanding of the meaning of the original author. Where he ventured to make his own contribution, he was often ridiculously far from the truth, as for instance where he said that he knew that some peaks in the Alps rise to a height of not less than 50 miles.

On the practical side, the only noteworthy map was produced by M. Vipsanius Agrippa, friend and counsellor of Augustus, whom Pliny referred to as *a very painstaking man and also a very careful geographer*. Little is known about this map except that it was probably extremely crude, and that it was placed in the portico of Octavia in Rome for the information of the local inhabitants. From all accounts it appears that it was drawn in the form of a circular disc within which was placed the *Orbis Terrarum*. Asia occupied the upper half of the circle and was separated from Europe and Africa in the lower half by the Nile on the right and the river Don to the Black Sea on the left. The Mediterranean divided the two lower land masses, and together with the waterways mentioned, appeared to form a letter T inscribed within the whole circuit of the world represented by the letter 0. This map was the forerunner of the famous T-O maps which dominated mediaeval cartography from the fourth century and for nearly a thousand years afterwards, during which time map making became subservient to the religious dogmas of that period.

Such maps were adapted to conform to the idea of that divine simplicity and perfection which permeated mediaeval religious concepts until in their extreme form, it appeared that the Latin monogram had become incorporated within the Orbis Terrarum itself, while the Holy City was situated in the very centre in accordance with a text in the Book of Ezekiel : *This is Jerusalem : I have set it in the midst of the nations and countries that are round about her.* And even the fundamental fact of the spherical form of the earth had to give way to a flat disc in order to agree with Isaiah's expression *the circle of the earth*. When the exponents of the flat earth theory were called upon to defend their views they often, as did Lactantius in the fourth century, ridiculed their opponents by asking *Is it possible that men can be so absurd as to believe that crops and trees on the other side of the earth hang downwards and that men there have their feet higher than their heads?*, or as Augustin, at the end of the same century, simply asserted that there could be no inhabitants on the other side because no mention of such races was recorded in Scripture.

In 410AD, the storming and sacking of Rome by Alaric the Bold, King of the Visigoths, signified the imminent fall of the Roman Empire and the gradual submerging of European civilization by the retrogressive forces of Teutonic barbarism. And so, followed the Dark Ages, a period of obscurity in cultural and scientific thought, when men's minds were void of any principle of general philosophy and science was merely a collection of opinions rather than an accurate record of the universal truths of nature.

But while the European mind floundered in the depths of ignorance and despondency, there arose unobtrusively an oriental power built upon the framework of Greek and Roman civilization and nurtured upon the wisdom of the East. For the first six centuries of the Christian era, the Arabs were of no account as a world power either politically or culturally; they were a simple folk living in a tribal society, interested more in fighting, trading and idle speculation than in science, politics or philosophy. Then, in 622AD Mohammed fled from Mecca to become the founder of a new religion based upon the doctrine of submission to the will of Allah. Soon the quickening power of Mohammedanism swept through Syria and Persia, Turkestan and the Punjab, North Africa and Spain and even stretched into France. For the next four centuries the peoples of Islam became the intellectual leaders of the world. The multiplicity of races, united in a single all embracing faith fostered a tolerance which in turn led to that spirit of inquiry characteristic of a growing civilization. In such an environment, arts and science received encouragement not only in the hands of the learned but also under the patronage of the powerful and wealthy Saracen princes. In spite of this, the Arab mind was not sufficiently inventive to make any outstanding original contribution to science and our indebtedness to them lies in the fact that they preserved and perfected it during a period of darkness and stagnation, until Europe was ready to receive it back again.

In the first century after the Hegira, the geography of the Arabs was still of a very primitive character, reaching its nadir when it was based on a conception of the earth as fantastic as that of *a bird, whose head is China and whose tail is North Africa*. Shortly afterwards Caliph Harun-al-Raschid (reigned 786-809AD) set up at Baghdad a Great Translation Bureau, which developed to its fullest extent during the next quarter of a century under the reign of his successor al-Mamun. Manuscripts and books were brought from all parts of the world, sometimes at great cost, and translated into Arabic by teams of translators of all nationalities and creeds - Hindus, Christians, Jews and Muslims. In this way, Ptolemy's astronomical and geographical treatises were translated into Arabic and as they became the property of the Muslim world, they aroused interest in these sciences.

Inspired no doubt by Eratosthenes' classical determination of the dimensions of the earth, al-Mamun sent out a party of surveyors to the Syrian desert, where they measured an arc of meridian in the plain of Sinjar. Starting from a point in latitude 37°N, one group of surveyors, using a long rope, moved northwards, measuring as they went, until they reached a point whose latitude they found to be 38°N, while another group in a similar way reached the southern terminal of their arc in latitude 36°N. Each distance was measured twice and of the four values 56, 56 2/3, 57 and 57 1/3, they adopted 56 2/3 Arabic miles as the length of 1° of their arc. Since an Arabic mile is known to be equal to 6,472.7 English feet, it is easily shown that their result agrees with the best known modern value to an accuracy of about ¾% - a truly astonishing feat. Later on, we shall see what a curious effect this result of 1° equal to 56 2/3 miles had on Columbus in influencing him to sail across the Atlantic towards the end of the fifteenth century in search of India.

Of Arabic cartography comparatively little is known, largely because the Arabs themselves seemed to be more interested in certain mathematical aspects rather than in the practical side of map making. We have already seen how they not only knew of the sphericity of the earth, but were able to measure it with great accuracy. Their astronomical knowledge was unsurpassed particularly as reflected in the scientific works of al-Biruni under whom the construction of instruments and the preparation of star tables were improved to such an extent that al-Zarkali was able to determine the difference in longitude between his observatory in Toledo (Spain) and that in Baghdad as 51° 30' compared with the modern value of 48° 29'. Furthermore, the Arabs devised a simple type of stereographic projection for the representation of the celestial sphere on a plane surface. Unfortunately, little of this knowledge seems to have been used in the construction of maps.

The only map of any importance which has been handed down to us from this period is that of al-Idrisi, prepared in 1154. al-Idrisi was a Mohammedan of Ceuta, who travelled widely in Europe, Asia and Africa, after which he settled at the court of the Christian King Roger II, in Sicily. Here he had access to the knowledge of both the Islamic and the Christian worlds. Moreover, he was ideally situated, in the middle of the Mediterranean, to have direct contact with travellers both from the Orient and the Occident, and thus his task of making a map of the world was facilitated. His work consisted of a single rather crude map showing the world as known at the time together with seventy sheets depicting in greater detail various portions of the globe. In spite of a more extensive geographical knowledge, the map of the world was still drawn as a circular disc with a central land mass surrounded by an ocean, while the detailed maps were constructed on a simple rectangular grid which did not do justice to the work of either Ptolemy or al-Biruni in map projection. Nevertheless, credit must be given to al-ldrisi for the accuracy of topographical detail along the coast of the Mediterranean and the wealth of information about India and the headwaters of the Nile, which as recently as 1840 led his French translator, Jaubert, to maintain that this represented an increased knowledge of Africa. At the same time, there seems to be little doubt that al-Idrisi's maps contributed much to the portolan charts of the great navigators a century later.

During the twelfth century there appeared the first signs of a gradual revival of learning in Italy. Many of the classical Greek and Roman writers were rediscovered while others were translated from Arabic into Latin by men like Gerard of Cremona. In this way were preserved for posterity many of Ptolemy's works including his Almagest and a treatise on astronomy written by al-Farghani, who worked under Caliph al-Mamun at Baghdad and who was therefore well acquainted with the measurement of the arc of meridian in the Syrian desert. Similarly, the astronomical and mathematical knowledge acquired from other Islamic observatories, was in due course imparted to a reawakening Europe. Some of this knowledge was of a purely academic nature while the contribution to the practical side of astronomy and navigation was no less important; the Arabs helped to develop spherical trigonometry and they adapted some of their astronomical instruments for sea navigation, the astrolabe and cross staff being the most important of these. At this time, too, the magnetic compass began to play a, greater part in navigating ships far out of sight of the land. The origin of the magnetic compass is completely lost in obscurity, although reference is often made to it in ancient Chinese legends and there is indisputable evidence of its use by them for sea navigation towards the end of the eleventh century. The first mention of the use of the mariner's compass in Europe was made by Alexander Neckham in 1187, but as he did not regard it as a novel instrument, it may have been used previously by the Arabs. However, we may safely assume that it was used in conjunction with the portolan charts as an aid to navigation even if it was not used for the construction of these charts themselves.

The portolan charts appear to have originated in Genoa towards the end of the thirteenth century. They were drawn primarily for purposes of navigation and so place names along the coastline were given in great detail to the exclusion of virtually all inland topographical detail. The characteristic feature of these charts is a network of straight lines radiating from an arbitrarily chosen central point and also from either eight or sixteen other points spaced equidistantly around it to agree with the directions of the compass, the whole giving the impression of a multiplicity of compass or wind roses. As no lines of latitude or longitude were given, it is practically impossible to determine the kind of map projection used. Originally the charts were orientated on magnetic north since the map makers of this period appear to have been unaware of the existence of magnetic declination, and it was not until Bianco's map of 1436 that the variation was noted for the first time. At this epoch the magnetic declination in the Mediterranean was about 10 to 12 degrees west of north and decreased to zero at a point a few hundred miles east of the Island of Corvo in the Atlantic, a circumstance noted for the first time in 1492 by Columbus in his voyage across the Atlantic.

In 1482, a year after King John II had ascended the throne of Portugal, there began a series of maritime enterprises which during the following half century resulted in the discovery by the seafaring nations of western Europe of the whole of southern Africa and the great American continent. These coasts of Africa were discovered by Diego Cam, Bartholomew Dias and Vasco da Gama, while Columbus and Cabot sailed to America and Magellan circumnavigated the globe. Within this short period of time, the old Greek concept of the oecumene was overthrown and the map of the world had to be redrawn.

The discovery of the western and southern coasts of Africa was spasmodic. At the time of the death of Henry the Navigator, the west coast of Africa had been mapped as far as Sierra Leone and by 1472 the equator had been crossed. In his first voyage, Diego Cam found the mouth of the Congo and reached Cape St. Mary in latitude 13° South. Two years later, on his second voyage (1485-1486), he sailed on another 9° farther south and arrived at Cape Cross. In 1487 Bartholomew Dias rounded the Cape of Good Hope and was forced to return home a short distance beyond Algoa Bay. A decade later, Vasco da Gama left Portugal, sailed round the southern extremity of Africa, and up the east coast to Malindi, whence an Arab pilot guided him to India. Although this is the first authentic record of a sea journey around the southern coast of Africa, the possibility of similar voyages by the Arabs cannot be excluded, particularly in view of the triangular form of this part of the continent, so clearly shown on the maps of Marino Sanuto (1320) and Fra Mauro (1457) and on a Genoese portolan chart of 1351.

In his second voyage down the west coast of Africa, Diego Cam also provided the facilities for the measurement of an arc of meridian by Master Joseph and Martin Behaim. This had a decisive effect on Columbus' plan to find a sea route *to the East* *by the West*. Twenty years before he actually set sail on that momentous voyage, which led to his accidental discovery of the Americas, Columbus had already formulated his plans. He accepted without hesitation the spherical form of the earth and so the vital issue was simply how far would he have to sail to reach the coast of Asia. At that time, the generally accepted value for the length of a degree of the equator was the Arab result of $56\frac{2}{3}$ miles, transmitted to western Europe through the astronomical works of al-Farghani. Columbus clearly used this value and no other, for in his own writings we find this statement *…each degree corresponds to $56\frac{2}{3}$ miles. And this is a fact, and whatever anyone says to the contrary is only words*. As we have already noticed, this value was for all practical purposes quite correct. But what Columbus does not seem to have noticed was the fact that whereas al-Farghani's measurements were in Arab miles (1 Arab mile = 6,472.7 English feet), he used Italian miles (1 Italian mile = 4,855.6 English feet), so that when he based his calculations on a circumference of 20,400 miles, his world was only about three quarters of its true size. No wonder he observed in another of his writings *The world is but small…I say that the world is not so large as the common crowd says it is, and that one degree on the equator is $56\frac{2}{3}$ miles*. When he submitted his proposals to King John, we are told that the monarch was much impressed with the force of Columbus' reasoning, but unable to decide for himself, he referred the matter to a council which included the celebrated Martin Behaim and the King's physician and astrologer Master Joseph, two of the most able geographers and astronomers in the kingdom. The council rejected the proposal as absurd, but as this opinion found little favour with the King, Columbus was left without a definite answer, and so eventually he decided to approach the court of Spain. In his absence, King John decided to verify the Arab result for the length of a degree, so he commissioned Master Joseph to accompany Diego Cam on his voyage of discovery to *ascertain the elevation of the sun in diverse places in Guinea*. Four years previously Behaim and Joseph had affected a number of improvements to the astrolabe whereby navigators were able to determine their latitude from meridian observations of the sun, and for a voyage south of the equator where the Pole Star was no longer visible, such an instrument and such a technique were now indispensable. Starting from Lisbon, whose latitude was taken as 40° 15'N, they sailed southwards until they reached the island of Los where they again determined the latitude, and thus having obtained the distance between the two places from their pilot's log they reported to the King in the presence of Columbus that they had confirmed the Arab result. But this was far from true. Columbus tells us that on 11 March, 1485, Master Joseph found that *he was distant from the equator one degree five minutes on an island called `Los Ydolos' which is near Sierra Leone, and he made this observation with the very greatest of care*. The amplitude of the arc was thus clearly equal to 39° 10'. But unfortunately, there is no direct record of the distance between the two places. We can, however, easily derive it from another statement made by Columbus as follows :*…in sailing frequently from Lisbon to Guinea in a southerly direction, I noted with care the route followed, according to the custom of pilots and mariners; and afterwards I took the elevation of the sun many times with quadrant and other instruments, and I found agreement with Alfraganus, that is to say, each degree corresponds to $56\frac{2}{3}$ miles, wherefore credence should be given to this measure. Therefore, we are able to say that the circumference of the earth on the equator is 20,400 miles, likewise that Master Joseph, the physician and astrologer, found this, as did many others sent solely for this by the most serene King of Portugal*. If, therefore, Master Joseph found 1° equal to $56\frac{2}{3}$ miles, he must have obtained a distance not far from $2{,}219\frac{4}{9}$ miles for the whole meridian arc, which agrees fairly closely with the modern value (2,186) in *Italian* miles. As the correct value for the latitude of Los Island is 9° 30'N, we cannot escape the conclusion that Master Joseph was so obsessed with the result that he wanted to find, that he *measured* the latitude 1° 05' as the only value consistent with this and the distance obtained from the pilot's log. The astonishing conclusion that not only Master Joseph but also all the other pilots sent specially for the purpose - even Columbus himself, on many occasions - all deluded themselves and their contemporaries in stating that they had found agreement with the Arab result of 1° equal to $56\frac{2}{3}$ Arab miles, when they in fact recorded their result as 1° equal to $56\frac{2}{3}$ *Italian* miles must surely be one of the strangest enigmas in history.

If any one single event can be regarded as the harbinger of the age of modern cartography, that event must undoubtedly be the publication in 1569 of Mercator's map of the world, drawn on a system of projection which has earned undying fame for the inventor. Born in Flanders in 1512, Gerhard Kramer, known today by his Latinised name Mercator, devoted his whole life to the study and improvement of maps. At the age of twenty-six he produced his first cartographic work, a map of the world on an equal area projection, and twelve years later he made his first attempt to devise a projection in which a loxodrome or rhumb line would be represented by a straight line. If such a projection could be found, then the problem of navigating a ship between any two points on the map would be solved by sailing along the path represented by the straight line connecting those two points. Such a line would have a constant direction or bearing but it would not necessarily be the shortest distance between the points. The difference in distance, however, would be insignificant for navigational purposes, especially in the case of a line not exceeding a few hundred miles in length. Mercator found a partial solution to this problem in 1550, when he published a map in which the meridians were parallel straight lines and in which the parallels were spaced at increasing distances from the equator towards the poles. Unfortunately, he gave no proper account of his method of construction. Nineteen years later he found the complete solution by empirical methods, his projection being the first in which the parallels were represented by a series of parallel straight lines spaced at distances which increased towards each pole *in proportion to the lengthening of the parallels with reference to the equator*. This was the vital clue which he needed to make his map orthomorphic or conformal, and in conjunction with the meridians drawn as parallel straight lines, imparted to it a property which is universally regarded today as indispensable for both sea and air navigation. After nearly four hundred years of use, Mercator's projection stands supreme as a basis for the construction of mariner's charts.

Parallel with Mercator's discovery of a new basic principle for the construction of mariners' charts, developments of a fundamental character took place in the drawing of maps of the land. During the early part of the sixteenth century maps were generally drawn on much the same principles as the old portolan charts. In 1528 for instance, Sebastian Munster, a cosmographer trained at Heidelberg University, published an appeal to his colleagues to assist him in the construction of a new set of regional maps of Germany. He proposed that each of his collaborators should map an area of about 50 square miles around his home town by measuring and plotting the distance and direction to all the neighbouring villages, using an angle measuring instrument orientated by magnetic compass. This operation had to be repeated at each observing station until the map was completed, since the idea of fixing the position of a point by two intersecting rays had apparently not occurred to him. Later on, Munster's method was developed by Leonard Digges, who in 1571 proposed that the map should be drawn directly in the field by mounting a sheet of parchment or paper to *a plaine table or boarde,* and drawing rays to the various points by means of a sight rule aligned on the ground object. In some respects, this apparatus resembled Waldseemuller's Polymetrum, which consisted of a vertical semicircle for measuring altitudes and a horizontal circle with movable index mounted on a wooden board. There seems little doubt that these instruments were the precursors of the modern theodolite and plane table. At about the same time, new field techniques were developed. In 1533 Gemma Frisius described clearly for the first time what may be regarded as a method of triangulation, by showing how an actual survey between Brussels and Antwerp was carried out and in this connection, he explained how the position of a point could be fixed by two intersecting rays. He also showed that the scale of both the triangulation and the resultant map could be found from the measurement of a side of any one triangle. Twenty-five years later, Philip Apian carried out a complete survey of Austria using a similar method in conjunction with star observations of latitude and longitude. In this survey he used lines up to 30 miles in length, and from his field notes it appears that within an area of about 300 square miles, he observed at twenty-eight stations using about 200 sights.

Whether Christopher Saxton used the methods of triangulation taught by Frisius and Apian in his great Atlas of County Maps of England and Wales published in 1579 is not certain, since practically nothing is known of the technical details of that survey. Of particular interest at this stage are the cartographical details of the maps themselves. The complete atlas consisted of a general map of the whole area together with 34 sheets of the individual counties, drawn on scales varying from 1¾ miles to 4 miles to the inch. The general map was based on a rather crude conical projection with a zero meridian passing through St. Michaels in the Azores after the fashion of Mercator, and a circumference of the earth equal to 24,600 miles. It was superbly engraved on copper and was - indeed still is - regarded as a masterpiece in the art of map making. The county maps are notable for the way in which certain topographical features were represented. All the hills were shown in elevation as in a panoramic view, while the towns were symbolized either by a single church or group of high towered buildings. When the latter method was adopted a circle with a dot in the centre was placed opposite the most prominent of the buildings. In the surrounding seas were depicted a multiplicity of sailing vessels, fishes, whales and monsters of the sea and the maps were further ornamented by elaborate cartouches consisting mainly of the armorial bearings of the chief county noblemen.

The next phase in the development of cartography followed from the discovery of the flattening of the earth in the latter half of the seventeenth century, although neither the exact date nor the name of the discoverer is known. In 1687 Sir Isaac Newton published his immortal work, *Philosophiae Naturalis Principia Mathematica*, in which he deduced (Book III, Proposition XVIII) *that the axes of the planets are less than the diameters drawn perpendicular to the axes*, but the truth of this statement was known at least twenty years earlier, in the case of the planet Jupiter, from actual observations by Cassini. In fact, it is now thought that the discovery of the ellipticity of Jupiter may have led Newton to seek the explanation of its cause in his own recently discovered laws of gravity, the validity of which he is known to have started testing as early as 1666. However, accepting Picard's value for the length of an arc of meridian between Amiens and Malvoisine as one degree equal to 57,060 toises and the value of the intensity of gravity at Paris, Newton was able to determine the ellipticity of the earth on the assumption that it was a homogeneous body, as 1/230 compared with the modern value of 1/297 based on trigonometrical observations. Newton, however, was not the only one at this time working on the problem of the shape of the earth. Huygens had also deduced that the earth was flattened at the poles from the results which Richer had obtained in 1673 when he found that his pendulum clock lost more than two minutes a day at Cayenne, just north of the equator, as compared with its rate at Paris. But the conclusions of Newton and Huygens were based on theoretical considerations. When their results were announced, the savants of the French Academy of Sciences, who considered the measurement of the earth to be their metier, were sceptical and decided to subject the theory to a practical test. And so, Picard's triangulation was extended by the Cassinis (father and son) southwards to Collioure and northwards to Dunkirk. From the southern arc they obtained 57,097 toises while the northern arc gave 56,950 toises for the length of a degree of latitude, a result which indicated that the spherical surface of the earth was prolate instead of oblate as stated by Newton and Huygens. The immediate effect of this anomalous result was to divide the whole of the scientific world into two hostile camps for by that time both Newton and Cassini had achieved considerable eminence in their own fields and each had attracted many staunch supporters in his cause. The matter was not resolved until, after many years of bitter controversy, an analysis of the Cassinis' work showed that the difference between the radii of the two arcs of meridian was so small that it could not be detected with the instruments at their disposal and an error, for instance, amounting to no more than 20 seconds (the least count of their quadrant) in the latitude of the station at the junction of the two arcs was sufficient to produce a result fully in accordance with that announced by Newton. The Cassinis' result was therefore inconclusive and it could be used neither to support, nor to refute, Newton's argument. In 1735 the French Academy of Sciences decided to submit the matter to a crucial test by measuring two arcs of meridian in widely differing latitudes. One party under MM Bouguer and de la Condamine was accordingly sent to Peru, where it succeeded in measuring an arc of 3° 07' intersected by the equator. Another party under Maupertuis measured an arc of 0° 57' across the polar circle in Lapland. The results obtained for the length of a degree were 56,753 toises for the equatorial arc and 57,438 toises for the polar arc, which satisfied everyone that the earth was an oblate spheroid.

The close association between astronomers and surveyors at this time was responsible for many improvements in cartography. The eldest of the four generations of the Cassini family, Jean Dominique, was an astronomer at the Paris Observatory, and he perfected a method of determining longitude by observations on the satellites of Jupiter. His method was applied by Picard and La Hire to the construction of a new map of France in which particular attention was paid to the accurate delineation of the coast line. When the map was finally published in 1693, it showed the new position of the west coast about 1½° east of the old position and the south coast around Marseilles about ½° north of the old position. This led Louis XIV on seeing the map, to exclaim that the survey had cost him, more territory than a disastrous military campaign. The second Cassini, Jacques, then realized that the only way in which a country could be properly mapped was by starting with a complete framework of triangulation extending over the whole country. In 1733 he and his son, Cesar Francois Cassini de Thury, were commissioned to prepare the new map. They started with a chain of triangulation along the meridian through Paris and at intervals of about 70 miles along this chain they carried additional chains east and west, from which they fixed the positions of towns and other topographical features. This procedure ultimately gave rise to the construction of the well known Cassini projection commonly used until fairly recently in the national surveys of Great Britain, South Africa and other countries. When the map was finally completed in 1818, it comprised 182 sheets on a scale of 1 in 86,400. It was carefully engraved and showed a considerable amount of topographic detail obtained mostly by plane table survey. Towns and villages rivers and lakes, buildings and roads, and even the homes of nobility and gentry and public gallows (grim reminders of the recent Revolution) were shown in great detail.

The lead taken by France at the end of the eighteenth century in completing a national survey of the whole country was soon followed by all the other great nations of the world. Each country set up its own national survey organization responsible for carrying out a systematic triangulation and mapping programme to suit its own requirements. While those who directed the technical operations in each of these countries studied the work of the surveyors of other countries, they effected what improvements they could in the design of instruments, in field techniques and methods of calculation until there gradually emerged a standard pattern in the whole science of cartography. Briefly this consisted of a study of the fundamental standards of length, followed by the design and construction of suitable apparatus for the measurement of base lines about ten miles long. These base lines were then extended trigonometrically to a distance varying from 30 to 100 miles to form the first side of the geodetic or primary triangulation which covered the whole country, either in the form of a uniform network, or of chains of simple geometric figures running along the meridians, parallels and coast lines. Additional base lines were measured at intervals of a few hundred miles at suitable places in the triangulation. When the angles of all the triangles had been measured with the greatest precision, they were adjusted either by the method of least squares or some less rigorous method to render the entire system geometrically consistent on the adopted spheroidal surface of the earth. Latitude, longitude and azimuth were then determined astronomically at a number of points of the triangulation in order to determine their absolute positions. Finally, the whole system was transformed mathematically to a plane surface by a suitable choice of map projection and this provided the basic control for all the topographic detail which appeared on the finished map.

In 1783 Cassini de Thury made representations to the Royal Society in London for the connection of the Observatories at Paris and Greenwich by a chain of geodetic triangulation. On the completion of this work, a start was made on a systematic survey of the whole of the British Isles, grounded on two base lines, one on Salisbury Plain and the other near Lough Foyle in Northern Ireland. Two 36 inch diameter theodolites constructed by Ramsden were used for the angular observations, which required the simultaneous solution of 920 equations of condition for their adjustment. The geographical coordinates of the 218 stations of the triangulation were then computed using ten figure logarithms and their plane positions were determined on the Cassini projection, which thus formed the basis of the main series of maps published by the Ordnance Survey. In 1935 it was decided to revise the entire triangulation framework. Where possible, the previous stations were adopted, but many new stations had to be selected too. All the angles were reobserved and, of course, readjusted. Instead of the old Cassini projection, which was not orthomorphic, it was decided to adopt the Transverse Mercator Projection and to use the International Metre as the unit of measurement. When all the maps are published on the new National Grid, Britain will probably be best mapped country in the world.

Similar methods were adopted by the well known astronomers Struve and General de Tenner in their measurement (1816-1851) of the Russian-Scandinavian arc, which extended for nearly two thousand miles from the mouths of the Danube, through Besserabia, the Baltic States, Finland and. Lapland to Finmark, bordering on the Arctic Ocean. At about the same time, Bessel carried his survey from France through Hanover, Denmark, Prussia and Bavaria to link on to the Russian arc. In 1857 Struve initiated a project for the measurement of a longitudinal arc along the 51° parallel from Orsk in the Ural Mountains, right across Europe to the West Coast of Ireland.

The Great Trigonometrical Survey of India is a classic example of what can be done in the fields of geodesy and cartography by several men, who in succeeding one another carried on the traditions of their office and never once relaxed the high standard set by their predecessors. It was started in 1800 by Colonel Lambton, who was succeeded a quarter of a century later by General Everest, after whom the highest peak in the Himalaya Mountains was named. On his retirement, he was replaced in turn by Generals Waugh and Walker. These four men carried out between them the survey of a large number of meridional and longitudinal chains of triangulation from Cape Comorin at the southern extremity of the peninsula to Afghanistan and the Himalayas in the north and westwards from Burma to Baluchistan, all rigorously adjusted to a framework of stations accurately fixed in position by the most refined astronomical observations and calculations. The survey of a single country covering an area of nearly two million square miles, much of which was wild and desolate and climatically unsuited for occupation by the small band of Europeans who were under constant threat of disease and pestilence, made an outstanding contribution to the history of human endeavour and scientific achievement.

In South Africa, the first general maps were constructed according to methods very different from those employed by Lambton and Everest in India. As the European occupation of the Cape was confined to a fairly small area up to 1795, when the Dutch East India Company relinquished its control, cartographical interest was directed more to the accurate delineation of the coastline around the *Cape of Storms*.

Barrow's map was produced in 1798, three years after the British occupation had displaced the government of the Dutch East India Company. He was not, however, able to make use of any of the large number of maps prepared under the direction of Governor Van de Graaff, who realising the military importance of such documents had secretly taken them back to Holland when he was recalled in 1791. Indeed, he appeared to be unaware of the existence of such material for he complained that *at the capture…there was not a survey of one of the bays that could be depended on…not a single map that took in one-tenth part of the colony.* Although he employed methods not very different from Wentzel's, he had the advantage of better instruments, which included a six inch sextant made by Ramsden, an artificial horizon and a pocket chronometer, and with these he was therefore able to produce a map which was for many years regarded as a good map of the Cape, in spite of a number of errors.

Creditable though these maps were, they could certainly not be considered as having an accuracy approaching anything like that of maps based on a network of triangulation of even the poorest quality. So, the need for the establishment of a system of accurately fixed control points for cartographic purposes became ever more pressing. In 1859 a start was made by Captain Bailey, who was entrusted with the task of carrying a chain of triangles along the coast from Cape Town to East London. Unfortunately, when the work was completed three years later and he was on his way back to England on board the coasting steamer *Waldensia* with his instruments, field book and calculations, the vessel struck on the rocks near Cape Agulhas and became a total wreck. All his work would have been irretrievably lost had he not supplied copies of some of his observations to certain persons. From these copies he was able to reconstruct almost the entire work.

Twenty years later, Sir David Gill was appointed Her Majesty's Astronomer at the Cape and soon afterwards he decided that the traditions of his office not only justified, but demanded, that he should spend some portion of his time in studying the general question of the geodetic survey of South Africa. In 1883 he succeeded in getting the Governments of the Cape and Natal to agree to a joint systematic geodetic survey of their respective territories by a detachment of Royal Engineers under Captain Morris. The satisfactory completion of the work to the high standard set by Gill was constantly in jeopardy, however, because the Colonial Secretary for

Natal, for financial reasons, had repeatedly to urge that the operations be brought to a close as quickly as possible. In the Cape, the project was seen by the Governor, Sir Bartle Frere, in a very different light, for he was able to draw on his experience of Indian administration and according to Gill *realised the economy of having all land surveys based upon a Principal Triangulation of such accuracy that its results might be considered definitive for all future time*.

Gill now turned his attention to the rest of Southern Africa, for by this time he had already formulated his proposal for the survey of a great chain of triangulation along the 30th meridian of east longitude. In this proposal he envisaged a survey which, starting from the Cape, would extend through the South African Republic, Southern and Northern Rhodesia, the East African territories and along the Nile to the shores of the Mediterranean. From here it would be carried along the coast of the Levant across Greece to connect on to Struve's arc, which terminated on the shores of the Arctic Ocean. This great enterprise found ready support by the administrators of all the territories concerned, but the means for executing it was in many cases completely lacking. In the South African Republic, plans for carrying the survey from the Natal boundary to the Limpopo were approved by the Volksraad but were never acted upon because of the parlous state of the country's finances. In 1897 largely through the good offices of Rhodes, a beginning was made with the Rhodesian contribution to the plan and it was hoped that this would provide a further incentive for the South African Republic to complete its share of the work. But the country was on the brink of war and nothing could be done. At the conclusion of hostilities, Gill lost no time in persuading the new Governments of the Transvaal and Orange River Colony to obtain the services of Colonel Morris in closing the gap between Natal and Rhodesia, thus completing at least the southern portion of the arc. Thereafter, the final execution of the plan had to be left to succeeding generations. With the most difficult section of the work left to the end, it needed a great effort to complete it. A few months ago, the last triangle was closed, and the master plan conceived by Sir David Gill as long ago as 1879 was finished.

To conclude this brief review of the origin and development of cartography, mention must be made of some of the instruments techniques used in modern mapping.

In theodolite design and construction, most of the improvements have been made in obtaining greater accuracy in reading and in reducing the weight of the instrument. How great this improvement has been may be judged from the fact that whereas the theodolites used by Everest in the Survey of India weighed more than 1,000 pounds when packed, the corresponding instruments of today have a far greater accuracy and weigh less than 25 pounds. This reduction in weight has been due mainly to the replacement of the 36 inch diameter silver circles of the older instruments by glass circles less than 6 inches in diameter and read by an optical micrometer in such a way that a single reading automatically gives the mean of two diametrically opposite readings. More recently some of these instruments have been fitted with miniature cameras for photographing the circle readings and used at triangulation stations several hundreds of miles apart for observations on parachute flares released from aircraft flying at a great height, the observations being obtained simultaneously at the various observing stations from specially transmitted radio signals. In this way, a geodetic connection was obtained shortly after the war between Denmark and Norway across the Skagerrak.

Another recent development has been the application of certain radar devices such as *Gee-H*, *Oboe*, *Decca* and *Shoran*, used during the war for navigation and *blind bombing*, to the survey of long geodetic lines. The principle underlying the determination of distance by radar methods is the accurate determination by electronic instruments of the short interval of time taken for a radio pulse superimposed on an electromagnetic wave, to be transmitted to and fro from a transmitting to a receiving station. When it is arranged that an aircraft carrying either the transmitting or receiving set flies roughly midway between, and at right angles the line joining two ground stations, the distance between stations can be found from the minimum sum of the two separate distances to the aircraft. Suitable corrections must then be applied to allow for the height of the aircraft in relation to the ground stations and the physical state of the atmosphere which affects the velocity of propagation of the radio waves. Using this method accuracies of more than 1: 20,000 have been obtained for distances of up to 400 miles, and thus trilateration instead of triangulation has become a practicable method for the survey of sparsely populated territories such as Australia. In another instrument, called a geodimeter, invented by Bergstrand of Sweden, a beam of light is used instead of radio pulses. Light from a projection lamp is made to pass through a pair of crossed Nicols prisms, between which a Kerr cell is placed. When a crystal controlled high frequency, voltage is applied to the Kerr cell, rays of light emerge from the second prism which vary in intensity with the same frequency as that imposed by the oscillator on the Kerr cell. After reflection from the surface of a mirror placed at the station whose distance from the geodimeter is required, the rays are received back at the initial station, the elapsed time being measured to a high degree of accuracy electronic methods. In a series of tests conducted by the Ordnance Survey in 1953, a line of about 6 miles in length was measured to an accuracy of about 1: 500,000 which is only slightly inferior to that obtained with invar tapes.

Finally, there is the subject of photogrammetry, which may without hesitation be regarded as having made the greatest single contribution to the development of modern cartography. Following immediately upon the invention of the *Daguerreotype* process in 1839, Arago suggested that photographs might be used to supply the basic information required for filling in the topographic detail on a map. Laussedat took up the challenge at once and started experimenting with a camera supported in the air by kites or balloons but the method failed and so he reverted to ground photogrammetry. By attaching a camera to a theodolite, he converted it what is known today as a phototheodolite and proceeded to use e new instrument for making a map of Paris. Very soon interest was aroused in all parts of the world and experiments were begun in Canada, United States of America, Germany, Italy and in Austria where Scheimpflug successfully obtained the equivalent of a vertical air photograph from a camera which was suspended from a balloon and contained seven oblique lenses grouped around a central vertical lens. In 1909 Wilbur Wright took the first photograph from an aeroplane in a flight over Italy, and four years later, Tardivo produced a mosaic of Benghazi in Libya. Meanwhile, in 1896, Pulfrich began working on the stereoscopic rangefinder and went on to apply his knowledge of stereoscopic vision to the design of an instrument with which heights could be determined from a pair of overlapping photographs. This was the beginning of a new science - surveying from air photographs. From then onwards progress was rapid. Parallel with the development of aircraft came corresponding improvements in the field of air surveying, new wide angle lenses free from distortion, more efficient shutters, improved film bases and emulsions, gyrostabilised cameras and radarcontrolled flights. In quick succession there followed, too, a large number of stereoplotting instruments used in the taking of measurements from pairs of air photographs and in compiling the final maps. Further scope for advancement came during the Second World War, when it is estimated that the United States Air Force alone photographed 15 million square miles of territory and the Army Map Service, with its affiliated organisations, produced 500 million maps of which 70 million were used in the

Normandy invasion.

At the present time, therefore, it may safely be said that all the means are available for the quick and accurate survey of the entire surface of the earth. But in spite of all the technical improvements which have been made, it is astonishing to realize that there is still less than 2% of the land surface of the world which has been mapped on a scale of 1: 25,000 or larger and probably less than 25% for which even reconnaissance maps on a scale of 1: 250,000 are available. With the exception of a few European states and very limited areas in other countries, the status of cartography is such that nowhere are the maps adequate for the proper economic development of the natural resources of the world. Is it too much to hope that the present generation will yet live to see the fulfilment of the ambitions of some of the ancient Greeks in having a map of the whole world with all its rivers and seas, valleys and mountains?

Lauf, Gordon Bertram (1955), *The Origin and Development of Cartography*, Professor of Surveying at the University of the Witwatersrand, Inaugural Lecture delivered 23 June, 1955, Witwatersrand University Press, Johannesburg.