HOW MAPS ARE MADE.

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The subject on which I am deputed to address you to-night is what in the slang of the day may be described as "a very large order." Though the title seems simple enough, the subject itself is so large, and it spreads and ramifies itself through so many arts and sciences, that the temptation to go off from the distinct line of my subject into the different branches that introduce themselves is great, and all these branches are to me so interesting, that I have found great difficulty in confining myself strictly to the story of how a map is made. I have forced myself, however, to stay on the centre line of map-making, and I hope, before the evening is over, to give you a clear and distinct idea of the principles on which a map is made, for the subject of my paper is not "How Maps are Drawn," but "How Maps are Made"; and I will attempt to show you the naked machinery of the process.

I have often been amazed at the popular ignorance of what would seem to be the very first principles of geography and of map-making, and this has induced me to begin at the very A B C of the subject. I intend throughout this paper to avoid technical phrases and mathematical terms. I have nothing new to tell you; much that I am about to say is known to every person here present, and I ask you to bear with me if occasionally I seem childish in my descriptions.

One thing more I should like to premise, and that is, that in this paper I do not propose to go into any great detail, or to confuse any one here with the numberless scientific corrections and modifications that have to be made in all scientific calculations. I will only speak on general principles; those who know the science thoroughly will understand the modifications necessary, while those who have not the same advantage will, I trust, be able to grasp the principles of what is shown.

My intention to-night is to show (1) how a spectator finds his position on the earth's surface; (2) how he defines and records that position; (3) how he makes a map from the information he has found; (4) how he fills up the details of that map; and (5) briefly to describe how the map so made is drawn and printed, and incidentally to show the use of the various tools and instruments employed in these operations.

I assume that we all know that the earth is (roughly speaking) a sphere, spinning round on its axis once in twenty-four hours. Now, if we take up a sphere, like this ball, and mark a spot on it, there is nothing whatever to define its position: no north, no south; nothing to guide us. One point on this sphere is the same as any other point, until we find some reference spot to measure from; but we have assumed that we know that the earth spins round on its axis, and here we at once discover something we can measure from. The ends of the axis of the ball, which we call the poles, are, we see, at rest compared with the rest of the surface of the spinning ball.

Now, this so-called polarity gives us at once two points of reference. Although no one has ever been at either of the Poles, the study of the subject for hundreds of years has proved their existence as surely as if the Poles had been visited and been discovered marked with upstanding posts. Between these two points, which we call the Poles, I can mark a point half-way, which, by spinning the ball in contact with the pencil, I convert into a line—called the Equator, the equal divider—popularly *the* Line. You will observe that this middle line—this Equator—is also the largest possible circle on this sphere, and it is from this circle that all measurements and references North and South are made. We see on the globe and on maps a number of other circles parallel to the Equator to the north and south of it, and drawn at equal distances. These are called the *parallels of Latitude* (or wideness), and they mark certain degrees of *angular divergence* from the Equator.

Consider for a moment what this means. In the first conception of them these lines have no specific distance apart, because they really are angular measurements, and it is this conception of them I wish you to get hold of. A degree of latitude is not necessarily a number of miles, and until we know the actual diameter of the earth we cannot tell what the length of a degree is. It is a proportion of the circumference of a circle—a fractional measurement of it. We may speak of a half, a quarter, of anything, but, until we say what it is a half of or a quarter of, the phrase conveys no idea of magnitude. It might be half a mile, or half a kingdom, or half an inch, or half a crown. Similarly, a degree of a circle means nothing so far as length is concerned, until you know the size of the circle, when you can at once calculate, with the proper mathematical knowledge, the numerical value of a degree at the Earth's circumference.

Now, having marked these lines on the surface of the Earth, we have certain marks on our globe to which we can refer any and every point. It may be said, "Why mark these lines on the map? They do not exist; they are only imaginary." Quite true! But then the first principle of all map-making is to begin with imaginary lines, from which to measure the position of every place on that map; and all such imaginary lines are carefully recorded, as we shall see later on, so that they can be accurately laid down at any moment by those who know how to find them. We find them a great convenience—an absolute necessity indeed—so we leave them drawn on the globe. Imagine a street—any street will do, but for a good analogy imagine a street built, like Moray Place, in a circle. We can say, speaking of, say, a water-plug, or any point in that street, that it is on the centre line of the street, or the line of the lamp-posts, or so many feet to one side of either of these lines. There is no visibly marked centre line or line of lamp-posts, but it can be filled up in a moment by human intelligence, and if there were to be frequent references to them these lines would be marked on a plan for constant use. The parallels of latitude are similar lines drawn for convenience of reference.

The circumference of the Earth, like any other circle, is divisible into 360 degrees, and we number the parallels by the number of degrees of angular divergence; only, instead of beginning at a pole and going right round, we, for convenience' sake, begin at the Equator and then number 90 degrees towards the North Pole and 90 degrees towards the South Pole.

But one set of reference lines is not enough; we must have another set, and we get them in the *meridians of Longitude.* We draw these through the poles, at right angles to the Equator. They are all "great circles"; that is, each circle is concentric with the globe. The Equator being a circle, we divide it as before into 360 degrees, and the meridians through the points of section form a second system of lines of reference. But, unlike the parallels of latitude, they are all the same size. One is the same as another. How are they to be numbered? Go back for a moment to Moray Place, and remember the lines we drew—the centre of the street, and the line of the lamp-posts. How are we to define a spot on one of these lines? They are circular, and consequently have no beginning and no end. What we should do would be to mark a convenient spot with a flag, or a peg, or a stone, and say—"That is the beginning; measure from that."

This is exactly what we must do in longitude. We must mark a starting line on the earth, and call it Zero; and as all nations have a free choice they have not chosen the same. We have chosen the meridian of Greenwich, the French that of Paris, the Americans Washington, and the Russians Pulkova and the Germans used to use Ferro; but for all English maps, and now for most foreign ones, the meridian of Greenwich is the starting line—the Zero of longitude.

The custom here again is not to reckon 360 degrees round the circle, but to reckon 180 degrees east and 180 degrees west. We saw that latitude was angular divergence from the Equator; but what are these degrees of longitude? Look at a ball spinning round opposite a candle. We assumed a knowledge that the earth spun round its axis in 24 hours. Every part of it comes in turn opposite a heavenly body (say the sun) once in 24 hours, just as every part of this ball comes opposite the candle once in each revolution. Longitude is, then, angular divergence measured by the *difference of time* in coming opposite a heavenly body. As the circle is divisible into 360 degrees, so the day, *i.e.* the revolution of the earth, is divisible into 24 hours, and one hour of longitude is consequently equal to 15 degrees. In maps longitude is marked in degrees, while in almanacs the elements given to reckon it are always written in hours, minutes, and seconds.

Remember, once more, that these degrees are not lengths measured on the surface, but are the record of angular divergence from the initial meridian. It is all the more necessary to bear this in mind because the length on the surface of the Earth of a degree of longitude varies enormously, being greatest at the Equator and nothing at all at the Pole, differing thus from degrees of latitude, which, roughly speaking and for the purposes of this paper, may be considered equal.

The idea that latitude and longtitude are the measures of angular divergence and not absolute distance in miles or yards may be easily grasped by a familiar illustration. If you can imagine two travellers leaving Italy by road, the one over the St. Gothard pass, and the other over Mt. Cenis, and two other travellers following them by rail at such an interval of time that they are in the railway tunnels at exactly the same moment that the pedestrians attain the summits of the passes: the pedestrian on the mountain and the railway traveller in the tunnel of the St. Gothard pass will be in exactly the same latitude and longitude, and so will the travellers by the Mt. Cenis routes. The pedestrians, however, will be about sixty yards further apart from each other than the railway travellers. The reason of this of course is, that the pedestrians are further away from the Earth's centre, but their angular divergence from the Equator and the Earth's axis are precisely the same, whether they are on the mountain or in the tunnel 5000 feet below.

Now, having defined latitude and longitude and shown how the lines representing them are drawn, we must see how in practice the surveyor finds the latitude and longitude of a place, and thereby begins his map. The Poles, as we saw, are first points to measure from, and the Equator the half-way line. It is evident he cannot measure directly a line from Pole to Pole, find out the half and call it the Equator, and leave pegs at each parallel in passing. He must look to things outside the Earth itself from which to reckon, and he gets such reference-points in the heavenly bodies. To his eye these are situated in the great vault of the heavens. He sees them as if on the surface of a hollow globe continually revolving around him, rising in the east till they reach their highest point above him, called the culminating point, then setting in the west. For thousands of years astronomers have studied these bodies, and fixed their apparent positions in the celestial vault; and these positions are recorded with the utmost possible accuracy in a book compiled by Government, called the *Nautical Almanac*, and from the practical information given there the surveyor finds his position. He may take the sun, or he may take the stars; but the positions of the sun being affected by the motion of the earth round it, I propose to take a star to illustrate my next remarks, as its movements are simpler.

The pole of the heavens is the end of the axis of the earth infinitely prolonged. The intersection of the plane of the Equator with the celestial vault is called the *Equinoctial;* and as the angular divergence on the surface of the Earth is measured in degrees from the Equator and called Latitude, so the angular divergence of a heavenly body from the Equinoctial is called its *Declination.* As the angular divergence from the meridian of Greenwich was called Longitude, so the divergence in time from a starting-point in the heavens is called *Right Ascension.* We had to fix arbitrarily the meridian of Greenwich as a starting-line on the Earth. We have also to fix equally arbitrarily a starting-point in the heavens, and that point may be most simply described as the point in the heavens in which the sun is in spring, when the day and night are equal.

The latitude of any place on the earth's crust is equal to the altitude of the celestial pole. You can see this in a moment if you imagine yourself on the Equator and look to the pole, marked, say, by the Pole Star. You will see it on the horizon and of no altitude at all; and at the Equator you have no latitude, or it is called Zero, but, as you approach the

Pole, the Pole Star will gradually appear to rise higher and higher until when you reach the North Pole it will be directly over your head, and consequently at right angles to, or 90 degrees from, the horizon, and your latitude is then also 90 degrees. But though the Pole Star is very near the North Pole, it does not actually coincide with it, and we must find some other way of finding our latitude accurately. We get this by taking the altitude of any known star in various ways. I will explain the simplest method, of which all others are only slight modifications:—

1. Measure the *meridian altitude* of the star—that is, its highest altitude above the horizon.
2. Deduct that altitude from 90 degrees, which gives its *zenith distance*, or the angular distance from a point exactly over your head.
3. Add (or subtract) the *declination* of the star (found in the *Nautical Almanac*) to the *zenith distance*, and the result is your latitude.

I have here a diagram showing how the latitude of Edinburgh would be found from the bright star Arcturus, which "culminates," or reaches its highest altitude, on our meridian a few minutes before twelve to-night.

I measure first its *altitude*, which I find is 54 degrees. Deducting that from 90 degrees gives its *zenith distance* = 36 degrees; to that I add its *declination*, which I find from the almanac is 20 degrees, and the result is 56 degrees = the latitude of Edinburgh.

Longitude is a more difficult matter, and I have no time to go into it anything like fully. You will find a beautiful description of it in *Herschel's Astronomy*—the best by far of all popular books on the subject. While latitude is absolute, longitude, being difference in time, is relative, for there is no such thing as absolute time; and noon at any place is merely the moment when the sun culminates on the meridian. If the observer has a clock whose going he can depend on, and he sets it to, and keeps it always at, Greenwich time, he knows from that clock or chronometer what time it is at Greenwich when any star comes to the meridian. If, then, he can observe any astronomical phenomenon, such as the meridian passage of a star, he has only to observe the difference of the times recorded on the clock set to Greenwich time and on his local clock, and the difference is the longitude in time. This is the principle on which longitudes are taken at sea, where chronometers can be kept undisturbed, but for explorers on land it is more difficult.

The moon, however, is a natural clock—very complicated, but still readable to the initiated.[1] It is continually moving through the stars, and its angular distance from prominent stars is carefully computed for Greenwich, and recorded in the *Nautical Almanac* for every hour in the year. The observer, then, finding the moon's position by observation, and recording its local time, can find in the *Nautical Almanac* when it had the same position at Greenwich, and the difference of the times is the measure of the longitude.

In old days, when ships met, the first question was, Who are you? the next, What 's your longitude? The invention of the chronometer by Harrison 120 years ago has, however, for sailors at least, vastly simplified

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[1] The student should read the beautiful explanation of longitude in Herschel's *Astronomy*, § 220 *et seq.*

MERCATOR'S PROJECTION.

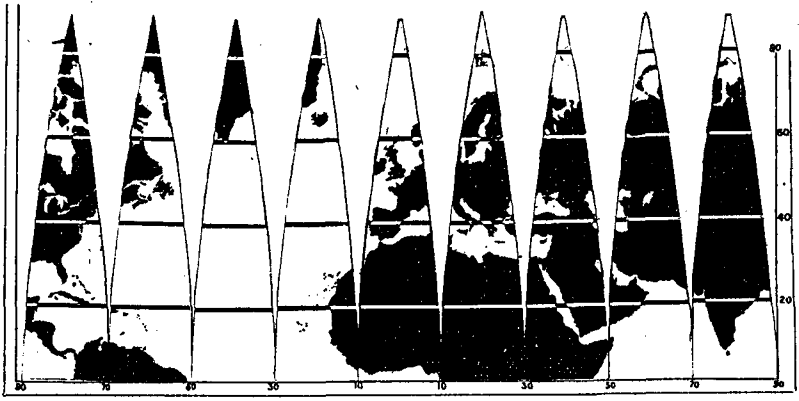


FIG. 1.—Gores from the Globe.

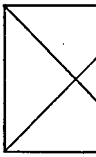


FIG. 1

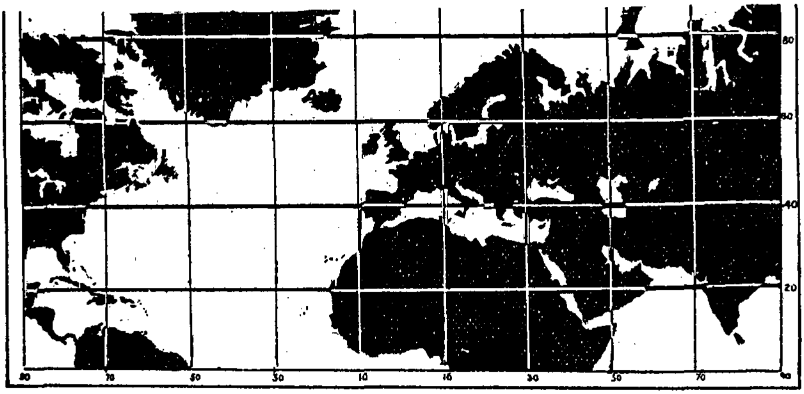


FIG. 2.—The Gores stretched out horizontally to meet in straight vertical lines.

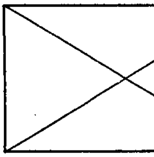


FIG. 2a

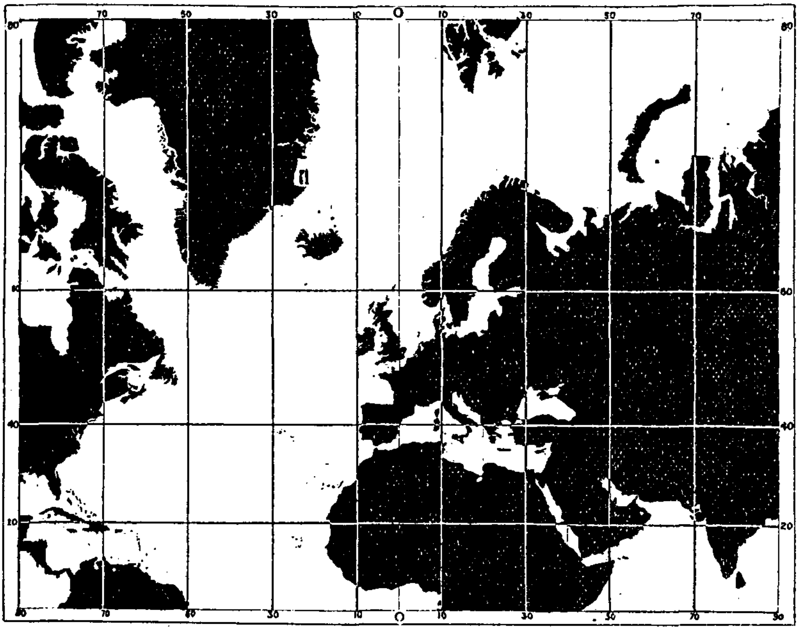


FIG. 3.—The map distorted vertically in same proportion as horizontally.

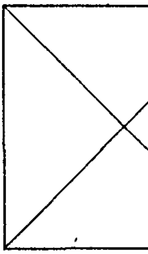
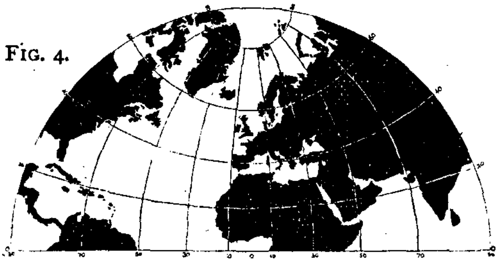


FIG. 3

FIG. 4.



STEREOGRAPHIC PROJECTION.

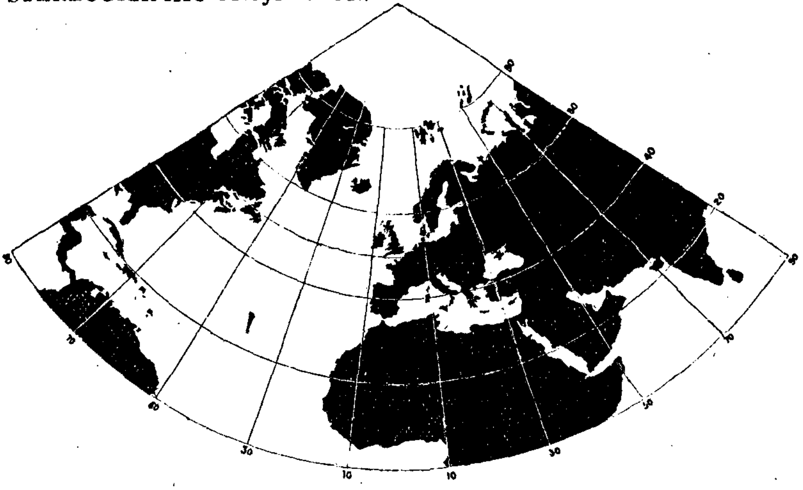


FIG. 5.—CONICAL PROJECTION.

the finding of longitude at sea; and I find from inquiry among sailors, that "lunars" are practically a lost art. In illustration, I may state that I find from the *Nautical Almanac* that Arcturus comes to the meridian of Greenwich at 11.37 to-night. If I have a clock or chronometer marking true Greenwich time, I shall find that this star will come to our meridian at 12 minutes and 40 seconds later; the difference of longitude in time is therefore 12 minutes and 40 seconds, which, converted into angular measurement, is 3 degrees 10½ minutes, the longitude (west) of Edinburgh.

Note here that at stations differing only in latitude the same star comes to the meridian at the same *time*, but at different *altitudes*. At stations differing only in longitude it comes to the meridian at the same *altitude*, but at different *times*. The instrument generally used for taking altitudes is the sextant.[1] At sea, where we have a visible horizon —the line where the sea meets the sky—we measure altitudes from this horizon; but on land we have no true horizon, and then we use, what is more accurate, an *artificial horizon*, which is a cup of mercury in

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[1] In reading this paper the sextant, artificial horizon, theodolite, level, plane table, and other instruments were all shown and their uses described. These descriptions are omitted here, and the student is referred for detailed and illustrated descriptions of these and other instruments to Professor Rankine's *Manual of Civil Engineering* (Griffin, Bohn and Co.), or Mr. Usill's *Practical Surveying* (Crosby, Lockwood and Son, 1889).

which the heavenly body is reflected. Measure the angle between the real body in the sky and its reflection in the mercury, and half the angle is the true altitude.

PROJECTION.—Having discovered our position on the surface of the globe, we come to the representation of it on a flat sheet or map.

The Latin dictionary tells us that "mappa" is a sheet or napkin. Now the surface of the globe is curved, and in a map we have only a flat surface to represent it on, and we shall for a short while study how, as it is the basis of all map-drawing. The conventional representation on a flat surface of the curved surface of the Earth is called Projection, because in its fundamental idea it is a picture of the globe projected or thrown forward from the eye on to a flat sheet; but this idea of it is so confusing to the mind unaccustomed to think out such things that, although it is the invariable way of describing it in all text-books, I have preferred to show you three forms of projection without assuming any ideal throwing of the rays on to planes.

The first I show is the modified STEREOGRAPHIC or equi-globular projection (Fig. 4), invented by Philip de la Hire about the end of the seventeenth century. A simple way of investigating this projection is to fit an iron ring over the centre of the globe, and stretch tightly, from the North Pole to the South, indiarubber bands that coincide with the meridians of longitude on the globe, fastening them firmly to the ring at the Poles. Similarly stretch indiarubber bands over the parallels of latitude, fastening them to the iron ring and to the meridians where they cross. While the ring is kept on the globe these indiarubber bands show the parallels and the meridians on the sphere. When the ring is lifted off the globe the indiarubber shrinks to a plane and shows exactly the lines of the stereographic projection. This is the projection used in all atlases for the world in hemispheres, for continents, and for large surfaces. It gives, indeed, a notion of rotundity and a general idea of proportion, but the central portions are shrunk in, and the edges are distorted.

The next projection to be studied is MERCATOR'S. Mercator was a Fleming who lived in the sixteenth century. He was almost an exact contemporary of John Knox. He was a writer on theology and geography. His real name was Gerard Kremer, which name, meaning merchant, he Latinised, in accordance with the custom of the day, into Mercator.

His invention is very clever. The construction of it is a little complicated, and is generally shirked in text-books, but the actual idea is very simple, and I have here designed a piece of apparatus to illustrate exactly what I believe Mercator did when he evolved his system.

Though I have no direct evidence to show how Mercator argued out his system, I have not the least doubt that it was somewhat thus:—

Mercator was a globe-maker, and no doubt worked from the globe. He stripped his gores off the globe, forming a map like this (Fig. 1), which was naturally very inconvenient, owing to the hiatuses between the meridians. He was obliged to join the gores along their meridians (Fig. 2). He then found that he had distorted everything, and the distortion increased in the higher latitudes owing to the gores being further apart towards the top of the map. In order to restore a balance of orientation (or the relative positions and direction of places), as he had distorted in longitude, so he had exactly in proportion to distort in latitude, as *shown in Fig. 3, a complete Mercator's Map of half the Northern Hemisphere*, in which you will observe that the parallels are farther and farther apart as the latitude gets higher.

As these gores are not a familiar shape, I have a square here which will catch the eye at once (Fig. 1*a*). I distort it first by pulling it out horizontally as Mercator did in joining the meridians, and it ceases to be a square and the orientation is changed (Fig. 2*a*). I then distort it in height in the same proportion, and it becomes once more a square with the true orientation but larger than the original square (Fig. 3*a*). This is exactly what we did before with the gores of the globe.

Every parallel, in Mercator's Projection, is a straight line, and every meridian is also a straight line. We have, then, an excellent sailing chart; sailors can now find their direction or course by drawing a straight line from point to point. As Sir George Grove puts it very neatly (though he shirks the explanation of the projection), "The most ignorant sailor can lay down his course without calculation. In fact, the invention of this map has been justly called one of the most remarkable and useful events of the sixteenth century; because it enables common, unlearned people to do easily and correctly what only clever, learned people could have done without it."

Mercator's Projection is that used in all nautical charts to this day, because to the sailor it is far more important to know his direction or course than his distance, which with ordinary nautical knowledge, or from nautical tables made for him, he can easily calculate, but he needs to see his course.

In the CONICAL PROJECTION (Fig. 5) we imagine a cone of paper to be rolled round the globe, touching it on the middle line of the map. Near their line of contact the map coincides very nearly with the globe surface, and is fairly accurate; but as it gets further away from the touching point the distortion grows, the places being shown larger than in reality. For comparatively small areas, such as for maps of England or France, it is fairly accurate, and is the projection used in atlases.

In the diagrams on pp. 424, 425, we see the same globe projected on the same scale, but with very different proportions. These three projections are typical ones and the most commonly used, but there are many others. For those desirous of studying the subject the best work on it I know is the article by Mr. Taylor, in the June number of the *Scottish Geographical Magazine* of last year, and to that article I refer them.

MAP-MAKING.—We have now seen how the traveller finds his place on the globe's surface, and how, when found, he can *project* or map that information on a flat sheet. We shall now see how a map will grow. Imagine a ship sailing into unexplored seas and coming to some land, say an island. The navigator at once fixes his position in the ship in latitude and longitude. The navigator's instruments are the sextant, the chronometer, and the mariner's compass. The general idea of the mariner's compass is that it always points to the north; but accurately this is not so. The general direction of the compass, or the Magnetic Pole, is not the true north, but a spot very considerably to the west of it, and, in fact, shifts continually; not only in different places, but even in the same place, the direction changes from time to time, as there are many local causes of disturbance. The navigator, then, to fix true north, must find his meridian—that is, he must observe the direction of a star or the sun when it culminates or comes to the meridian, and from this observation he computes the amount of the local variation of the compass. In practice it is not the moment of culmination he actually observes, but the statement is accurate enough for the purpose of this popular description. Knowing the variation of the compass, he can then take accurate bearings or directions to any feature he desires to record. Two or more such bearings to (say) a mountain, crossing each other from different known places, fix its position on the map.

THE NAVIGATOR.—We can now show how a country is mapped. Suppose a ship visits this island, and fixes, by the ways already indicated, a few latitudes and longitudes from meridian altitudes, and sails round it, fixing here and there points on the coast, and perhaps taking bearings of some mountain, then the island would be represented in an atlas with several points fixed and joined by dotted lines. Nautical surveying is always done with the sextant, which measures both vertical angles and horizontal.

EXPLORER.—Following in the wake of the sailor comes the explorer. I had intended, when I first sketched out this paper, to give an imaginary explorer's map of a journey across this island, but I have the privilege of showing you something so infinitely precious that I feel it would be a piece of bathos to concoct a sham map. Here I have two of Dr. Livingstone's own original manuscript maps made on his last journey, kindly lent me for to-night by his daughter, Mrs. A. L. Bruce. Here we have no conjectures as to what the traveller might do; here are the real power, the actual materials of geography. Instead of imagining what an explorer should take with him, I may mention Livingstone's actual equipment:—a 6″ sextant; an artificial horizon; a pocket chronometer; a prismatic compass and a pocket compass; two boiling-point thermometers and two common thermometers; aneroid barometer; a *Nautical Almanac* and a book of mathematical tables.

The sextant, as we have seen, is for taking astronomical, as well as terrestrial angles; the thermometer and barometer for taking heights. The principle on which the latter are calculated is the pressure of the atmosphere. The aneroid everybody knows; the boiling-point thermometer is considered better and more accurate, though I observe from Livingstone's notes—who was the most painstaking and thorough observer, and who always observed with both—that there was little practical difference in the readings. Roughly speaking, water boils at sea-level at 212° Fahrenheit, and the barometer stands at 30 inches, while at 5000 feet altitude water boils at 202°·6, and the barometer falls to 24·7 inches.

The traveller in unexplored parts generally estimates his distances from the time taken at the average rate of marching, just as on board ship distances covered are roughly taken from the average rate of the ship indicated by the log. He takes compass bearings as he goes, and keeps an itinerary recording all useful information gathered on the march. He corrects his reckoning by taking daily latitudes, and at greater intervals, say once a fortnight, longitudes from moon observations if he can. He notes heights, gets reports from natives of estimated distances, and in fact gathers all the information he can on every subject—rainfall, botany, zoology, anthropology, and so forth. Livingstone did all these, and did them thoroughly. A whole lecture could be written on these maps I hold in my hand. Here is one of his notes:—

> "Eight days up this river 96 miles, then cross and go three days, say 36 miles, to stone houses 132 miles—course S.W. Lobula, comes to N.E., has dark water."

A traveller with his wits about him can do much with very rough instruments, or even with none at all. He can train himself to use his fingers for rough angular measurements, and he can improvise in many ways. My own old chief, the late Colonel W. B. Holmes, R.E., used to make wonderful surveys with his watch alone.

One great geographical problem—where does the huge river Sang-po, which flows in Tibet at the back of the Himalaya, discharge its waters?—was solved by a native surveyor, A. K., sent out by the Government of India, who was obliged to conceal all his observations. I quote from the official account:—

> "For linear measurement A. K. trusted entirely to his own pace or step, which, as hereafter shown, is convertible into the unit of a foot, or any other unit desired; and notwithstanding that in Mongolia he was looked down upon as a particularly inferior individual, because, unlike the Mongols, he persisted in walking instead of following the universal custom of the country, which enjoins riding a horse on all possible occasions, he yet manfully strode along his travels, pleading poverty, or otherwise, until at last, on his return journey along the eastern flank of his route, the Láma with whom he had taken service insisted on his riding, if only to promote flight from robbers, especially the mounted bands of Chiámo-Goloks, of whom travellers are in constant dread. Thus compelled, A. K. mounted a horse, but here also he proved equal to the occasion, for he at once set to work counting the beast's paces as indicated by his stepping with the right foreleg. In this way he reckoned his distances for nearly 230 miles, between Bárong Chaidam (lat. 36° 5′, long. 97° 3′) and Thuden Gomba (lat. 33° 17′, long. 96° 43′), and the results do credit alike to the explorer's ingenuity and to the horse's equability of pace."

An account of his journey will be found in the *Scottish Geographical Magazine* for 1885, p. 352.

After the Explorer comes the SURVEYOR. His business is to produce a detailed survey or map of the country. The operations of a cadastral[1] survey on a grand scale, generally made by the Government, are divided into two parts: (1) the great triangular survey, and (2) the topographical part, or the filling in of the details required for civil information.

Before we go further we should gain a thorough idea of the principles of triangulation, because on it are founded all the conditions of an accurate

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[1] A cadastral survey is properly and etymologically a survey made by a government for fiscal purposes. The word being derived from the Low Latin *capitastrum*=a register for a poll-tax. As such a survey was naturally carried out with the utmost completeness, the term "Cadastral Survey" came to be used equally with the term "Ordnance Survey," for the great Government Survey of Great Britain and Ireland.

map. The great property of a triangle is this, that of all plane geometrical figures it is the only one of which the form cannot be altered, if the sides remain constant, and that the three angles of a triangle are together equal to two right angles, so that if we know two of the angles of any triangle we can at once calculate the third angle by subtracting the number of degrees in the two known angles from 180 degrees, which is the sum of two right angles. If also we know the length of one of the sides of the triangle as well as the number of degrees in the angles, a very simple mathematical formula enables us to calculate the length of the other sides.

Now this is exactly what is done in the great trigonometrical survey made in this country by the Ordnance Survey:—The Surveyor measures what is called a *base line.* He purposely selects an absolutely horizontal plane otherwise conveniently situated for the purpose of measurement. The base line is seldom more than five or six miles long, but it is measured with "every refinement which ingenuity can devise or expense command." In the Ordnance Survey of the British Isles—to give an idea of the care with which such base lines are measured—the original base line, which was on Hounslow Heath, was measured in 1791, first with a steel chain, then with deal rods, next glass tubes, and lastly, again with the chain; and was over five miles long. Another line was subsequently measured seven miles long, on Salisbury Plain, in 1794, which is the base of the existing triangulation. The verification line at Lough Foyle, which was seven miles long, was measured with specially designed compound metal rods of brass and iron, 10 feet long, compensating like the balance and spring of a chronometer, so as to be independent of expansion and contraction, and their contact adjusted with microscopes. From this base once fixed, its latitude and longitude being most carefully taken, the surveyor measures the angles of suitably laid out triangles, and computes the length of their sides. Each of these sides in its turn becomes the base of a new triangle. The surveyor plants his instrument on the spot fixed on and measures new triangles, and gradually covers the surface of his island with a network of great triangles. The length of these sides are all calculated from the angles, not measured, but, as a matter of fact, the lengths of these sides so computed from angular measurements are infinitely more accurate than if they were actually measured with a chain.

So accurate, indeed, was the triangulation of this country that when the Ordnance surveyors verified their calculations 33 years after, in 1827, by actually measuring the check base on Lough Foyle, as already described, the greatest possible error was found to be less than five inches. This, be it remembered, was calculated from the base in Salisbury Plain, only seven miles long, at a distance of over 300 miles. The mean length of the sides of the triangles was 35 miles, and the longest side was 111 miles. The history of the triangulation is quite a romance, but Sir Charles Wilson referred to all this at length, last month.[1]

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[1] *The Scottish Geographical Magazine,* vol. vii. p. 248. An admirable popular account of the operations of the Ordnance Survey will be found in *The Ordnance Survey of the United Kingdom,* by Lieut.-Col. T. P. White, R.E. (Blackwood, 1886).

The instrument with which the angles are measured is the theodolite. This net-work of triangles so laid down is the backbone of all details of map-making. All these imaginary sides of triangles are, like the parallels of latitudes and meridians on large maps, the lines to which all the filling in of detail is referred. Every point on this net-work is absolutely fixed, and from these points, as from the line of lamp-posts we considered at the beginning, all details are measured. The great triangulation in the Ordnance Survey being complete, the officers then lay off from the great triangles what are called secondary triangles, the sides of which are about five miles in length, and, where necessary, tertiary triangles, with sides of about one mile in length, and from them the surveyor breaks up the interior of the triangle with a net-work of cross lines, all self-checking when laid on the paper, and this is the beginning of ordinary land-surveying.

LAND SURVEYING.—The filling in of a survey is like writing a book. Men work differently. No two surveyors use exactly the same method of working, and it very much depends on the nature of the ground, the extent of his resources, and the accuracy of detail required what method the surveyor employs. In a theoretically perfect survey the triangular system would be pursued throughout, but in practice this is not necessary, nor is it done.

Of the methods of filling up, which are several, I will briefly describe two or three of the principal:—

Traversing with the Chain and Theodolite.—A traverse is defined as a circuitous route performed on leaving any place on the Earth's surface by stages in different directions and of various lengths with a view of arriving at any other place; the angles which the stages (or station lines) form with the meridian (*i.e.* the north and south line) are called bearings. In other words, it is a walking from point to point in straight lines, always recording your distance and your direction.

These traverse lines are measured with the chain. They are generally laid out round the country to be surveyed, and are as multifarious as the necessities of the ground require. The bearings in a good permanent survey are measured with the theodolite, and when the traverse is complete it should be closed where begun, when, if no error is made, the bearing of the first line will read on the theodolite exactly as it read at the beginning. Cross checks and connecting lines are constantly taken to test the accuracy of the work, and, while the survey is going on, the measurements of all the features of the country are set down in what is called the Field Book. Where the line does not cross the natural features, perpendiculars, called offsets, are set off and measured from the traverse line to the bends and angles of all surface details—bends of streams, fences, houses, roads, and so on, and so the map gets filled in bit by bit. Either it is set off at the beginning from the Ordnance triangulation, or subsequently joined to it by trigonometrical measurements. Such detail may be made piecemeal and fitted in like a Chinese puzzle to the main map of the country and altered, or more minutely surveyed, according to requirements. For rapid and not very accurate purposes exactly the same methods may be adopted as for a military reconnaissance or sketch map, by pacing the traverse lines and taking the bearings with the prismatic compass, and this is what is generally done in military sketches. All these operations and measurements are noted in a field book, and are afterwards taken to the office and "plotted" on a sheet or sheets of paper.

There is also a contrivance for filling in a survey, with which no field-book is used, but by which very fairly accurate work may be obtained. It is very little used in this country except for military purposes, and then generally in a modified form shortly to be noticed; but it is much used for topographical work in India and on the Continent, and the United States. This instrument is the *plane table.* It serves itself as a theodolite, and the plan actually grows on the ground without after office-work.

CONTOUR LINES.—A very important part of a cadastral survey is the plotting on the map of contour lines, or lines of equal height. This is done after the features of the surface have been mapped. To draw the contour lines we must have a starting-point, or, as it is called, a datum level. In our Ordnance Survey this is the level of the mean tide at Liverpool.

From the datum great lines and cross lines of levels are run all over the country, covering it with a net-work; and at all convenient spots the heights are permanently recorded by the well-known Broad-Arrow, and called bench-marks. Wherever the Broad-Arrow is found engraved on the ground, its height from the datum line will be found in the Ordnance map of that part of the ground. A very common spot to find an Ordnance bench-mark is the keystone of the arch of a bridge, which would naturally be the last thing to be removed. These levels are got by spirit-levelling. When the main levelling operations have been completed, the surveyor fixes at what intervals of height his contours are to be drawn.

The surveyor starts, let us say, to determine the line at 100 feet above datum. He goes to the nearest bench-mark he has to this height,—say it is 105 feet. He levels down until he finds a point 5 feet below this bench-mark. There he leaves a flag, or a peg, and goes on finding point after point at the same level; that is, he must read the same figure on the levelling staff. These points he then surveys as he would any natural feature, and permanently marks the imaginary lines joining them on the map, thereby showing a line of equal heights.

MILITARY SKETCH, or RECONNAISSANCE, is a form of map which ought not to pass entirely undescribed. The object of a staff officer in making a sketch is to give such a representation of the nature of the ground as will give useful information to his general. It may take any amount of elaboration—may be as complete as a cadastral survey taken with instruments of precision, or it may be merely the roughest indication of the nature of the ground, taken with such instruments as may be carried in the pocket, or even improvised without instruments, and be a mere eye-sketch of the features of the ground. As the military information generally desired is the nature of the ground—whether suitable for manœuvring, for artillery, for cavalry—the nature of the roads, of the hills, of the rivers, should all be looked to, and rough contouring and hill-shading is a very important part of the officer's work. He must also get information of defensible spots, of the water supplies, the food supplies, and the resources of the country, and this should be embodied as much as possible on the plan, or on the report attached to it.

Though any degree of elaborateness may be used, any instruments of precision employed, the typical military sketch is made with a sketching case, which is merely an improvised plane table. The main lines or traverses are taken from the bearings of the prismatic compass laid down on the sketch itself. The lines are generally paced or guessed, distant objects fixed by bearings from the station points, and the contouring measured angularly by Abney's level, or sketched by the eye. The shading of the hills shows steepness by the lines used to indicate them being drawn closer or further apart.

CARTOGRAPHER.—The plans and maps having been drawn, and all notes made of information, they reach the cartographer or atlas-maker. His duty is first to compare all new information with what is already known. To eliminate manifest errors, to reduce to scale and to projection uniform with his great maps of the same part of the world, and generally to make everything ship-shape for publication.

ATLAS MAKING.—I do not here refer to the Ordnance Survey maps, drawings, and prints, which were described with the utmost detail and precision by Sir Charles Wilson, but to the general atlases, such as Johnston's and Bartholomew's. With the information so gleaned the cartographer is able to make those beautiful orographical maps, which are now so common, showing different levels.

In our diagram I have coloured the island orographically, which is done by drawing the contour lines and washing over the areas so marked with different variations of tint. But I shall not go far into this subject. Mr. Bartholomew must do that some other day. Imagine the map drawn. It may be then engraved, like any other picture or line engraving, on a copper-plate, and either printed from that plate or from lithographic stones, to which an impression of the plate has been transferred.

In the Ordnance Survey printing-office, instead of lithographic stone, the maps are printed from sheets of zinc, which has much the same property of absorbing greasy ink.

By this time we have got into the printing-office, and to describe it in detail would be beyond my province; this part of the subject, though very interesting, really embraces the whole art of the engraver, the lithographer, and the printer. But there is one process I desire to show before closing.

You see daily in books and newspapers, and in our own journal, maps printed in black along with the type. There are numberless processes for their production—one only I shall briefly note. It is the type-process of Messrs. Walker & Boutall, who have kindly sent me a specimen in course of manufacture.

On a brass plate a coating of a waxy composition is laid; the outlines of the map are either drawn on this coating or photographically transferred to it. The engraver then scratches through the wax down to the brass with a needle. He next takes suitable types, and stamps in the names also down through the wax to the brass, and completes the matrix with the necessary amount of detail, which may be great or little. After verification and correction the matrix is ready for electrotyping. You who know the appearance of stereotype moulds will see that this resembles the mould of an ordinary stereotype or electrotype page. The mould is next covered with black-lead, and an electrotype taken from it, when all the punctures that have been made through the wax to the level brass plate come out level—the scratches as lines, and the type as lettering. It is then mounted on wood, and is ready to insert among type and be printed along with it.

I have tried to give you very roughly an outline of how maps are made from the beginning to the end, in almost the same form that actual necessity forced me to learn it for practical use.

REWA RIVER, FIJI.

By H. H. Thiele.

(*With a Map.*)

It is with the view of contributing some useful information about a small part of Fiji that I take the liberty of laying this paper before the Royal Scottish Geographical Society.

During the last thirty or forty years several books have been published describing these islands and their inhabitants, but, without being exactly unfaithful to the subject on the whole, the authors have evidently written with a view to the sale of their books rather than for the purpose of imparting accurate and useful information. Dr. Seemann's *A Mission to Fiji* forms an honourable exception, but yet I cannot help thinking that if he had resided five or six years amongst the natives of these islands, the experience he would have gained would have led him to alter his opinion on several subjects relating to them.

The Fiji group consists of two large islands, Viti Levu (Large Viti) and Vanua Levu (Large Land), and upwards of 250 smaller ones, ranging in size from over 200 square miles (Taviuni) down to islets consisting of an acre or less of barren rock. All the islands together make up an area of about 7400 square miles, of which about 4200 square miles belong to Viti Levu, the island dealt with in this paper.

A cursory glance at a map shows that the island of Viti Levu is of an oval shape; it is about 97 miles long from east to west, and 67 miles across from north to south at its broadest part.

Although the island is of no great extent, its climate varies very considerably in different parts; generally speaking, the southern and eastern districts and the greater part of the interior receive plenty of rain, while