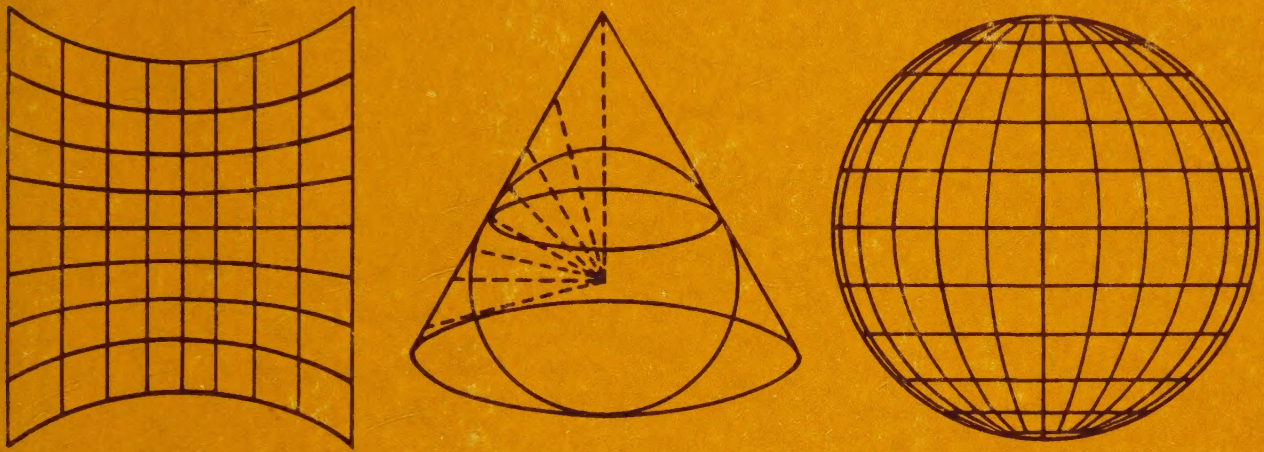
A GUIDE TO
MAP PROJECTIONS



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MAP PROJECTIONS

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FOREWORD

THIS little book, designed primarily for Sixth Form Geography students, aims at covering the requirements at Advanced Level of the various G.C.E. Examining Authorities, most of which, but not all, do not demand actual constructions of map projections. Experience in teaching and, in the case of one of the authors, in examining, has shown that, probably because of its precise character, many students are keenly interested in the subject of map projections, especially when the mathematical hurdle has been overcome. The approach in this notebook is *geographical* rather than mathematical; hence the unusual arrangement of the headings and the contents of each chapter. This allows the student with the minimum of mathematics to work through without loss of sequence, while those who are inclined or required to master constructions can continue with this more mathematical aspect from the text appearing in small type in the latter part of each chapter.

An attempt has been made to anticipate the several difficulties in the study of map projections in schools. The geographer's chief tool is the map; hence its properties and limitations must be appreciated if its correct use is to be ensured. Sufficient mathematics for the actual construction of map-projections often cannot be assumed; hence we have relied in the earlier parts of chapters on the use of "qualitative" statements rather than "quantitative" mathematical expressions, despite the fact that substitution is at times not entirely satisfactory.

Another difficulty in the classroom arises from the fact that little time can be afforded for this single topic—only one of many in the wide field of study. The examples of projections chosen have therefore been restricted to those specified in the various G.C.E. syllabuses. Most, but not all, are common to these examination syllabuses.

Since it has usually been possible to give diagrams of only the "nets" and not the "map" outlines, *constant reference should be made to atlases.* A twofold difficulty arises in the use of modern atlases in that a few of the examples may not appear at all, having been replaced by new projections (sometimes specific to the particular publishers) too difficult in construction for full comprehension by the Sixth Form student. It is hoped, however, that the principles involved in the study of comparatively simple examples will give some measure of comprehension of the more complex types appearing in modern atlases.

Students who do not actually make the suggested constructions may nevertheless profit from the drawing of neat sketches of map-nets, especially if some such convention is used as continuous lines where latitude and longitude are, by construction, represented true to scale and dotted lines elsewhere.

Some questions at G.C.E. (Advanced) standard have been given in Chap. 7 and the authors wish to express their thanks to the relevant Examining Authorities for permission to use them.

G. A. G.
R. E. B.

CONTENTS

1

THE PROBLEM

Plane and Spherical Surfaces

The earth is nearly a sphere; hence its surface can be truly represented only by the globe. It is indeed impossible to represent with complete accuracy any considerable portion of the wholly round earth's surface (which extends in three dimensions) upon a flat or plane surface (which extends in only two dimensions). Examination of a globe will show the "triangle" formed by two meridians at 90° and the equator, contains *three* right angles—thus illustrating one difference between "plane" and "spherical" trigonometry. One might almost succeed in sticking gummed paper the size of a postage-stamp on a large globe without serious ruffling but one would be far less successful with a larger square of paper—an illustration of the fact that the greater the area of the world to be shown on a flat surface, the more serious becomes the problem of complete accuracy.

Before considering the methods used to attempt a solution of this problem of representing what is curved upon a flat surface, it is essential to study *on a globe*, preferably one on which they are clearly marked (e.g. in white on a black surface) the lines of latitude (*parallels*) and of longitude (*meridians*). These lines form the framework, the transferring of which to a plane surface constitutes the main task of map projection. Once such a grid has been established, features such as coasts and islands can be plotted from known data giving the co-ordinates of latitude and longitude of a sufficient number of points on the features concerned. Such a grid or framework is often called a "*graticule*" or "*map-net*", though the word map "projection" is still used in spite of the fact that most maps are drawn on graticules which have not been "projected" in the geometrical sense.

Our first concern, then, is with the study, at first hand *on a globe*, of parallels and meridians.

Characteristics of Parallels and Meridians on the Globe

From an inspection of the globe the following properties of parallels and meridians, *on the globe*, can be deduced:

(i) Meridians and parallels cross at right angles.

(ii) Meridians are of equal length and converge at the poles.

(iii) The poles are points on which all meridians converge.

(iv) Parallels are circles, equally spaced along the meridians.

(v) Parallels decrease in length polewards; hence the length of the intervals between the meridians along the parallels varies from nothing at the pole to a maximum at the equator (which is the only line on the globe where distances between meridians are the same length as the distances between all parallels).

(vi) The equator and all complete meridians are earth circumferences and together with other circumferences are called *Great Circles*. Great Circles are important in navigation by sea and air because the shortest route between two points on the earth's surface is along the Great Circle on which they lie.

It is sometimes possible by inspection and measurement of meridians and parallels on a map, to find out which of the characters of the globe a graticule retains and therefore to discover in which respects it is accurate. Although the map-maker cannot obtain accuracy in every respect he may, after considering the uses to which he wants to put the map, aim either at getting some specific property accurate, or at obtaining a graticule which will give him a map in which, while no property is wholly accurate, there is a minimum of error all round. It is important to know what properties may be required in an atlas map and also the terms used to describe them, hence we now turn to the consideration of the terms used in describing the properties of map-nets.

Map Properties: Terms

Four properties in which accuracy may be sought in a map are:

(*a*) AREA, (*b*) DIRECTION, (*c*) SHAPE, (*d*) SCALE.

It is possible by sacrificing other properties to obtain maps which preserve correct area in all parts. The Mercator net alone achieves complete accuracy of direction. No atlas map, however, can give absolute accuracy of scale, while true shape can be achieved only in a limited sense (if scale and shape could be truly shown in all parts of a map there would obviously be no problem of map projection!)

The uses to which a map may legitimately be put are determined by its projection, which gives the map certain characteristics while denying it others. Knowledge of the properties of maps constructed on different projections is thus essential to the geographer, whereas the method of mathematical manipulation necessary to achieve these properties is largely the field of study of the cartographer and the mathematician.

Recognised terms are used for maps based on nets attempting to show accuracy of the properties enumerated above, and although shape and scale can never be wholly accurate, nevertheless the terms applying to those properties are sometimes used for certain map-nets in which they are partially preserved.

(*a*) AREA ACCURACY—EQUAL AREA OR HOMOLOGRAPHIC

An equal area map preserves correct area in all parts of the map. This can be wholly achieved by distorting shapes. Equal area map-nets are of great use in the mapping of statistics involving area comparisons, e.g. commodity distributions, population density, political areas, etc.

(*b*) DIRECTION ACCURACY (*no special terms*)

Many map-nets have limited accuracy of direction, e.g. from their centres only, or merely in one or two directions, but the Mercator "Chart" (to be studied in Chap. 3) preserves direction in all directions and in all parts of the graticule.

(*c*) SHAPE ACCURACY—ORTHOMORPHIC (CORRECT SHAPE) OR CONFORMAL

On the globe, parallels and meridians cross at right angles and some maps may be called "orthomorphic" if their net lines also cross at right angles. But accuracy of shape can only be achieved at the expense of the area property; it involves the distortion of *large* areas. On an orthomorphic map the scale about a point can be correct and small features can have correct shape, but large features are distorted. For instance, on a map of the British Isles drawn on such a projection, the shape of such small features as the Isle of Wight, Holderness and the Fife peninsula would be preserved, but, owing to their differing latitudes, the increase in the scales varies between the different areas so that when the whole is assembled as the British Isles the overall shape is not correct.

(*d*) SCALE ACCURACY—EQUIDISTANT

Scale is the relationship between distances on the map and the corresponding distances on the earth. No map can wholly achieve the equidistant property, although some graticules maintain it correctly in certain directions, e.g. along certain parallels or meridians, or from the centre of the map. The map-maker has to be satisfied with, for example, correct scale in certain directions and minimum error in all others, varying with the purpose for which the map-net was constructed.

Scale is a vital consideration, especially on parallels and meridians. Two aspects of scale on parallels and meridians concern us here:

(i) The method of calculating the length of the divisions into which meridians and parallels are divided to give the degrees of latitude and longitude to be used—on the *scaled* globe (e.g. a net of 10° of latitude and longitude on a globe scaled to a radius of 4 inches).

(ii) Some results which follow from *varying* the scales along the meridians and parallels in regard to the properties of shape and area.

Scale—Scaled Lengths of Latitude and Longitude Divisions

Even for those who do not require actually to

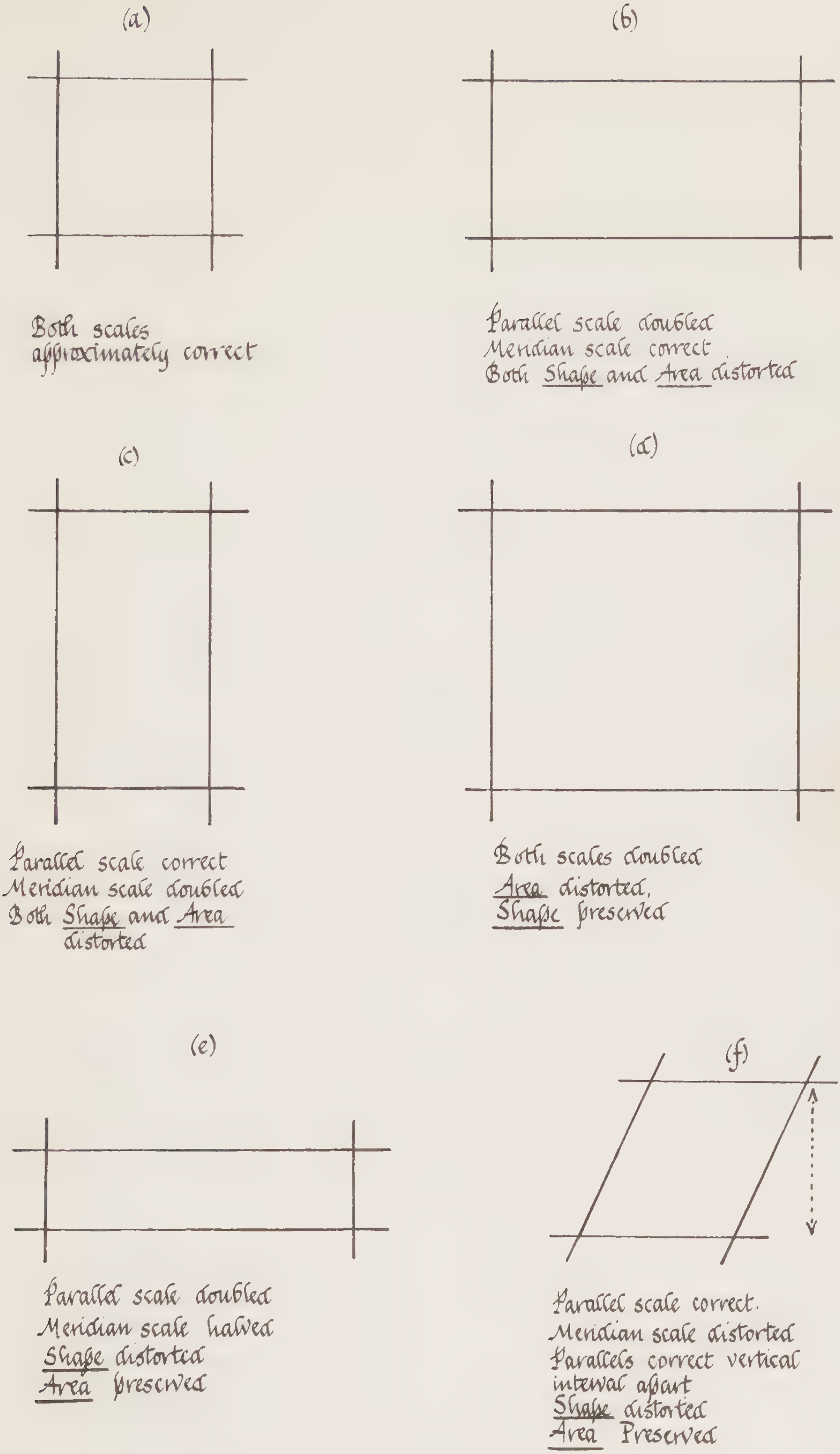

(a)
Both scales
approximately correct
(b)
Parallel scale doubled
Meridian scale correct
Both Shape and Area distorted
(c)
Parallel scale correct
Meridian scale doubled
Both Shape and Area
distorted
(d)
Both scales doubled
Area distorted,
Shape preserved
(e)
Parallel scale doubled
Meridian scale halved
Shape distorted
Area preserved
(f)
Parallel scale correct.
Meridian scale distorted
Parallels correct vertical
interval apart
Shape distorted
Area Preserved

Fig. 1

construct map-nets, comprehension of their properties is helped by an understanding of the simple mathematics necessary to calculate the scaled distances of the divisions of (*a*) latitude (set out equally along meridians) and of (*b*) longitude (set out along *each* parallel):

(*a*) LATITUDE

All meridians are earth circumferences; hence if R is the radius of the earth to the scale used, the distance to scale of 1° latitude $=2\pi R/360$ and $x°$ latitude $=2\pi Rx/360$ (e.g. setting out for every 10° latitude with an earth scaled down to a radius of 4 inches, the distance intervals of the latitude divisions $=2\pi 4\cdot 10/360$ inches).

(*b*) LONGITUDE

The values of the divisions of longitude, to be set out along *each* parallel, are a little more difficult to establish. For those wishing to follow the mathematical reasoning used in obtaining these values the necessary data are given at the end of the chapter. Here it will suffice to state that it is usually convenient to express intervals of longitude in terms of 1° of longitude at the equator, in which case longitude interval along a parallel $=d \cos \theta$ where $d=1°$ longitude at the equator (the value of which is the same as 1° latitude since the equator itself is an earth circumference) and $\theta=$the latitude.

Scale—Variations in Scale in Relation to Area and Shape

In map projection we are primarily concerned with the scales along meridians and parallels, since the extent to which a graticule corresponds to the network of lines of latitude and longitude on the globe depends upon the errors in scale which the particular projection produces. Certain variations achieve equality of area, others sacrifice area but may produce correct shapes (in the limited sense). The effects of some variations in scale are illustrated in the accompanying diagrams. Fig. 1*a* represents a very small area near the equator (*on a graticule*) bounded by two parallels and two meridians. Over such a small area scales along both meridians and parallels may be regarded as approximately correct. In Fig. 1*b* the parallel scale has been doubled while the meridian scale has been maintained correct. As a result the area has been increased and the shape distorted. When the meridian scale is doubled and the parallel scale preserved, as in Fig. 1*c*, both shape and area are again distorted. The effect of doubling the scales along both meridians and parallels—i.e. of increasing both scales in the same proportion—is seen in Fig. 1*d* where area is obviously distorted but shape preserved. In Fig. 1*e* the parallel scale has been doubled, the meridian scale halved; i.e. they have been varied in inverse proportion and consequently shape has been distorted but area preserved. These examples are all ones in which meridians and parallels on the graticule intersect at right angles. Certain projections, however, produce graticules which are not rectangular, and though these distort shape they may preserve area. One method by which this may be achieved is that of keeping the parallel scale correct and also maintaining the parallels the correct *vertical* interval apart. This is illustrated in Fig. 1*f* where a parallelogram on a base of the correct length and of the correct vertical height has been produced, maintaining an area equal to that shown in Fig. 1*a*. These relationships of scale variation to area and shape will be illustrated in later chapters when specific nets are discussed.

(*For those whose desire is not only to comprehend but actually to construct certain map-nets there follows a section giving the minimum of mathematical knowledge necessary for such constructions. This section and others in small type may be omitted without interfering with the sequence.*)

Construction of Map-Nets—Preliminary Considerations

Some knowledge of the methods by which parallels and meridians may be divided, the former into intervals of longitude and the latter into intervals of latitude, is essential for the construction of graticules.

(*a*) INTERVALS OF LATITUDE ALONG MERIDIANS

The interval of latitude is marked off along meridians each of which is a circumference, and hence of length $2\pi R$ (where $R=$the radius of the globe to scale). As a circle contains 360°, one degree of latitude $=2\pi R/360$ while the linear measurement of any interval of latitude, $x°$, is found by $2\pi Rx/360$. Since the equator is also an earth circumference this value is also true of longitude intervals along the equator only, but not elsewhere since east–west measurement everywhere else is along parallels which are smaller than circumferences, decreasing to a point at the poles. These intervals may also be calculated approximately by a simple graphical

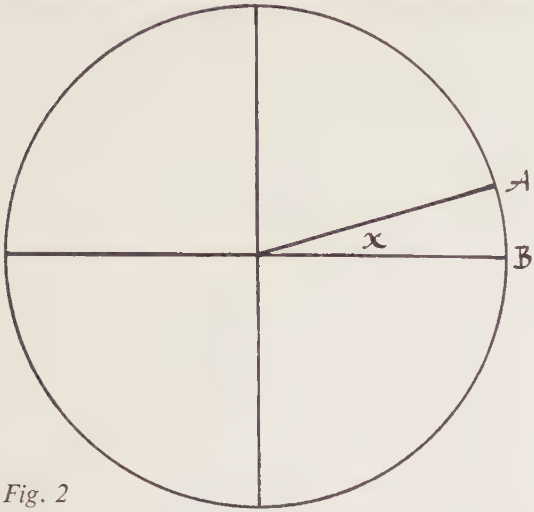


Fig. 2

method (Fig. 2). A circle is drawn to scale to represent the earth, and polar axis and equator are added. With a protractor a radius A is drawn at the required interval of latitude $x°$. The correct linear distance is then given by the arc distance AB, but on such a small scale this is approximately equal to the chord distance AB, which latter may be used in simple graphical constructions.

(*b*) INTERVALS OF LONGITUDE ALONG PARALLELS

The interval of longitude has to be marked off along each parallel and as the parallels are of different lengths, it is usually necessary to make a separate

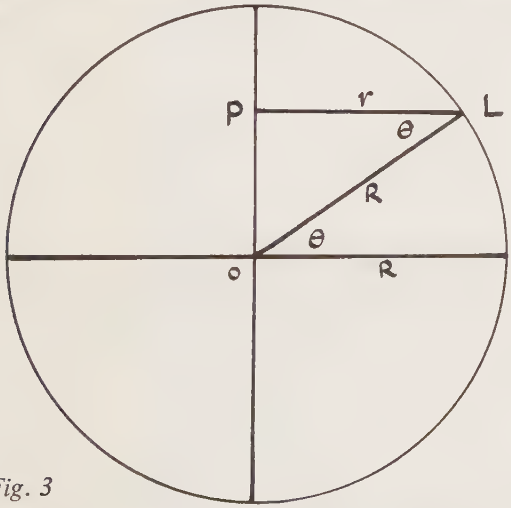


Fig. 3

calculation ior each of them. The full length of any parallel can be calculated if the radius R, of the globe to scale, is known, say 4 inches (see Fig. 3). Here the parallel selected is $\theta°$ N. and a radius has been drawn at this angle, and the radius r of the parallel has been erected at right angles to the polar axis. The full length of the parallel will then be $2\pi r$. But in the right-angled triangle LOP,

$$\frac{r}{R} = \frac{\text{adjacent side}}{\text{hypotenuse}} = \text{cosine } \theta.$$

Therefore $\frac{r}{R} = \cos\theta$ and $r = R\cos\theta$.

Hence the length of parallel $\theta°$ N.$=2\pi R\cos\theta$, and as R is known (4 inches) this can easily be calculated. From this the meridian interval to be marked along any parallel can be found, remembering that there are 360° around any parallel. Thus if x represents the interval of longitude in degrees, the linear interval to be marked along any parallel will be $2\pi R \cos\theta x/360$. In practice, the calculation is usually based not upon the radius of the generating globe R, but upon the linear equivalent of an interval of one degree of longitude along the equator. In terms of the above, this interval, d, $=2\pi R/360$, and from this it follows that the intervals to be marked along any parallel will be $d\cos\theta$.

(A simple graphical method of determining the interval is shown in Fig. 4. A circle has been drawn to represent the globe to scale and radius OL drawn as parallel θ. Radius OA has been drawn at the interval of longitude required, viz. $x°$. With radius AB and centre O an arc has been drawn cutting OL at y and a perpendicular to the polar axis erected through y. This line xy is then the linear interval to

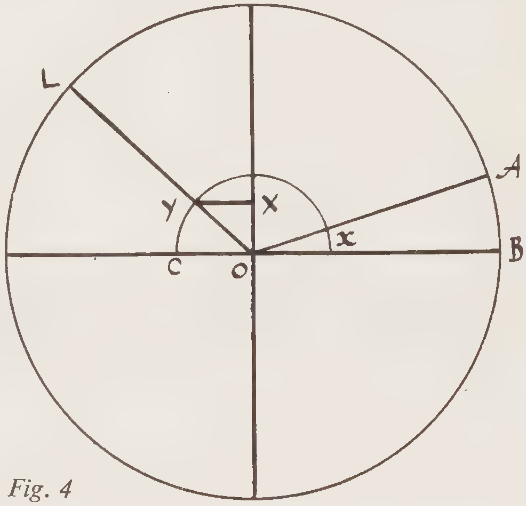


Fig. 4

be marked off along parallel $\theta°$ N. It should be noted that distance AB is the *arc* distance although in small scales an approximation may be obtained by taking the chord distance.)

(*c*) EXAGGERATION OF PARALLEL SCALE

In some cylindrical projections (the term cylindrical will be explained in the next chapter) all parallels are drawn equal in length to the equator, producing an obvious distortion. It is important to know what exaggeration of parallel scale this entails. On Fig. 3 the length of the equator is $2\pi R$ and on the graticules all parallels are made this length! But the true length of a parallel on this diagram (say θ° N.) is only $2\pi r$. Thus the exaggeration of that parallel on a graticule is $2\pi R/2\pi r = R/r$. But in the right-angled triangle LOP, R/r = hypotenuse/adjacent = secant θ. Therefore the scale along any parallel on a graticule where parallels are shown equal in length with the equator, has been exaggerated by an amount proportionate to the secant of the latitude.

2

MAP PROJECTION GROUPS

The Making of Map Projections and Nets

Having noted the possibilities and limitations inherent in the essential task of the map-maker—the attempt to transfer parallels and meridians from the curved surface of the globe to a plane surface so as to make his net or graticule—we can consider *how* this may be done.

Imagine a skeleton globe consisting solely of a wire framework representing meridians and parallels, with a source of light at its centre. In this way shadows of meridians and parallels could be "projected" on to any surface surrounding the globe. Of geometrical figures having curved surfaces which can be rendered flat, the cylinder and the cone are the most obvious; both could be placed to enclose the globe, the "shadows" projected on to their curved surfaces representing parallels and meridians. If these shadows could be retained (e.g. by photography) and each curved surface unrolled or "*developed*" to provide a flat surface the result would be a graticule. Yet another way of achieving this would be (in theory—though it might prove difficult in practice) to use a flat piece of paper at a tangent to the globe, e.g. at the north pole, and project straight on to this tangent plane. Projections based thus upon the tangent plane, the cone and the cylinder form three of the groups of map projections and are termed (i) *Tangentials* (usually called *Zenithals* or *Azimuthals* because they preserve correct bearing from their centres), (ii) *Conics*, and (iii) *Cylindricals*. But many "projections", even if they have been derived from one of these groups of projections, are not projections in the perspective sense but are derived from mathematical formulae. Such nets are often placed in a fourth group, viz. (iv) *Conventional* and in this group are many of the most widely used maps. The term "projection" is still in general use although in all four groups most maps are drawn on meshes which are mathematical rather than perspective in construction and are therefore better called "nets" or "graticules".

For our purposes we are concerned with only a few examples from each of the four groups, but before attempting to study specific nets some further general considerations of the first three groups and especially of terms employed, will assist in understanding the principles of projection, not only in purely perspective projections but also in other useful nets which have been derived from them.

Tangential (Zenithal or Azimuthal) Projections

Here (see Fig. 5) projection is on to a plane surface which is at a tangent to the globe. The point at which the plane touches can be varied, to give three *cases*:

(i) *the polar case* when the plane touches at a pole,

(ii) *the equatorial case* when the plane touches at the equator, and

(iii) *the oblique case* when the point of contact is at some point between pole and equator.

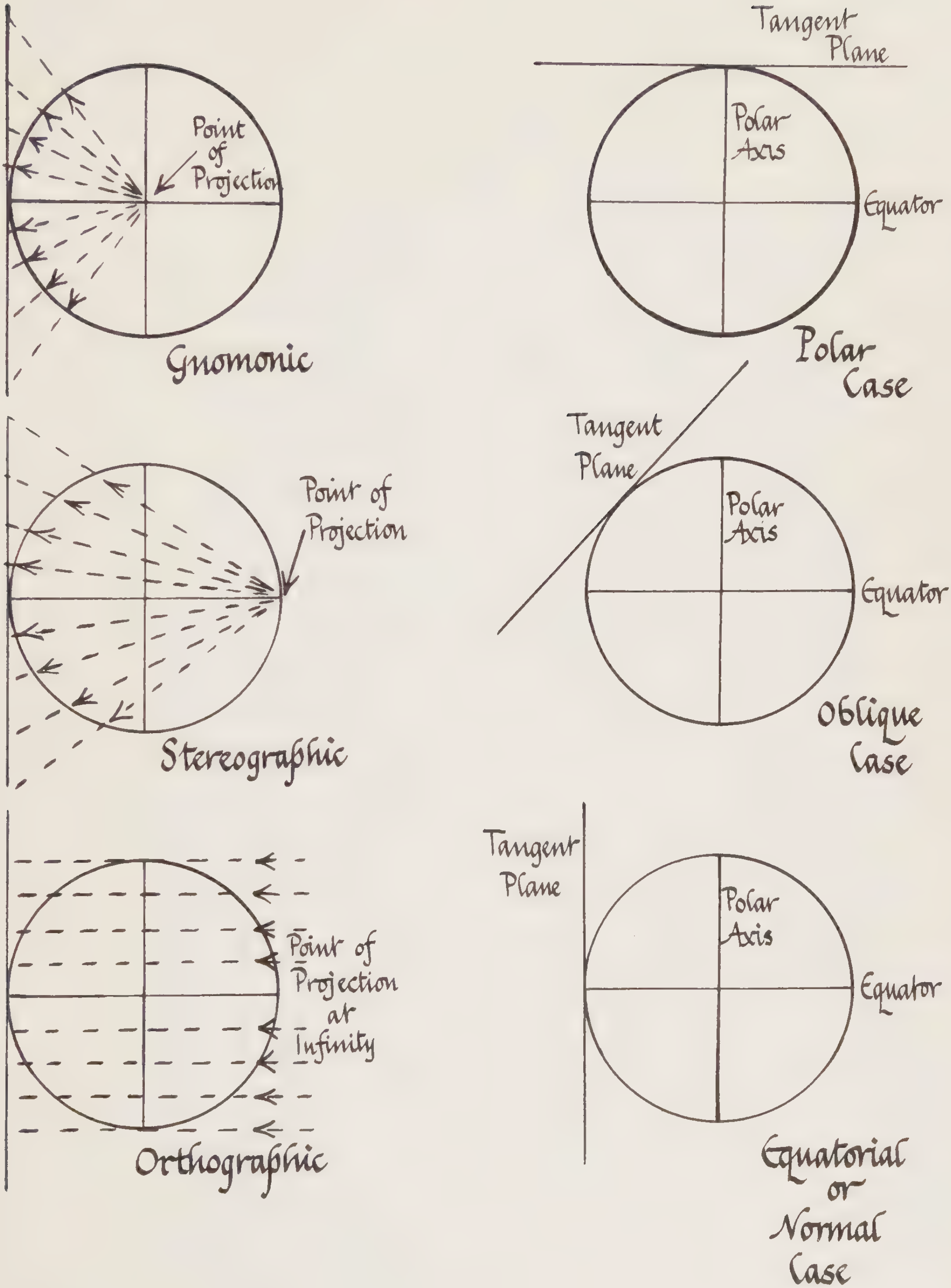

Point
of
Projection
Gnomonic
Point of
Projection
Stereographic
Point of
Projection
at
Infinity
Orthographic
Tangent
Plane
Polar
Axis
Equator
Polar
Case
Tangent
Plane
Polar
Axis
Equator
Oblique
Case
Tangent
Plane
Polar
Axis
Equator
Equatorial
or
Normal
Case

Fig. 5

This ability to choose the point of contact has results of great value, for there is usually less distortion of the map near the centre (i.e. the point of contact) and a contact point can be chosen which is most suitable for the country or area to be represented.

Previous reference has been made to a source of light at the centre of a wire mesh globe "projecting" shadows on to an adjacent surface. Although in practice no such light is used, it is convenient to think of this source as *the point of projection*. Three such points may be used (see Fig. 5).

(i) from the centre of the globe, giving GNOMONIC PROJECTIONS,

(ii) from a point diametrically opposite to the point at which the plane surface is tangent, giving STEREOGRAPHIC PROJECTIONS,

(iii) from infinity; the rays of light being visualised as parallel lines, giving ORTHOGRAPHIC PROJECTIONS.

In general, gnomonic projections produce extreme exaggeration towards the edges of the map whilst the orthographic tends to compression in these areas. However, few simple zenithal projections are in common use, and those which are most popular are the ones most difficult to construct, viz. the oblique cases of the Zenithal Equal Area and the Zenithal Equidistant.

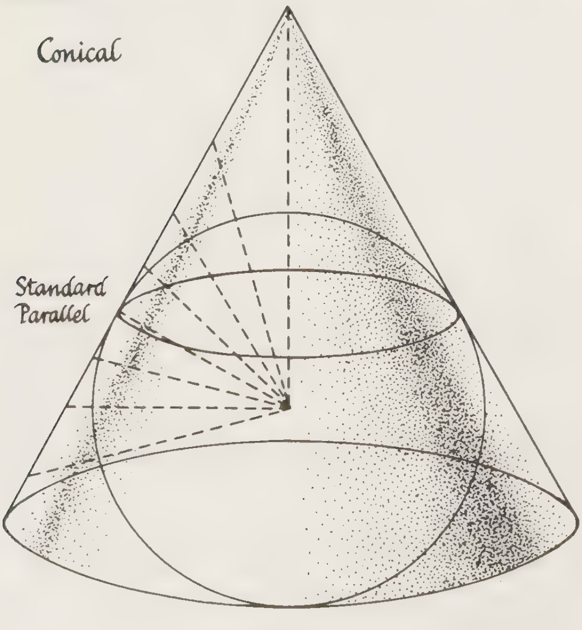


Fig. 6

Conic Projections (Fig. 6)

If a cone is placed on the globe with its apex vertically above one pole, it will be in contact with the globe along a parallel of latitude. This parallel along which the cone rests is known as the *Standard Parallel* and along it scale is correct and near to it there is little distortion of area or shape. In some cases the cone is visualised as cutting the globe; here the cone enters the globe along one parallel and emerges along another, both being regarded as Standard parallels. The point of projection (as in the Zenithal Gnomonic) is from the centre of the globe.

A projection which has one standard parallel produces exaggeration away from that parallel, whilst where there are two standard parallels the scale is exaggerated beyond them and is reduced between them. The advantage of conic projections is that by careful selection of the standard parallel so that it passes through the centre of the area to be represented, a graticule can be produced which shows little distortion over the area portrayed, especially where the area has little extent in latitude. Hence they are widely used for maps of small countries in mid-latitudes, for most parts of a small country will be near the standard parallel.

As no cone can touch the globe at pole or equator neither pole nor equator can be selected as a standard parallel, and the conic projections generally are not suitable for polar regions or high latitudes, nor for equatorial regions. Nevertheless theoretically the cone might be regarded as the basic shape for projection. When so "flattened" as to touch at the pole it becomes the plane surface of the zenithal; when so "widened" as to touch along the equator it becomes the cylinder.

Cylindrical Projections (Fig. 7)

Projection in this group is from the centre of the globe on to a cylinder which surrounds and touches the globe. The circumference or great circle along which the cylinder touches is normally the equator, and scale along this line is correct. Away from this line scale is distorted. As with the cone, so also the cylinder is sometimes visualised as cutting the globe, e.g. in Gall's Projection which is treated in Chap. 3. Projections which are "normal" (i.e. those which touch the earth along the equator)

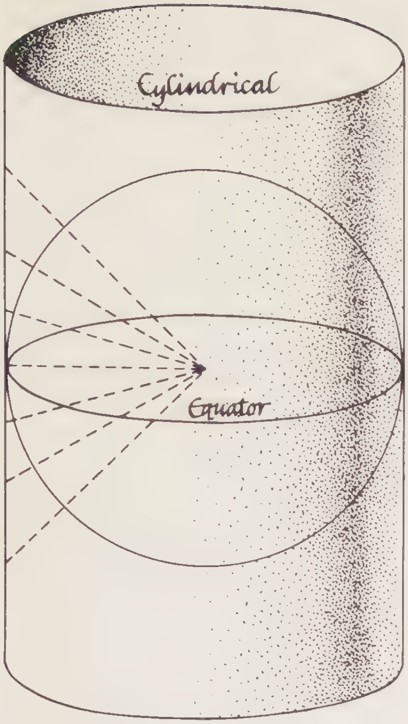


Fig. 7

produce good maps of low latitudes but distortion in high latitudes is pronounced.

Specific Projections (Chap. 3–6)

The particular few projections selected here for study are of necessity those which are comparatively easy to comprehend and which illustrate principles in construction and use. There are many graticules in bewildering variety which are mere mathematical abstractions and are never used by the geographer. Search in atlases should be made for examples of the nets to be studied, but it should be remembered that their use may be restricted or they may even be omitted and replaced by more complex projections favoured by the particular publishers, e.g. equal area nets of the world. Projections are sometimes named after their inventors and sometimes they are referred to according to their group and the property they exhibit.

Constant reference to atlases is essential for study of *maps* especially since here it is usually possible to give only the *graticules* on which maps are plotted.

ORDER OF STUDY

We commence with graticules of the *whole world*: first the Mercator as a unique example of a conventional net which sacrifices other properties to attain that of direction accuracy; then the Sanson-Flamsteed and the Mollweide, whose chief use is as world equal area nets but which also provide good graticules for maps of equatorial and tropical areas. Having thus covered regions of *low latitude* we turn to *high latitudes* where the polar cases of the Tangentials (Zenithals) are obviously the best choice. This leaves the very important *mid-latitudes*, and here the Conics are at their best.

3

THE MERCATOR CHART
(*and two other Cylindricals*)

Object of the Mercator Chart

The use of the compass (in the thirteenth and fourteenth centuries) and dead reckoning made sailing out of sight of land possible, but still hazardous, with the help of crude charts. There continued to be the need of charts which would permit the bearing of course between two places anywhere on the chart to be read off directly. Such a bearing held constantly from departure to destination would take a ship from one place to another. The Mercator net was evolved to meet this need and does so by sacrificing accuracy of area and distance in giving accuracy of direction on all parts of the chart.

Simple Observations on a Mercator World Map

The Mercator projection was used quite often until recently for world maps but in a modern atlas you may have difficulty in finding more than a single example. Examination of a world map on Mercator will show:

(*a*) MERIDIANS
The meridians are shown as equally spaced *parallel* lines which means that, as on the globe they converge on the poles, there is everywhere except at the equator east-to-west stretching.

(*b*) PARALLELS
As a result of this east-to-west stretching, the parallels are everywhere equal in length to the equator, which on the globe they are not. This shows that scales along the parallels have been exaggerated.

(*c*) SPACING OF PARALLELS
Distances between the parallels, which on the globe are constant, increase polewards indicating that along the meridians scale has been exaggerated.

(*d*) AREAS
Areas are grossly exaggerated towards the poles owing to the stretching in both north–south and east–west directions, e.g. Greenland looks larger than South America whereas it is really only one-eighth the size of the latter! The Mercator also magnifies Canada and the U.S.S.R.

(*e*) POLAR REGIONS
The far Polar Regions are not shown because the exaggeration has become so great; indeed the pole itself can never be shown as it lies at an infinite distance beyond the 89th parallel.

(*f*) CROSSINGS OF PARALLELS AND MERIDIANS
Crossing is everywhere at right angles and the net is orthomorphic and involves gross distortion of area in high latitudes.

The Principle of the Net—"Equal Stretching"

In order to keep accuracy of direction on this net, the east-to-west stretching is compensated by an *equal* north-to-south stretching. (Expressed in a different form this might be explained as compensating the increase in parallel scale by a proportionate increase in meridian scale.) This may be illustrated though not proved by a simple diagram, Fig. 8. This equal stretching explains the great areal exaggeration which increases with latitude. On the globe, parallel 60° N. is but a half of the length of the equator, but on Mercator it is of equal length; this twofold east–west stretching is accompanied by a twofold north–south stretching, giving a fourfold (2×2) areal exaggeration. At 80° on Mercator, parallel and meridian scales have each been increased six times, so that here the areal exaggeration is 36 (6×6); and at the poles stretching would be infinite—which is why this region cannot be represented at all. In practice, when a Mercator net is to be constructed, the intervals of latitude (or the intervals of longitude along the equator) are read off from tables in terms of 60 geographical miles or 1° of longitude at the equator: e.g. if at the equator 1° longitude is 1, then 1° of latitude at 10° N. or S. is 1·008, at 50° 1·552, at 60° 1·997 and at 87° 19·07!

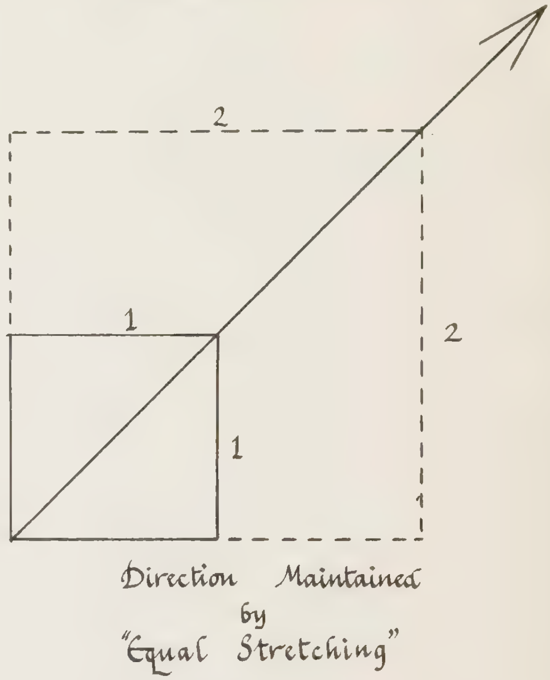


Fig. 8

Properties, Uses and Recognition

With the foregoing remarks on the character of the net in mind, one is equipped to consider some of the important geographical aspects of Mercator:

PROPERTIES
Its major properties are those of direction accuracy and orthomorphism:

(i) Direction is correct in any direction and in all parts of the "map" (better called "chart") since a straight line on it becomes a line of constant bearing. This property makes it of value for the sea and air navigator's "chart".

(ii) Meridians and parallels cross at right angles, and the projection is orthomorphic.

DEFECTS

(i) It cannot be constructed for the Polar Regions. The Polar Zenithal Gnomonic net—discussed later—is of some use, however, to the navigator in these regions.

(ii) Gross distortion of areas in higher latitudes limits its usefulness for general purposes, helping to explain the decline in its popularity in modern atlases.

(iii) Except along the equator, scale is incorrect and hence measurement of distance on it is very difficult since no single scale can be shown. Sometimes a separate scale is added for each 10° of latitude, the equatorial scale being the smallest. By using such a scale on ordinary navigational charts, e.g. in mid-latitudes and where the scale does not vary greatly over the chart's extent, fair measurement of distance can be obtained.

USES

(i) In equatorial and inter-tropical regions the exaggeration of parallel and meridian scales and of area is not very serious, hence Mercator is a *possible* net for low latitudes, e.g. East Indies, Inter-Tropical South America, and it even makes a fair net for Africa, which lies between 35° N. and 35° S. latitude.

(ii) Its straight edges make it an easy matter to fit adjacent sheets together, hence its use for Ordnance Survey Maps, e.g. One Inch, 6th Edition, for which it is employed in the modified and rather more complicated "Transverse" form.

(iii) Examination of atlases will show its geographical uses where direction is required, e.g. for winds, ocean currents, trade routes or voyages; but it must be remembered that the lengths of voyages cannot be read off, as scale is not constant over the map.

(iv) The *most important use is as a navigator's map or chart* because direction is everywhere correctly represented in any direction, thus making it possible to plot a course for ship or aeroplane on the map. Any straight line drawn on Mercator is a line of constant direction or constant bearing: i.e. it cuts parallels at a constant angle. Such a line of constant bearing is known as a *Rhumb line* or *Loxodrome*.

But a ship or aeroplane journey is concerned with shortest distance as well as direction; the shortest distance between any two points on the globe, as has already been indicated, is on the Great Circle passing through the points. But on the Mercator a Great Circle (or shortest distance route) is not a straight line except along the meridians and the equator. The problem then in sea and air navigation is how to reconcile the use of Great Circle routes with the property of direction accuracy given by Mercator, remembering that on Mercator a Great Circle route will be plotted as a curve with continuous change of direction. Consider (Fig. 9) a voyage from Cape Town to New York. If on a Mercator chart the navigator joined the two ports with a straight line and then, having measured the bearing of it, kept his ship on the bearing, he would eventually arrive at his destination; but he would not have followed the shortest route. When the Great

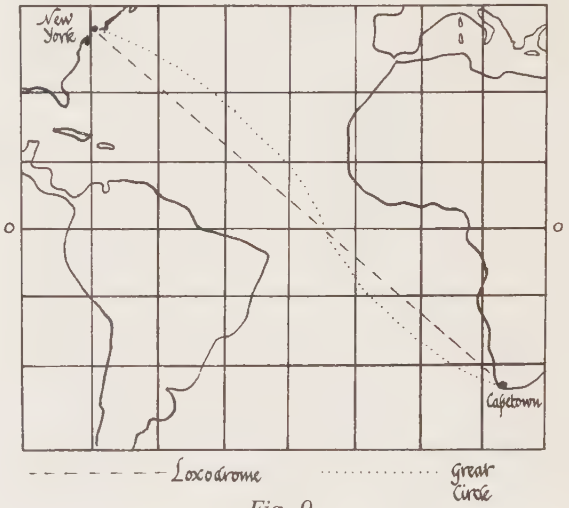


Fig. 9

Circle route is plotted between Cape Town and New York it appears as a spiral curve; this can be divided into a number of convenient "chords" each of which will be a line of constant bearing and have correct direction, and in practice the total length of the chords will add up to little more than the length of the curve itself. In practice, on well used routes, directions between ports are read off from prepared tables! It is interesting to notice that in the Northern Hemisphere the Great Circle routes trend north of the respective lines of constant bearing, and vice-versa in the Southern Hemisphere.

RECOGNITION

(i) The parallels are parallel straight lines of equal length, the intervals between which increase polewards.

(ii) The meridians are equally spaced parallel straight lines which cross the parallels at right angles.

The Mercator as the Cylindrical Orthomorphic Projection

The straight line parallels and meridians crossing at right angles are characteristic of cylindrical projections and Mercator may be classified as Cylindrical Orthomorphic. In the initial stages of its construction it can be regarded as derived from a cylinder touching the globe along the equator; but the later stages use conventional means of obtaining orthomorphism and accuracy of direction. This is done by varying the parallel and meridian scales in direct proportion (the principle of "equal stretching").

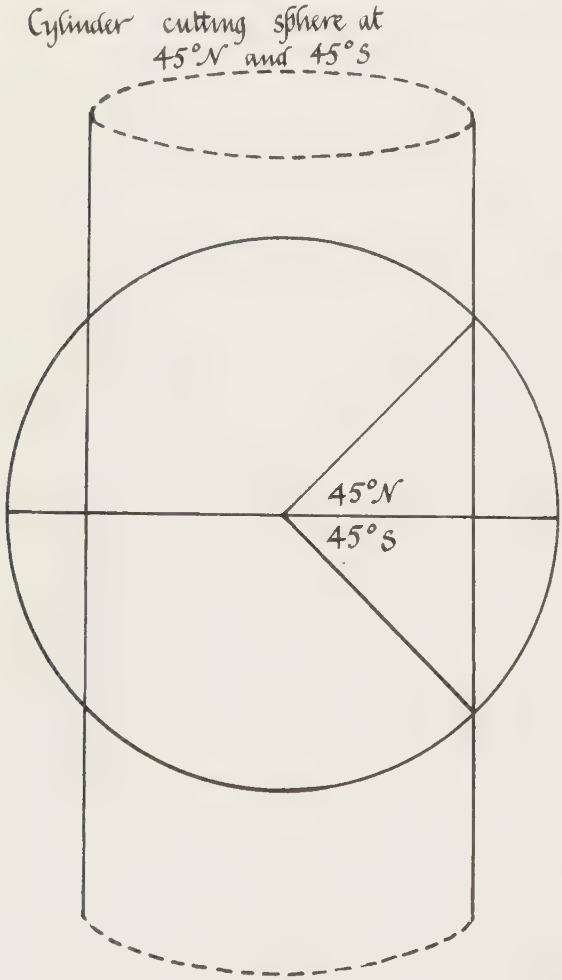


Fig. 10

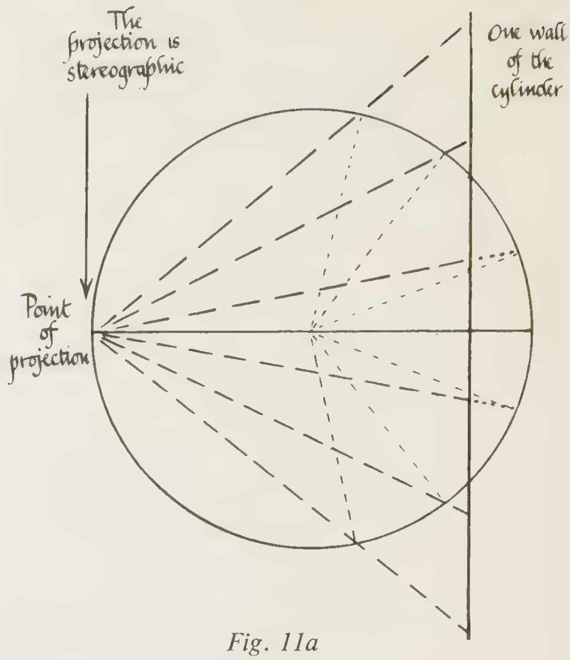


Fig. 11a

Two other cylindricals remain to receive a brief mention:

(i) A cylindrical aiming at a world net in one sheet, for general purposes and without the gross exaggeration of area of Mercator—Gall's Projection.

(ii) A cylindrical with the equal area property.

Gall's Stereographic Cylindrical Projection

In this net a cylinder, instead of touching along the equator, is visualised as cutting into the globe at, for example, Latitudes 45° N. and S., i.e. the radius of the cylinder is smaller than that of the globe. Projection on to the cylinder is stereographic (see Figs. 10 and 11*a*).

Examination of a world map on Gall's Projection (Fig. 11*b*) shows that the exaggeration of area in high latitudes, while considerable, is less than on Mercator. Though parallels and meridians cross at right angles, the east-to-west

Fig. 11b

stretching is not equalled by north-to-south stretching so that it has not the property of orthomorphism and the distortion of shapes is fairly obvious, especially in high latitudes. Direction accuracy is sacrificed and scale is correct only along the two parallels along which the cylinder is visualised as cutting the globe. Thus no property has been wholly preserved, but when used with discretion it is in no characteristic grossly inaccurate. Until recently Gall's net was much used in atlases but it has largely been replaced by equal area nets. The smaller exaggeration of the intervals between parallels and of area in high latitudes, together with the possibility of representing the poles on it, serve to distinguish it from Mercator. Another distinguishing feature is the narrowing of the continents, e.g. South America and Africa, between the parallels along which the cylinder "enters" the globe. This is the result of the reduction in scale between, and the enlargement of scale beyond, these parallels. Examination of many atlases will show the purposes for which it is used to be varied, in spite of its not being wholly suited to any one, i.e. it is essentially a compromise general purpose *world map* with parallels and meridians as straight lines conveniently crossing at right angles.

Cylindrical Equal Area Projection

This is one of the few nets which is a projection in a geometrical sense. The cylinder touches the globe along the equator, and thus on the graticule equatorial scale is correct. Projection on to the cylinder is from infinity by rays which are parallel to the equator. As Fig. 12 shows, meridians are parallel straight lines, correctly spaced along the equator. Because projection is from infinity by parallel rays the parallels can be spaced by drawing lines parallel with the equator through the latitude points on the circumference. Equal area results from all strips on the network having the same area as corresponding zones on the scaled globe. The closer spacing of the parallels towards the poles indicates that meridian scale decreases in this direction. Indeed it decreases in the same proportion as the parallel scale increases polewards—thus preserving areas. The increase in parallel scale is revealed by all parallels on the graticule being

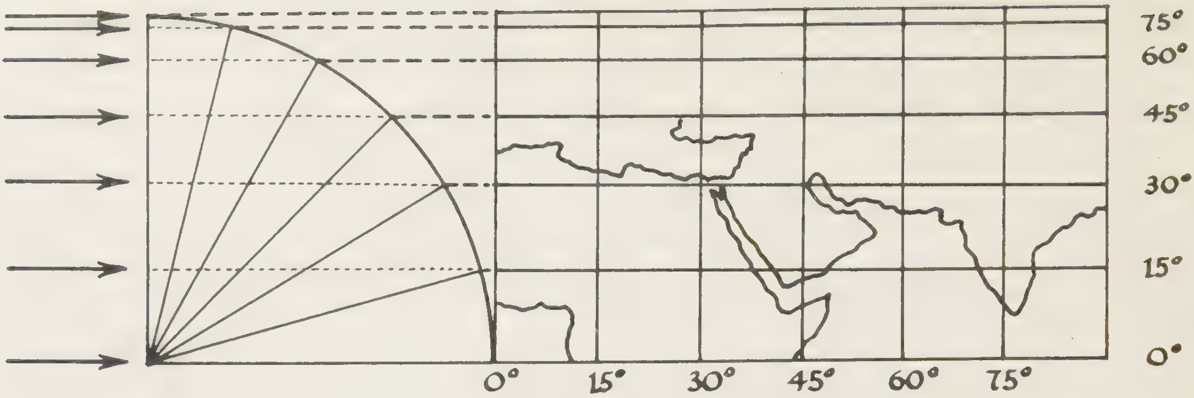


Fig. 12

equal in length to the equator—even the poles being lines of this length! Obviously the inevitable and enormous distortion of shape in high latitudes limits its usefulness; but in equatorial regions there is little distortion of shape and this, added to the valuable equal area property, and the convenience of straight meridians and parallels crossing at right angles, makes it a useful net for low latitudes, especially for the portrayal of distributions, e.g. equatorial forests or equatorial crops.

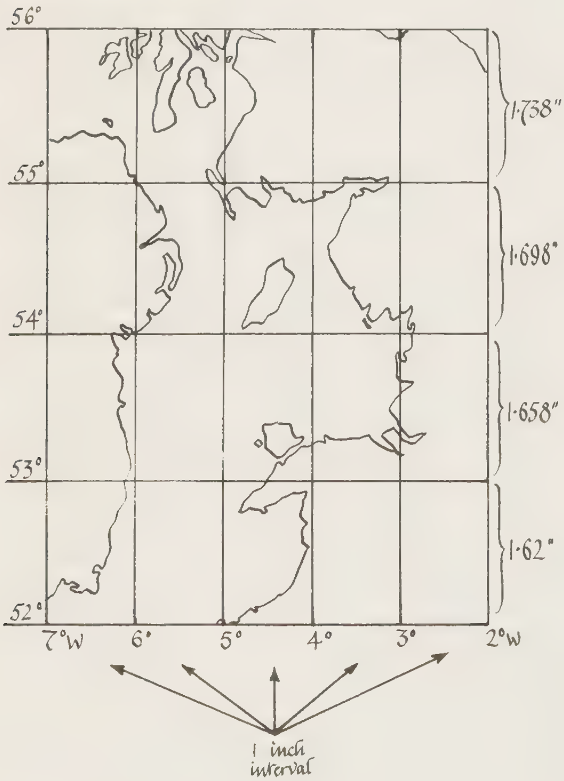


Fig. 13

(All of these three cylindrical projections provide, in varying degrees, nets suitable for areas not far removed from the equator; in Chap. 4 two *equal area* nets which can be used for the whole world, and which are often seen in modern atlases, will be discussed.)

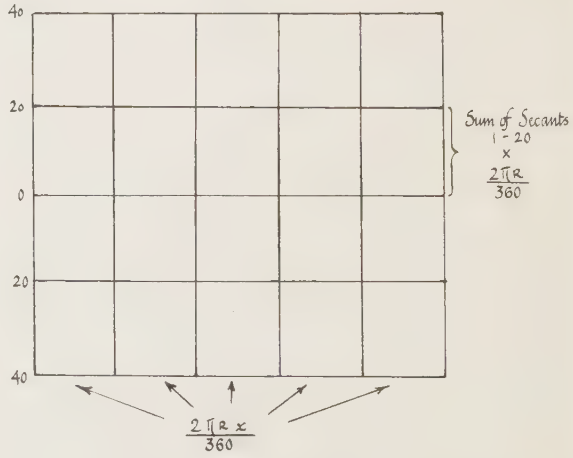
Cylindrical Projections: Constructions

MERCATOR

A Mercator net can be constructed without any knowledge of the intricate mathematical calculations involved by reading off certain values from tables. This, the normal method, will be outlined first. For those sufficiently interested, a brief account is also given of the theoretical construction.

SIMPLE CONSTRUCTION OF A MERCATOR GRATICULE

(Fig. 13.) Suppose that one wishes to construct a Mercator chart of the coasts of the Irish Sea over an area bounded by longitudes 2° W. and 7° W.,



MERCATOR

Fig. 14

and by latitudes 52° N. and 56° N.; and that the scale along the equator is to be 1°=1 inch. Using squared paper draw a line to represent the most southerly latitude (52° N.) and using the equatorial scale divide it into the appropriate number of intervals (in this case 1 inch intervals) to correspond with the lines of longitude from 2° W. to 7° W. At the intervals marked erect meridians as perpendiculars and label each one. The spacing of the other parallels north of 52° is obtained from tables, extracts from which are given below, in which the interval is given in terms of 60 geographical miles or 1° of longitude along the equator.

Extract:	52°–53°	1·620
	53°–54°	1·658
	54°–55°	1·698
	55°–56°	1·739

Note the increasing interval between parallels towards the pole.

As the equatorial scale is 1°=1 inch, these readings can be used directly on the graticule, 53° N. being drawn parallel to and 1·62 inches north of 52° N., etc. With the completion of the graticule the coastal outlines should be plotted in from an atlas.

CONSTRUCTION OF MERCATOR

(Fig. 14.) A straight line is drawn to represent the equator, which on Mercator is true to scale and can therefore be correctly divided using $2\pi Rx/360$ where R=radius of the globe to scale (say 3 inches) and x=the interval of longitude required (say 20°). Through the points so marked meridians are drawn at right angles to the equator. The parallels are drawn parallel to the equator, the distance of any parallel, say 20° N. from the equator being obtained by reading from tables, and adding, the secants of all the angles of latitude between that parallel and the equator (including the secant of that parallel itself), and then multiplying the total of secants by $2\pi R/360$.

(The reason for this construction can be understood if one recalls that in Chap. 1 it was established that by making a parallel equal in length with the equator, a projection exaggerated the scale of that parallel proportionately to its secant. Mercator, having produced such enlargement of parallel scale, can only maintain its orthomorphism and direction accuracy by increasing the meridian scale in the same proportion.)

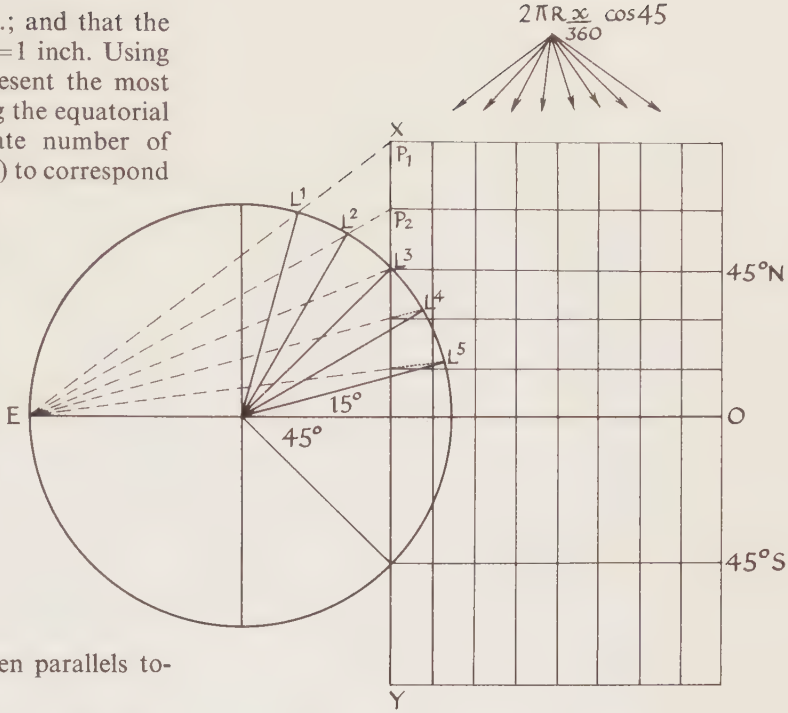


Fig. 15

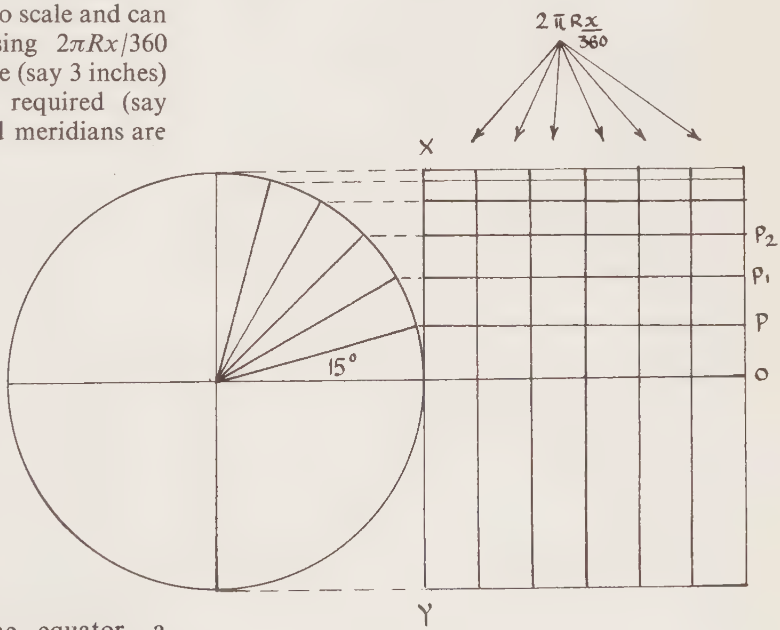


Fig. 16

GALL'S PROJECTION

In Fig. 15 a circle has been drawn to scale to represent the globe (say radius 3 inches), and radii drawn at 45° N. and 45° S. Through their junctions with the circumference draw a line XY to represent the "cylinder" (or the first meridian). Radii must then be drawn at the required interval of latitude (say 15°) and these latitude points on the circumference (L_1, L_2, etc.) projected stereographically on to XY by joining them to it with lines from E. Through the points at which these projections meet XY (P_1, P_2, etc.) lines are drawn parallel to the equator to represent parallels.

Meridians are drawn as straight lines at right angles to the parallels, the interval being the true interval along parallels 45° N. and 45° S. (both of which are the correct scale). It is found by using $2\pi Rx/360 \cos 45$ where R=the radius of the circle representing the globe (3 inches in this case) and x the interval of longitude required (say 15°).

CYLINDRICAL EQUAL AREA

Draw a circle to represent the globe to make, say radius 3 inches (see Fig. 16) and construct the tangent XY at the equator. With a protractor put in radii at the required interval of latitude, say 15°, and through the intersections of the radii with the circumference draw lines parallel to the equator (produced), to represent parallels (P, P_1, etc.). The meridians are erected as straight lines at right angles to the equator, the interval along the equator being calculated by using $2\pi Rx/360$ where R=the radius of the circle representing the globe (3 inches in this case) and x the interval of longitude required (say 15°).

4

TWO WORLD EQUAL AREA NETS

(*a*) *Sanson-Flamsteed* (*b*) *Mollweide*

Simple Rectangular or Plate Carrée Net

Before studying the Sanson-Flamsteed equal area world net it will be useful to consider briefly the "Simple Rectangular" or "Plate Carrée" net since from it, by modification of the arrangement of either parallels or meridians, the equal area property can be obtained.

Examine Fig. 17. Here a net of squares is produced by plotting latitude truly, so that parallels are equally spaced, and by drawing meridians as parallel straight lines at right angles to them. The meridians are correctly spaced along the equator, which is true to scale. Obviously such a net, sometimes called Simple Cylindrical, though very easy to construct, shows great distortion away from the equator and is therefore not used. But from this net an attempt can be made to arrive at an *equal area* net, in one of two ways:

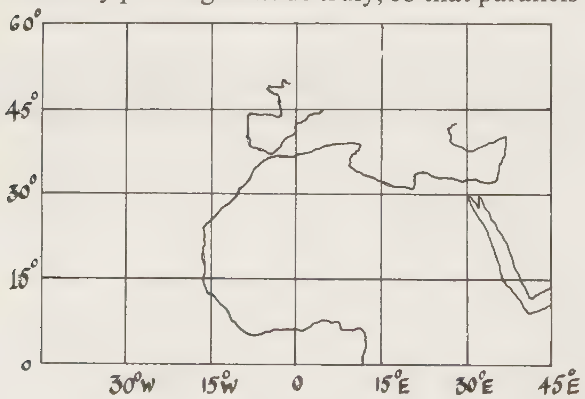


Fig. 17

(i) By leaving the meridians as in this Simple Cylindrical and by modifying the spacing of the parallels. This has already been done in the Cylindrical Equal Area Net (Chap. 3).

(ii) By leaving the parallels equally spaced and by modifying the spacing, and hence the direction, of the meridians. This is done in the Sanson-Flamsteed which makes the meridians converge on the poles.

Sanson-Flamsteed or Sinusoidal Projection

Examine Fig. 18, which shows a world quadrant on this projection. The meridian 0 (which on a world map would be called the central meridian), is drawn at right angles to the equator. The parallels are set out parallel to the equator and

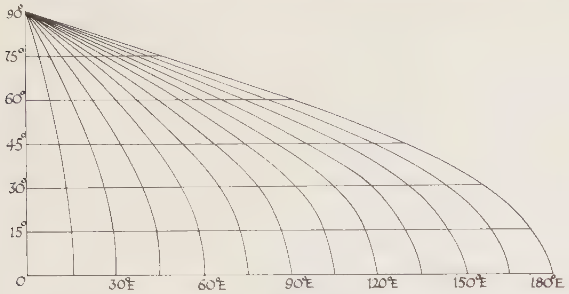


Fig. 18

the correct intervals apart, and along *each* parallel the intervals of longitude are measured truly for every 15° of longitude. In Chap. 1 it was shown that the true distance between two meridians along a parallel is $d \cos \theta$ where d=the equatorial distance of 1° of longitude and θ is the latitude, so that the intervals along each parallel are not difficult to calculate. The object of Sanson-Flamsteed is to obtain a world net with the equal area property and this property can be regarded as due to the setting out of the parallels at the correct vertical interval apart (done by truly dividing the central meridian, i.e. by preserving scale along it) and by truly dividing the parallels (i.e. by preserving scale along them) thus producing "parallelograms" on the correct base and of the correct height (see Chap. 1). As well as being named jointly after both authors who laid claim to it, viz. Sanson (a Frenchman) and Flamsteed (an Astronomer Royal) this projection is also called the Sinusoidal because its meridians are "sine curves".

Properties, Uses and Recognition of the Sanson-Flamsteed

PROPERTIES AND DEFECTS

(i) Scale is true in an east–west direction, but only on the central meridian in a north–south direction; elsewhere it is too great.

(ii) Direction accuracy is maintained in an east–west direction but only on the central meridian from north to south.

(iii) The net is not orthomorphic except near the central meridian where the net lines cross at right angles. The distortion of shapes increases away from the centre and becomes marked on the edges of the map, where meridians cut the parallels at an acute angle.

(iv) Its cardinal property is that it is an equal area net and can be drawn for the whole world.

USES

(i) For continents and regions in low latitudes and preferably with not a sufficient east-to-west extent to lead to considerable distortion of shape. Confirmation, by reference to an atlas, should be obtained of its use for distributions or for general purposes for South America, Africa, Australia and even Indonesia.

(ii) Though it may be used as a world equal area map in its simple form with one central meridian, there is considerable distortion of shape at the margins, whereas in a modified form with more than one central meridian (known as the "*Recentred*" or "*Interrupted*" form), this marginal distortion is minimised. (It is known as "Interrupted" because recentring—i.e. the adoption of several central meridians—entails spaces between parts of the map.) The central meridians can be chosen to give a minimum of distortion over selected areas, whether land or sea; thus some atlases use the Interrupted Sinusoidal for world maps required to show continental distributions, with the central meridians in the northern hemisphere at 100° W. and 20° E.; and in the southern hemisphere at 70° W., 30° E. and 130° E. It is instructive to examine an atlas (e.g. Bartholomew's Advanced Atlas) in which this form of map is used and to determine:

a the central meridians used (after deciding how to distinguish them);
b which land masses have their shapes improved by the modifications used;
c how far the purpose of the maps is met by the equal area property.

RECOGNITION

(i) Parallels are straight, equally spaced straight lines.

(ii) Meridians are smooth "sine curves" oblique to the parallels, except for the central meridian which is straight and at right angles to the parallels.

Mollweide (Elliptical Equal Area) Projection

The object of this graticule is to produce an

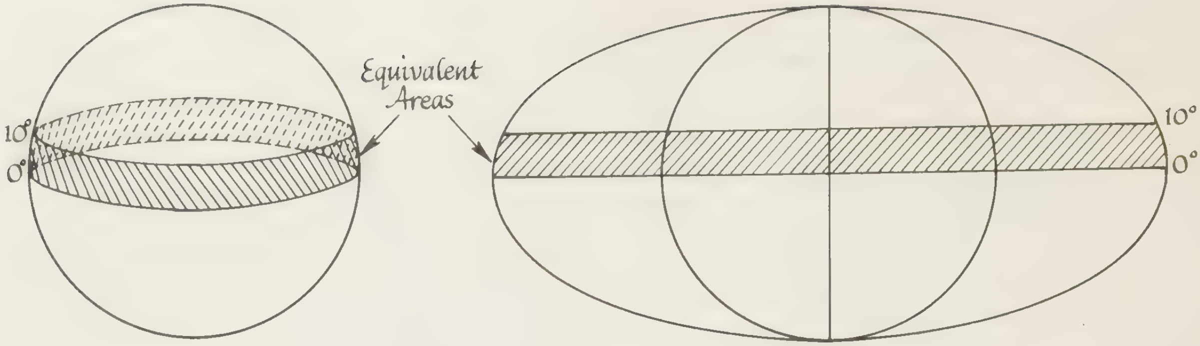


Fig. 19a

equal area map with minimum error in other respects. It is a conventional net involving difficult mathematical construction. Linear scale is sacrificed (except along the equator); in fact, the "scale" of this net is an "area" one. The principle of the net resembles that of many conventional nets, viz. the equating of certain areas on the globe to corresponding areas on a plane surface, and is illustrated in Figure 19*a*. The construction enables a *circle* to be drawn equal in area to one *hemisphere* of the "scaled" globe, and the ellipse drawn on the diameter doubled, adds an area equal to the other hemisphere. The parallels are so spaced that the zone included between any two parallels on the scaled globe is equalled by the area between the same two parallels on the Mollweide net. Since it may be difficult to find one in a modern atlas except in the hemispherical or interrupted form a Mollweide World Sketch-map is provided (Fig. 19*b*).

Examination of this will show that:

(i) The central meridian and the equator cross at right angles.

(ii) The meridians at 90° from the central meridian form a circle, all other meridians (except the central) are ellipses—hence the name the Elliptical Projection.

(iii) The equator is divided equally into the required number of intervals of longitude (e.g. thirty-six if the interval of longitude is 10°).

Fig. 19b

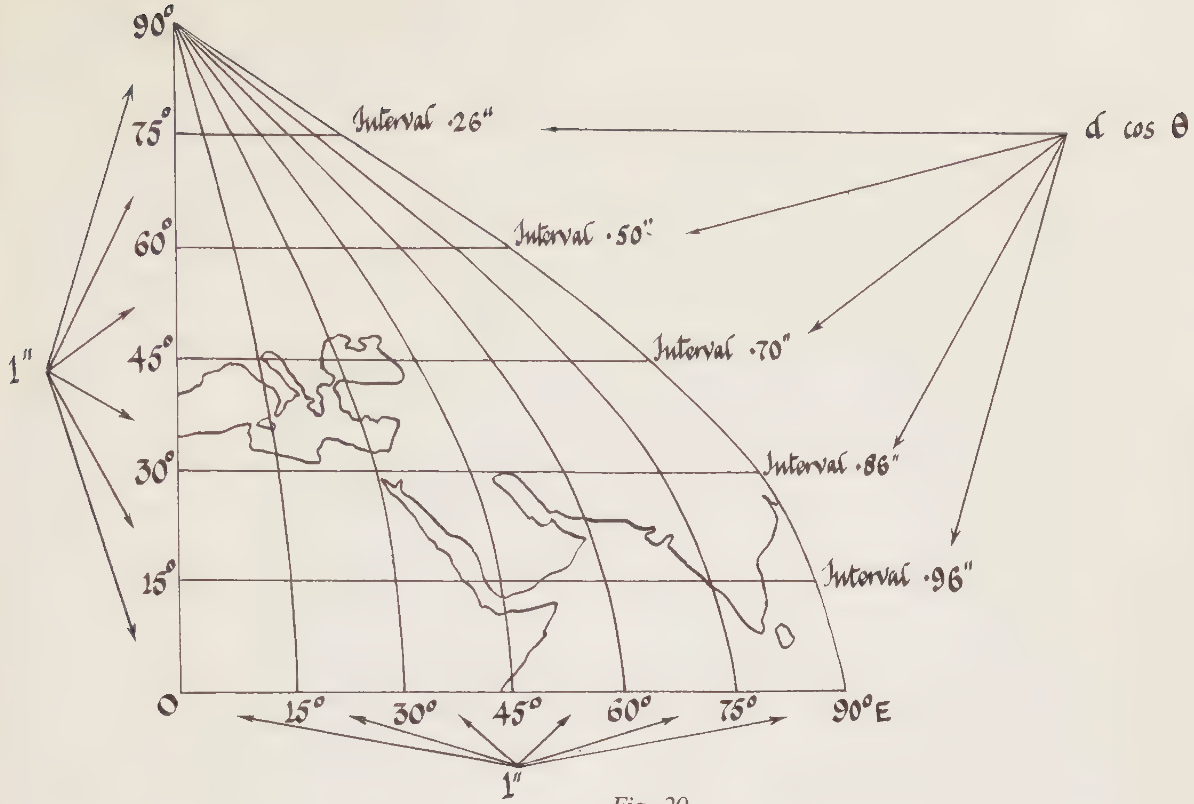


Fig. 20

Properties, Uses and Recognition of the Mollweide

PROPERTIES AND USES

(i) An equal area projection, widely used for statistical and distribution maps of the world.

(ii) Though there is some distortion of shape at the edges of the map, it is less apparent than in Sanson-Flamsteed.

(iii) As with Sanson-Flamsteed distortion of the shapes of continents or oceans can be reduced by using the recentred or interrupted form (e.g. in Philips' *University Atlas*). The central meridians chosen might be 90° W. and 65° E. in the northern hemisphere, 90° W., 20° E. and 140° E. in the southern hemisphere. On this map Asia is less distorted than on the Sanson-Flamsteed.

(iv) It can be used to represent the world in hemispheres and gives a fair representation of the Western Hemisphere (North and South America).

(v) The net is best for portrayal of shape near the intersection of equator and central meridian, hence its use where equality of area is required, for regions in low latitudes, e.g. the Congo Basin, and even for Africa.

RECOGNITION

Distinguishing features are its meridians (one straight, two forming a circle and the remainder ellipses) and its parallels, which are parallel straight lines the interval between them decreasing polewards.

(So far, the nets considered have been shown to serve, reasonably well, equatorial and tropical regions as well as world maps, but because of gross distortion of area or shape incapable of satisfactory representation of Polar regions or mid-latitudes. In Chap. 5 we shall consider some nets which cater precisely for the Polar regions, viz. the Polar Zenithals.)

Equal Area World Nets: Constructions

SANSON-FLAMSTEED

In the first instance a simple exercise will be described, enabling one to construct a portion of a Sanson-Flamsteed graticule; this will be followed by a theoretical construction.

SIMPLE CONSTRUCTION OF A SANSON-FLAMSTEED GRATICULE

(Fig. 20.) For this exercise it will be found that the use of squared paper is of assistance. Adopt a scale of longitude along the equator of 1 inch=15°.

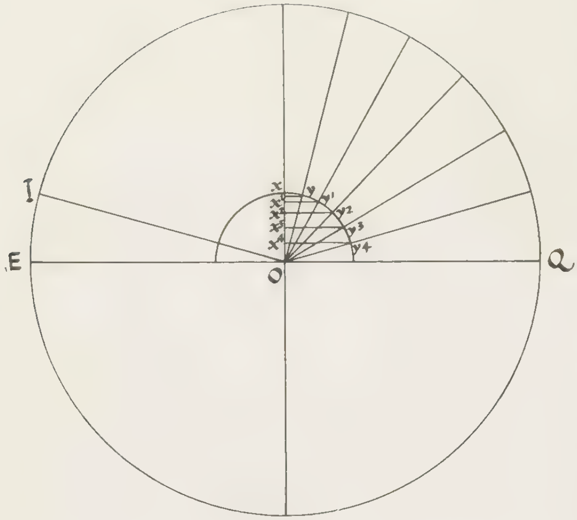


Fig. 21

Draw a horizontal straight line 6 inches long to represent a portion of the equator between 0° and 90° E. and subdivide into 15° intervals. At 0° erect a perpendicular to represent the 0° meridian and divide this into 15° intervals of latitude, each 1 inch. Through the points so determined draw parallels as lines parallel to the equator. The parallels are then truly divided using the formula $d \cos \theta$ (see Chap. 1), where d=equatorial distance (i.e. 1 inch) and θ=latitude. The values are given below.

At 0° latitude 1 cos 0°=1 inch
15° latitude 1 cos 15°=0·96 inch
30° latitude 1 cos 30°=0·86 inch
45° latitude 1 cos 45°=0·70 inch
60° latitude 1 cos 60°=0·50 inch
75° latitude 1 cos 75°=0·26 inch
90° latitude 1 cos 90°=0.

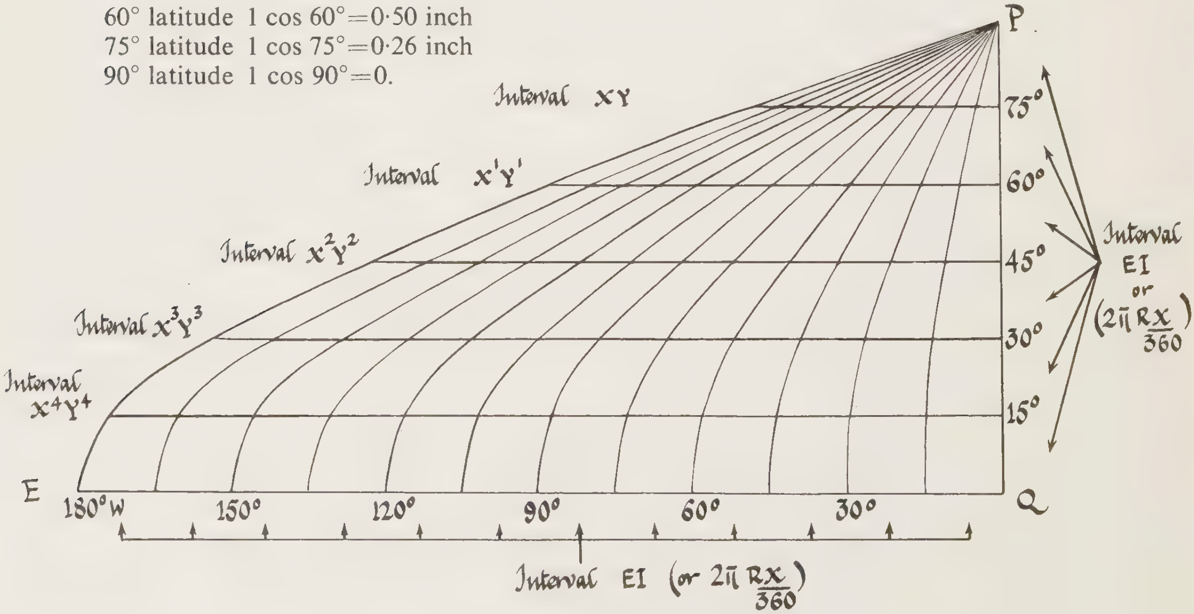
These intervals must be marked along the respective parallels and the points joined by smooth curves to represent meridians. When the graticule is completed the coasts of the Mediterranean Sea and of the Indian Ocean should be sketched in from an atlas.

THEORETICAL CONSTRUCTION OF SANSON-FLAMSTEED

Before actually constructing the graticule it is necessary to draw a circle to scale to represent the globe (say radius 3 inches) on which various calculations are made for transference to the graticule. This has been done at Fig. 21. The basis of the graticule is shown in Fig. 22, where a straight line has been drawn to represent the equator (*EQ*) and a line erected perpendicular to it (*PQ*). This is to serve as the framework on which to construct a quadrant bounded by 0° and 180° W. and by the equator; the vertical line is the prime meridian (0°). Both equator and prime meridian are true to scale and must be divided into correct intervals. Suppose the intervals required be 15°, there are two means of calculating them:

either (i) Draw a radius *OI* in the circle at the required interval of latitude (15°)—then *EI* is the distance to be marked along the equator and central meridian. (For explanation see Chap. 1.) It should be noted that though the chord distance *EI* is taken, this is indeed only an approximation, the arc distance *EI* being the true distance.

or (ii) Use $2\pi \frac{Rx}{360}$, where R=radius of circle (3 inches), x=interval of latitude (15°).



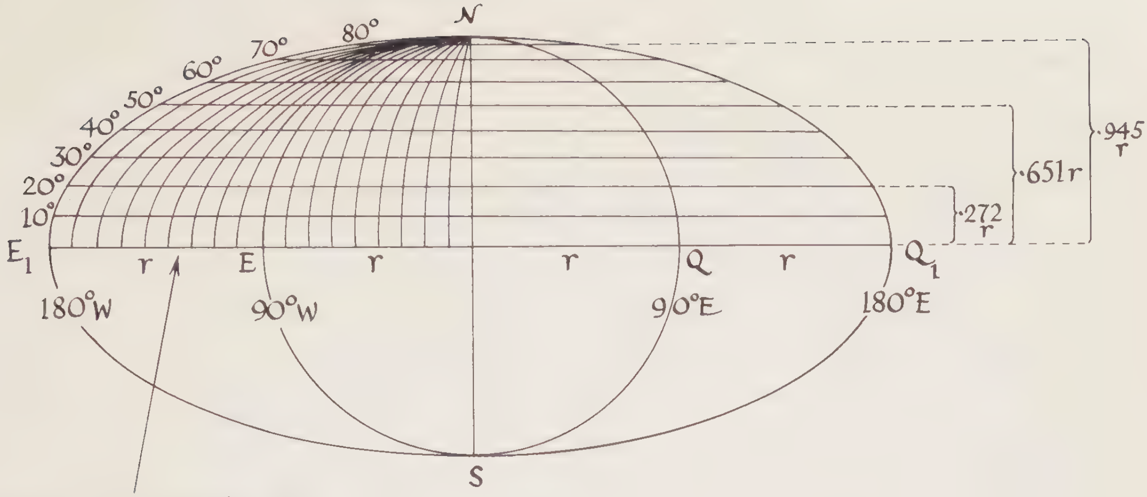


Fig. 23

The parallels, all of which are correct to scale, must then be truly divided. Again two methods can be used for obtaining this measurement:

either (i) Select the interval of longitude required and draw radii at this interval (say 15°) with centre O and radius EI describe an arc. Through the intersections with the radii at Y, Y_1, etc., erect perpendiculars to the polar axis. Then the intervals XY, X_1Y_1 are the ones to be marked off along the parallels, e.g. XY along 75° N. (See Chap. 1 for explanation.) Note that though the chord distance EI is taken this is only an approximation, the arc distance being the correct distance.

or

(ii) Use $2\pi\dfrac{R\cos\theta x}{360}$, where R=radius of the circle (3 inches),
x=interval of longitude (15°),
θ=parallel in question.

Through the divisions so marked along the parallels smooth curves are drawn for the meridians. On this framework the coasts, e.g. that of Eastern North America, can be sketched in from an atlas.

(Note that the method of spacing the intervals along the parallels is similar to that employed in Bonne's Projection which is described in Chap. 6.)

MOLLWIEDE

Mollweide is usually constructed by reference to tables but here a method will be described by which a sketch of a Mollweide graticule for the whole world may be built up, largely to underline the principles upon which it is developed and not to produce an accurate net. Refer to Fig. 23.

The first step is to draw a circle equal in area to one hemisphere of the globe (to scale). The radius to be used for the circle can be obtained as follows.

Let r=radius of the circle,
R=radius of the globe (to scale).
Area of circle=$\frac{1}{2}$ area of a globe.

$$\pi r^2 = 4\pi R^2/2,$$
$$r^2 = 2R^2,$$
$$r = \sqrt{2}R.$$

Suppose r has been calculated to be 3 inches, draw this circle and put in the central meridian 0° (NS), the equator (EQ). The equator is then doubled in length to E_1Q_1 and through N, S, E_1, Q_1 an ellipse is sketched in to represent the bounding meridian, 180° W. and 180° E. The equator is then divided equally, the number of divisions depending on the interval of longitude required (e.g. if this be 10°, then 36 equal divisions must be plotted). Through these points along the equator, N and S, draw ellipses to represent the other meridians.

The parallels are all drawn as straight lines parallel to the equator, the distance of each parallel from it being:

10°	0·137r	20°	0·272r
30°	0·404r	40°	0·531r
50°	0·651r	60°	0·762r
70°	0·862r	80°	0·945r
90°	r.		

This parallel spacing is such that the area between any two parallels is equal to the area included between the same two parallels on the scaled globe.

5

THE ZENITHAL (AZIMUTHAL) TANGENTIAL PROJECTIONS

Polar Tangential or Zenithal Projections

The Cylindrical and Equal Area nets so far studied provide for maps of equatorial and tropical areas but are of little use for the Polar regions. On a plane at a tangent to either pole, however, projection of half the earth is possible with the Polar areas reasonably well represented. Such tangential nets are called Zenithal or Azimuthal because true bearings from the centre (the pole) are preserved, since all the meridians pass through the pole. On all of them the meridians are truly spaced, and in the construction of the nets the meridians can easily be set out by using a protractor, as radial straight lines at their correct angles. Hence, meridians are azimuths or correct bearings. This being so, the only problem is the spacing of the parallels, which are circles concentric around the pole. This spacing will depend upon the particular property of the net it is required to achieve, e.g. correct scale along the meridians (*the Equidistant Zenithal*), or equal area (*the Equal Area Zenithal or Lambert's*). Both nets may be regarded as "projections" in regard to their radial straight meridians, but "conventional" in regard to the parallels, which are spaced at such distances that the desired property will be obtained. But there are also two other zenithals which are true projections in the perspective or geometrical sense of the term, viz. one in which the projection is from the centre of the earth's centre—*the Polar Gnomonic*; the other where the projection is from infinity—*the Polar Zenithal Orthographic*, of theoretical rather than practical interest.

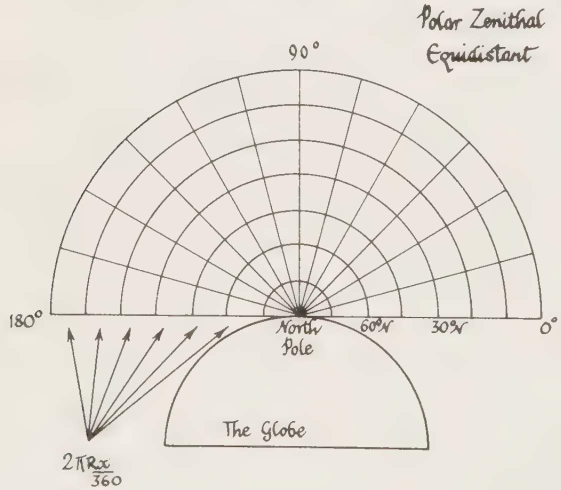


Fig. 24

The Polar Zenithal Equidistant Net

Fig. 24 shows:

(i) Meridians, as in all Polar Zenithals, are lines of true bearing drawn from the centre (the pole).

(ii) The parallels are concentric circles drawn at their true distance apart. The simple calculation for their spacing is $2\pi Rx/360$ where R=radius of the earth to scale, x=the interval of latitude.

Thus if R is 3 inches and x is 15° the distance between parallels is $2\pi 3\times 15/360=\pi/4$. As with all Polar Zenithal nets, direction along meridians is correct. This fact, together with the equidistant property (giving scale accuracy along meridians), makes this net of use for trans-polar journeys and flights. But the parallels have too great a scale. The net is neither equal area nor orthomorphic, and direction accuracy is limited to the meridians, but it can be used for polar areas as far as 60° latitude. The equally spaced parallels serve to distinguish the net.

The Polar Zenithal Equal Area Net (Lambert's) (Fig. 25).

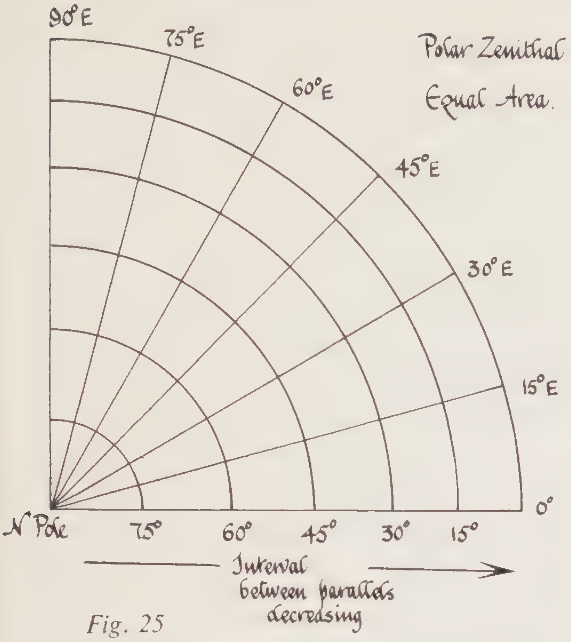


Fig. 25

In this net once again, the meridians are set out as straight lines from the pole at true angles; the parallels are circles concentric about the pole, but in this case, in order to achieve the equal area property, the increase in the parallel scale is compensated by a proportionate decrease in the meridian scale, as shown by the decreasing interval between the parallels away from the pole. The equal area property makes the net useful for polar areas, e.g. to show pack ice distribution or for reference in international territorial disputes. The greater the distance from the pole however, the greater the distortion of shapes, and the net is not usually drawn for latitudes lower than 60°. Once again, all bearings are correct from the centre, i.e. the pole. The net can be recognised by the following characteristics:

(i) as with other Polar Zenithals, the meridians are straight lines radiating from the pole;

(ii) in contrast with the equidistant, the concentric parallels are spaced at decreasing intervals away from the pole.

The Polar Zenithal Gnomonic Projection

In the Polar Gnomonic the graticule is a true geometrical projection, from the centre of the earth, on to a plane tangent at the pole. As can be seen from Fig. 26, the intervals between the parallels increase rapidly away from the pole; thus showing the great increase in meridian scale. Parallel scale also increases away from the pole, but not in the same proportion as the meridian scale; hence neither shape nor area is preserved. Indeed, with increase of distance from the pole distortion of scale, areas and shapes becomes progressively greater. Moreover it can be seen that it is impossible to project a whole hemisphere. But since all points on a Great Circle are in a plane passing through the centre of the sphere, every Great Circle must be projected as a straight line, as the projection rays originate in the centre of the sphere. This very interesting and valuable property, making every straight line drawn on this graticule a Great Circle, distinguishes the projection from others. Thus the most direct way of determining the Great Circle course between two places is to draw a line between them on a Gnomonic. Then for purposes of navigation, this can be transferred to the Mercator.

But, as was shown in Chap. 3 the Mercator becomes impossible in very high latitudes, so that it is possible to make use of the Polar Gnomonic for aeroplane flights along Great Circle routes across the poles.

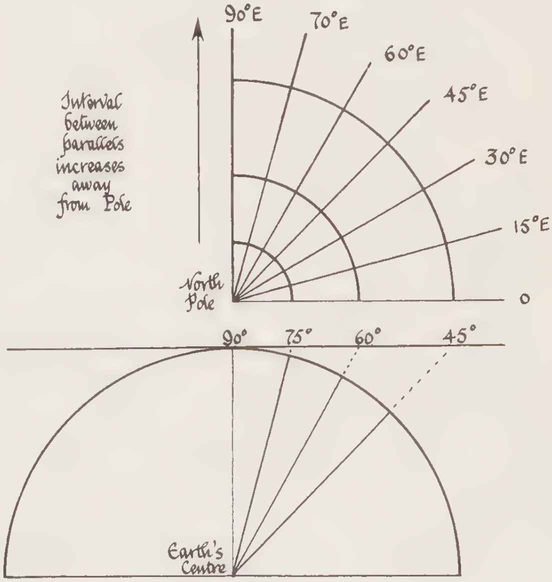


Fig. 26

The Polar Zenithal Orthographic Projection

If the point of projection is at infinity, so that the rays of projection can be regarded as parallel straight lines, as in Fig. 27, it can be seen that the parallels are projected on to the tangent plane as concentric circles, the interval between which decreases away from the pole, as in the Zenithal Equal Area but much more rapidly. This very great compression of distance along meridians towards the edge of the map, without any gain of other desirable qualities, makes this projection of little use and of largely only theoretical interest.

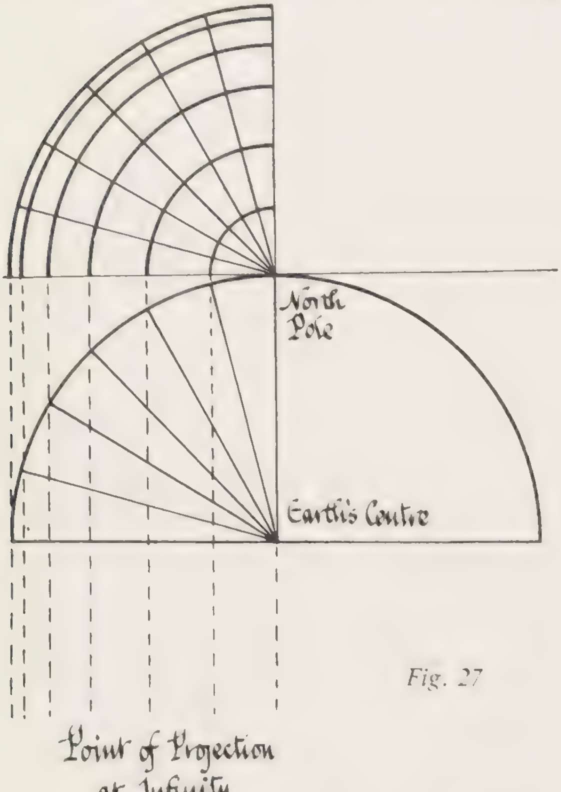


Fig. 27

(Such maps of Polar Regions may become increasingly important with the growth of interest, for example, in Polar exploration, in the development of the "Northlands" and in the planning of modern long distance air routes.)

Some Equatorial and Oblique Cases of the Zenithals

Usually very few maps of the Polar regions are found necessary in any atlas, but they have been studied here because the Polar cases of the Zenithals are comparatively easy to understand. When the tangent plane is touching *at* the equator (Equatorial case) or at a point *between* the pole and the equator (Oblique case) the Zenithals are more difficult to understand and construct; yet these are the very ones which are most frequently required. In these cases the meridians do not radiate from the poles and the parallels are not concentric circles.

The full comprehension and the construction of the Zenithals other than the Polar cases is beyond the scope of these notes, nevertheless, because of their use in atlases or elsewhere, there follow brief references to certain Equatorial and Oblique Zenithals.

(*a*) ZENITHAL EQUATORIAL EQUAL AREA (LAMBERT'S)

This is useful to show the world in *hemispheres*, e.g. "Old" and "New" worlds, with the great advantage of possessing the equal area property. Examination of an example in an atlas will show curved meridians except for the central ones, and curved parallels which are not concentric, except for the equator which is a straight line. It can be distinguished from Mollweide by the straight parallels of the latter.

(*b*) OBLIQUE ZENITHAL EQUAL AREA (LAMBERT'S)

This has considerable use for such large areas as the continents of Asia and North America, the main masses of which continents are in middle latitudes. There is rather less distortion towards the edges than on Bonne's Projection which is sometimes used and which is discussed in Chap. 6.

(*c*) ZENITHAL EQUIDISTANT OF THE WORLD, CENTRED ON A SELECTED PLACE

Under the name "The Air Age Map of the World" compiled by B.O.A.C., Edward Stanford Ltd. published in 1947 an Oblique Zenithal Equidistant Map of the World centred on London and designed to stimulate interest in this age of the aeroplane. On this map both distance and bearing are true for every position on the globe *from London*. These properties however, of interest to the widening public which make air flights, are obtained only by very great sacrifice of scale and shape, especially near the margins where, for example, New Zealand and Australia are so fantastically represented as to be unrecognisable. The Great Circle tracks drawn

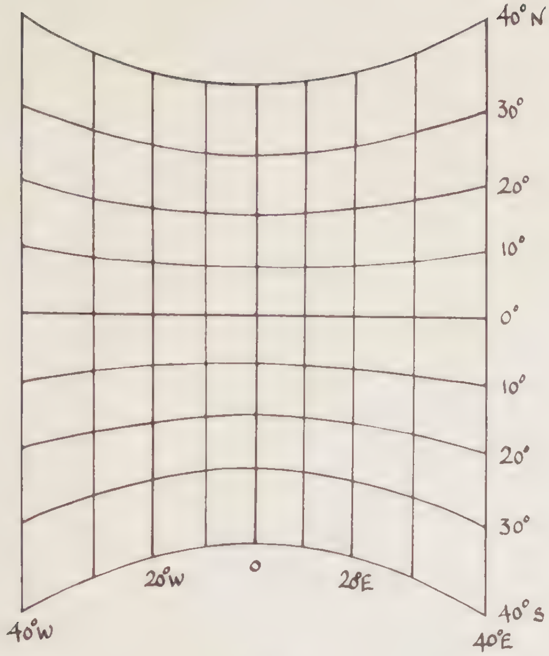


Fig. 28

from London to various termini may, in practice, be modified to accord with economic, political and physical factors; hence the claim for it made in its title may be somewhat exaggerated. It remains, nevertheless, an interesting example of a map graticule sacrificing area and shape to obtain bearing and distance *from a particular point*. Centres other than London have been used for such maps.

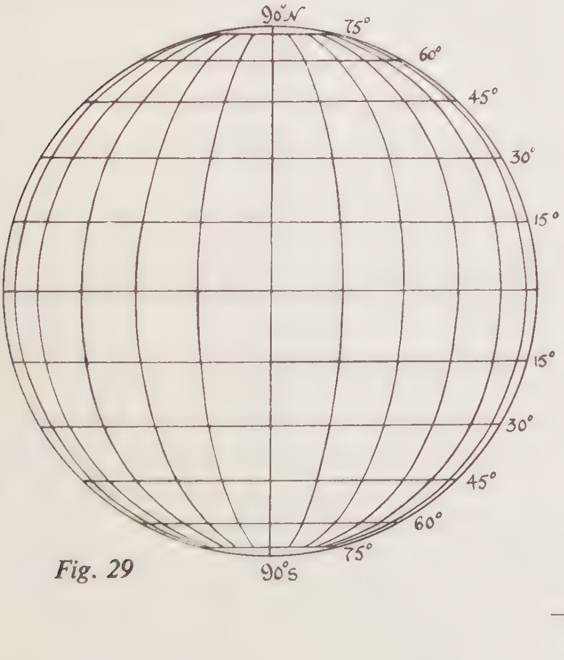


Fig. 29

(*d*) THE EQUATORIAL GNOMONIC

As in the Polar case all Great Circles will be represented as straight lines. From Fig. 28 it will be seen that on this account all meridians are parallel straight lines at right angles to the equator, the interval between them increasing towards the edges of the map. The parallels, other than the equator, are curves convex towards the equator. Since scales and areas increase rapidly away from the centre of the graticule, and as bearings cannot be read off

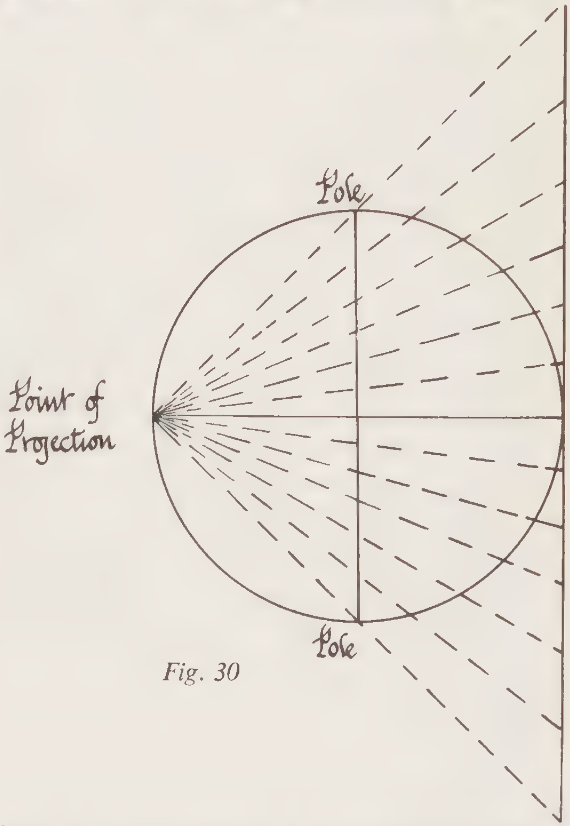


Fig. 30

from it, this projection is of theoretical interest only and is rarely used.

(*e*) ZENITHAL EQUATORIAL ORTHOGRAPHIC

Projection in this case (Fig. 29) is from infinity on to a tangent plane at the equator, and results in parallels being projected as straight lines, parallel to the equator and with the intervals between them decreasing polewards. The meridians are curves the intervals between which decrease rapidly towards the edges of the map, producing great distortion in these areas on the margins of the hemisphere. For this reason the world in hemispheres is rarely seen on this projection in atlases.

(*f*) ZENITHAL EQUATORIAL STEREOGRAPHIC

Figs. 30 and 31 show the method of projection and the appearance of one hemisphere on this net. Both meridians and parallels appear as curved lines, save for the central meridian and the equator. Neither shapes nor area is preserved, although there is rather less distortion on the margins of the hemisphere than in the Equatorial Orthographic.

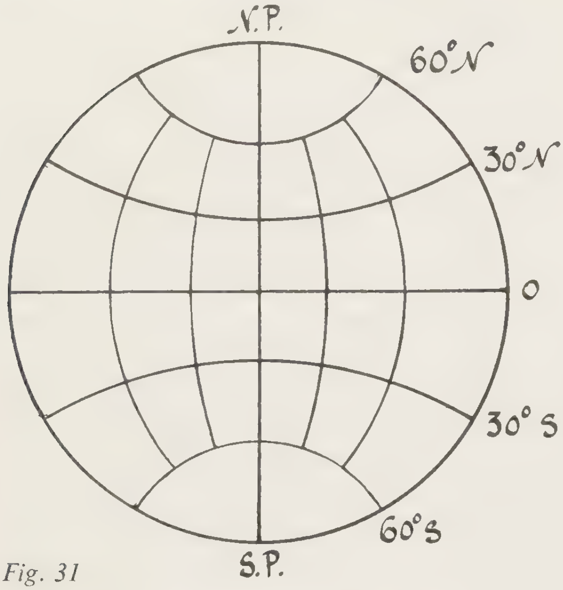


Fig. 31

Zenithal Projections: Some Constructions

Two detailed examples only will be considered, both having the merit of simplicity.

ZENITHAL POLAR GNOMONIC

Suppose a map of the North Polar Regions is to be constructed with intervals of latitude and longitude of 15°. Adopt a scale for the globe of $R=3$ inches. Refer to Fig. 32.

(i) Draw a circle radius 3 inches.

(ii) Put in the polar axis and equator and draw the tangent at the north pole.

(iii) Draw radii at intervals of 15° and produce to meet the tangent at L_1, L_2, etc.

(iv) With centre *P* and radii L_1, L_2, etc., swing arcs to represent the parallels.

(v) With a protractor draw from *P* straight lines at intervals of 15°—the meridians, numbering clockwise from 90° E., etc.

ZENITHAL EQUAL AREA: POLAR CASE

Suppose a map of the North Polar Regions is to be constructed with intervals of latitude and longitude of 15°. Adopt a scale for the globe of $R=3$ inches. Refer to Fig. 33.

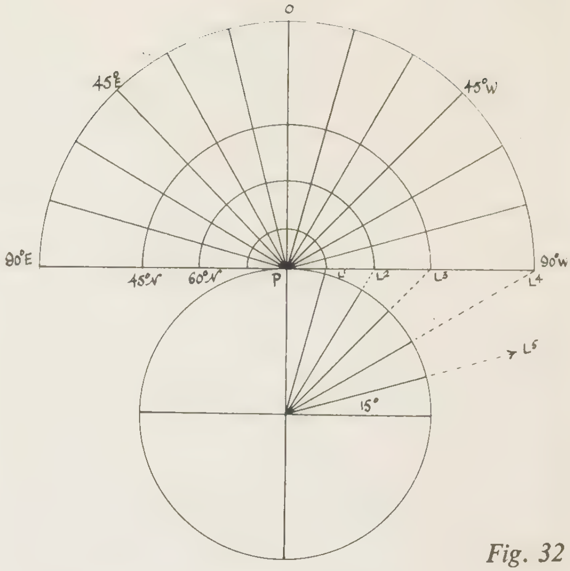


Fig. 32

(i) Draw a circle radius 3 inches.

(ii) Put in the polar axis and equator and draw the tangent at the north pole.

(iii) Draw radii at intervals of 15°.

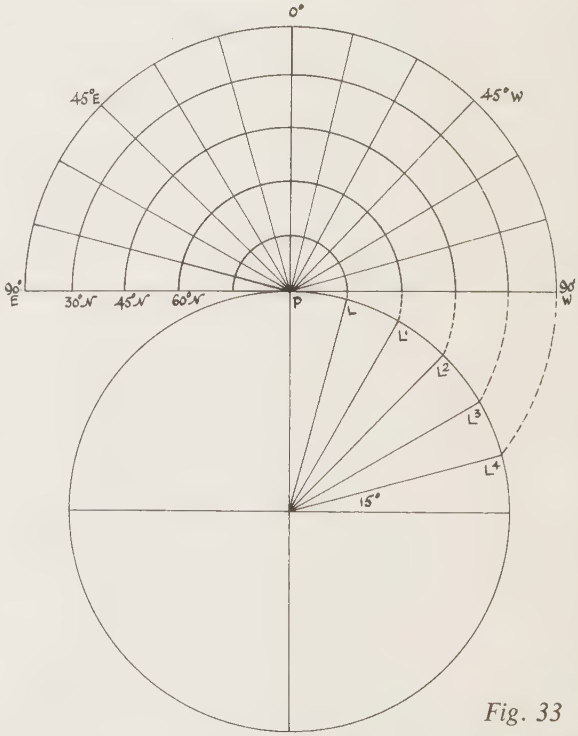


Fig. 33

(iv) With centre *P* and radii *L*, L_1, etc., swing arcs to represent parallels.

(v) With a protractor draw from *P* straight lines at intervals of 15°—the meridians, numbering clockwise from 90° E., etc.

6

THE CONICAL PROJECTIONS

Specific Uses of Conical Map-Nets

So far a study has been made of nets which are suitable for low latitude areas, while the Polar Zenithals were noted as valuable for Polar regions. The nets most required however are those for middle latitudes (30°–70°), and for this purpose the Conicals are admirable. Since middle latitudes include countries of great importance in the world it is not surprising that the conicals are possibly the most frequently used group. Of the very many conicals in existence we shall consider only four.

Origin of Conical Map-Nets

Conical projections depend, at any rate in their initial stages (as was seen in Chap. 2), upon the fact that a cone can be unrolled or *developed* to form a flat sheet. Such a cone, with its apex over the pole, contacts the globe along a parallel, and it will be remembered that this is the *standard parallel* and is true to scale (since it has the same length as the corresponding parallel on the globe to scale). Consequently it is chosen to pass, as nearly as possible, along the central latitude of the area to be shown on the map. Fig. 34 is a diagram showing a cone placed over the north pole with the parallel of contact indicated, and adjacent to it is shown the result of such a cone after being "developed". This reveals that the standard parallel appears as the arc of a circle with its centre at the apex of the cone. The central meridian is chosen to suit the particular area to be covered by the map. Such a map net is an example of the Simple Conic or Conic with One Standard Parallel.

Conic with One Standard Parallel (Conic Equidistant)

In this simple case, construction of the net involves the choice of the central meridian (which

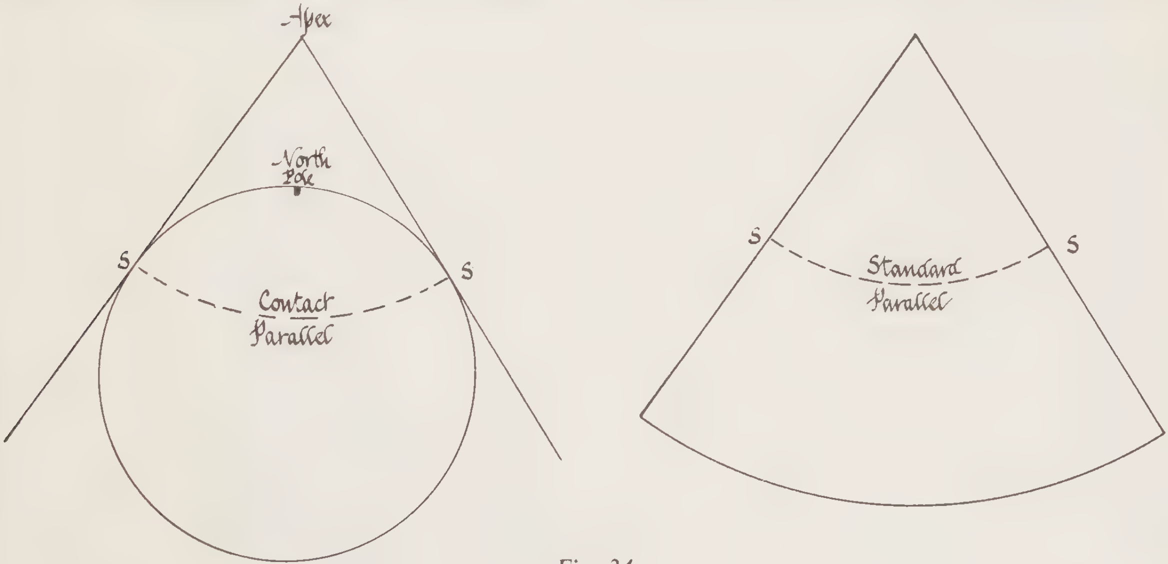


Fig. 34

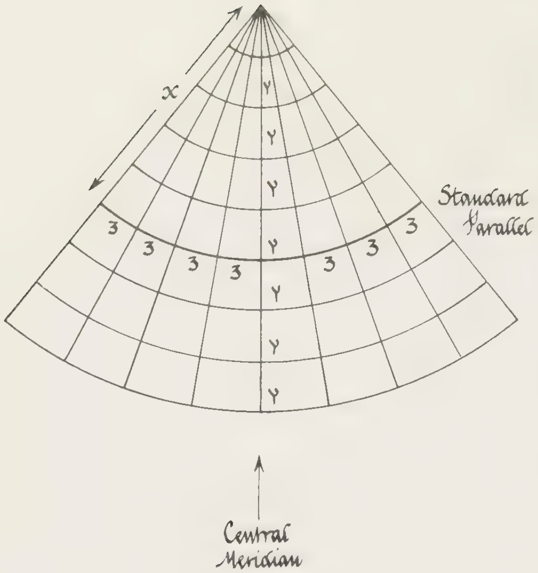


Fig. 35

is drawn as a straight line) and the standard parallel, plus three calculations:

(i) The radius of the arc (marked *x* in Fig. 35) drawn to represent the standard parallel.

(ii) The length to scale (marked *y*) of the required interval of latitude (say 10°), which is marked off as a number of equal divisions along the central meridian, making it true to scale.

(iii) The length to scale (marked *z*) of the required interval of longitude (say 10°) to be marked along the standard parallel. The net is completed by joining the points marked along the standard parallel to the apex to form meridians, and by swinging arcs of circles concentric about the apex through the intervals marked along the central meridian. The methods by which the lengths mentioned in (i) (ii) and (iii) are obtained are dealt with in the paragraph below on the construction of the Conic Equidistant.

Properties, Uses and Recognition

PROPERTIES AND USES

(i) Scale is correct along all meridians (hence the alternative name "equidistant" conic) and the standard parallel, but along all other parallels scale is incorrect, e.g. the pole appears as the arc of a circle. Hence the net is neither orthomorphic nor equal area.

(ii) The standard parallel should be selected to pass through the centre of the area to be portrayed, as distortion is least near this parallel.

(iii) The greater the distance from the standard parallel, the more the parallel scale becomes exaggerated, and the more shapes and areas show distortion.

(iv) It is useful for countries of limited extent in middle latitudes, e.g. the British Isles, although it may also be used for a general purpose map of an area as large as Europe. It is also suitable for larger areas which have a wide extent in longitude, but small extent in latitude, e.g. it might well be used for a map of the Canadian Pacific Railway, provided the standard parallel were correctly selected (about 50° N.).

RECOGNITION

(i) The parallels are arcs of concentric circles equally spaced.

(ii) The meridians are convergent straight lines.

The Conic with Two Standard Parallels

The Conic with One Standard is not widely used in atlases because comparative accuracy is confined to a small belt near the standard parallel. Rather larger areas of accuracy can be obtained by using two standard parallels, based upon the cone supposed to be sunk into the sphere (Fig. 36) so that it cuts the surface along two parallels (cf. Gall's Projection described in

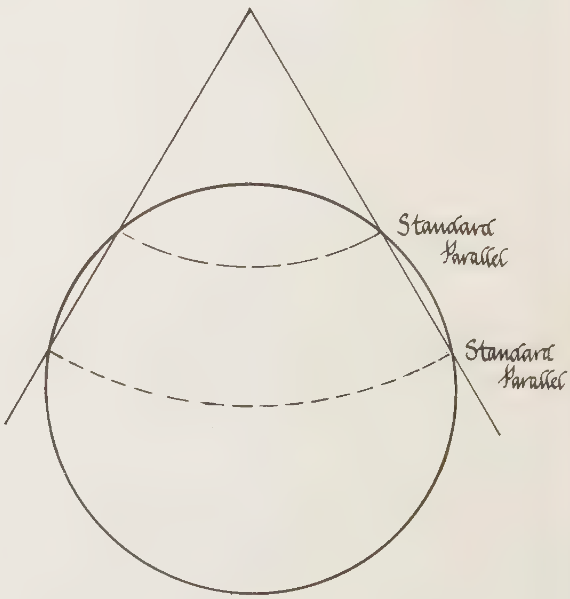


Fig. 36

Chap. 3). Along both these standard parallels scale is correct as well as along the meridians. Although both shape and area are distorted, the belt between the two standards is fairly well represented, and only beyond them does distortion become excessive. The two standard parallels are drawn true to scale and at the true to scale interval apart. The centre about which they are drawn is such that it permits these two conditions, and also that when the two parallels are truly divided and joined by straight lines, to represent the meridians, these lines meet in that centre. The standard parallels are not, that is, drawn on radii derived directly from the globe as in the simple Conic.

Properties, Uses and Recognition

PROPERTIES AND USES

(i) The scale is correct only along the standard parallels and the meridians; thus it is neither orthomorphic nor equal area.

(ii) It is not suitable for countries having a great extent in latitude, as away from the standard parallels distortion becomes pronounced.

(iii) The standard parallels should be so selected as to include the central part of the area to be portrayed.

(iv) It is widely used in atlases for Europe and Australia, especially for separate countries or states.

RECOGNITION

(i) The parallels are arcs of concentric circles equally spaced.

(ii) The meridians are convergent straight lines.

Polyconic

This projection is made upon a series of cones, each resting along a parallel of latitude; hence each parallel is true to scale and appears on the net as an arc of a circle. However, as the apices of the cones do not coincide, the arcs are not concentric, and the lines of longitude appear as smooth curves. A useful property of the net is that east–west scale is correct everywhere. If calculations are made for every degree of latitude a series of bands of half a degree on either side of each parallel have good accuracy. An interesting use of the Polyconic was in a famous but never completed series of the world on the uniform scale of 1 : 1,000,000, but in the case of this series the projection was modified to give straight edges to facilitate the fitting of adjacent sheets.

Properties, Uses and Recognition

PROPERTIES AND USES

(i) It is neither orthomorphic nor equal area, for though scale is correct along all the parallels it is correct only along the central meridian.

(ii) Distortion becomes very pronounced towards the margins of the map, i.e. away from the central meridian.

(iii) It is useful for maps of small areas, or for areas of great north-to-south extent (adjacent to the central meridian) but small in east-to-west extent.

RECOGNITION

(i) All the meridians except the central meridian are smooth curves.

(ii) The parallels are arcs of non-concentric circles.

Bonne's Projection (Equal Area Conic)

Examine an example of the Bonne net which can be found in almost any atlas.

The equal area property is obviously desirable in maps of middle latitudes for most purposes, and Bonne is an important modification of the Simple Conic. It is similar to the Sanson-Flamsteed Equal Area Net (see Chap. 4); indeed, the Sanson projection may be regarded as a special case of Bonne in which the equator is selected as the standard parallel. The construction is at first like that of the Conic with One Standard, with the parallels drawn as concentric circles and the central meridian divided truly to scale. Then, instead of having only the standard parallel divided truly and the meridians as straight lines, every parallel (as in Sanson-Flamsteed) is divided correctly, with the result that the meridians on Bonne are curves. Since every parallel has correct scale and is at its correct distance from adjacent parallels, area is preserved (see Chap. 1). Thus, in spite of distortion of shape away from the central meridian, Bonne is extensively used for statistical and distribution maps of middle latitudes. A comparison of maps of North America and Asia will show that distortion of shape on the margins of the map is rather worse on Bonne than on another equal area map already considered, viz. the oblique case of the Zenithal Equal Area.

Properties, Uses and Recognition

PROPERTIES AND USES

(i) As noted above, scale is correct along all parallels and the central meridian, away from which meridian scale is distorted. As the parallels are the correct vertical interval apart and also true to scale it is an equal area map (see Chap. 1).

(ii) Although the central meridian cuts the parallels at right angles, the intersections elsewhere are oblique, the obliquity increasing towards the margins of the map where shape is obviously distorted.

(iii) The standard parallel should be selected to pass through the area to be represented; it should not be used for low latitudes for which Sanson-Flamsteed is preferable.

(iv) It is suitable for areas of no great extent in longitude, though they may have great north–south length. Shape is little distorted near the central meridian so that for a country such as Chile it provides an ideal net if the central meridian is carefully chosen—in this case 70° W. (cf. Sanson-Flamsteed).

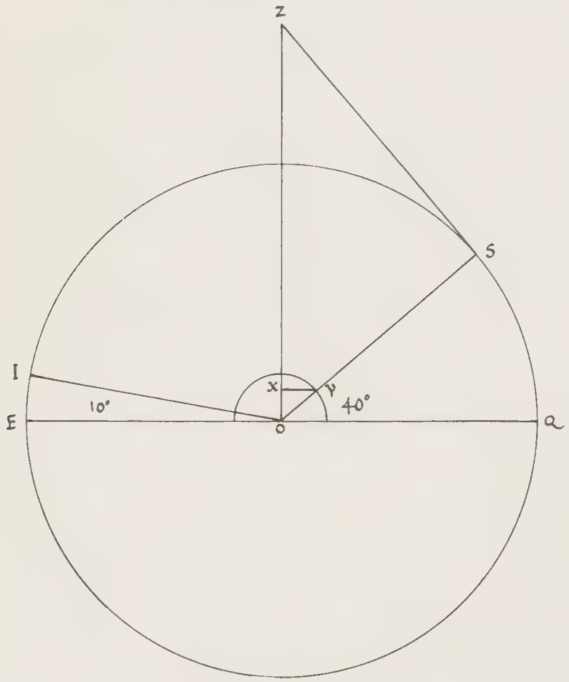


Fig. 37

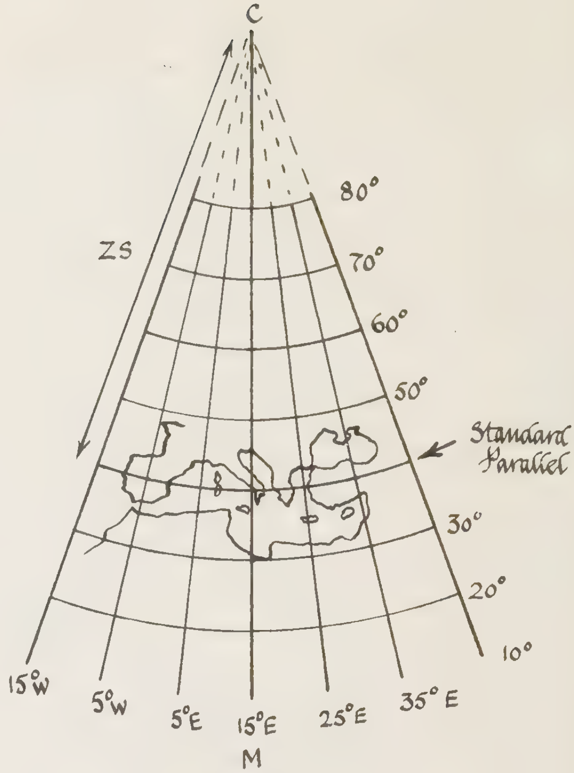


Fig. 38

(v) Much used in atlases for Europe, Asia, North America and Australia.

RECOGNITION

(i) The parallels are arcs of equally spaced concentric circles.

(ii) With the exception of the central meridian, meridians are smooth curves; they have a characteristic bend or "shoulder" in higher latitudes.

Conical Projections: Some Constructions

CONIC EQUIDISTANT WITH ONE STANDARD PARALLEL

Suppose that a graticule is required for a map of the Mediterranean Sea. The first step is to choose a central meridian and a standard parallel. For the former 15° E. is a convenient line, for the latter 40° N. as this passes along the Mediterranean Sea. The size of the globe to scale must also be decided and in this example a 3 inch radius will be adopted, though in practice one much larger would be taken. With these preliminaries complete, proceed as follows (remembering that there will be two diagrams: a generating circle, Fig. 37, and a graticule, Fig. 38).

(i) Draw the circle to scale (radius 3 inches), centre O. Put in the equator EQ.

(ii) Draw the radius OS at 40° N. to represent the standard parallel.

(iii) Construct the tangent at S and produce the polar axis to meet it at Z.

(iv) (Fig. 38.) Draw a line CM, the central meridian.

(v) With centre C and radius ZS describe an arc, the standard parallel.

(vi) Correctly divide the central meridian, commencing from the standard parallel, and through the points marked draw arcs parallel to the standard. The interval to be marked along the central meridian can be obtained by drawing a radius OI at the required interval of latitude (say 10°) and the required interval will then be the arc distance EI, though the chord distance will give a near approximation.

(vii) Correctly divide the standard parallel and through the points marked draw straight lines radiating from C. The interval is found by describing an arc centre O, radius EI and through the intersection of this arc and OS, drawing a line perpendicular to the polar axis. This line XY then gives the required interval. Note that the arc distance EI should be used but the chord distance gives a near approximation.

In Fig. 38 more of the graticule has been completed than would indeed be completed for an actual map of the Mediterranean; in fact perhaps only the area between 30° N. and 50° N. might be shown. On this graticule the coastal outline can easily be plotted in.

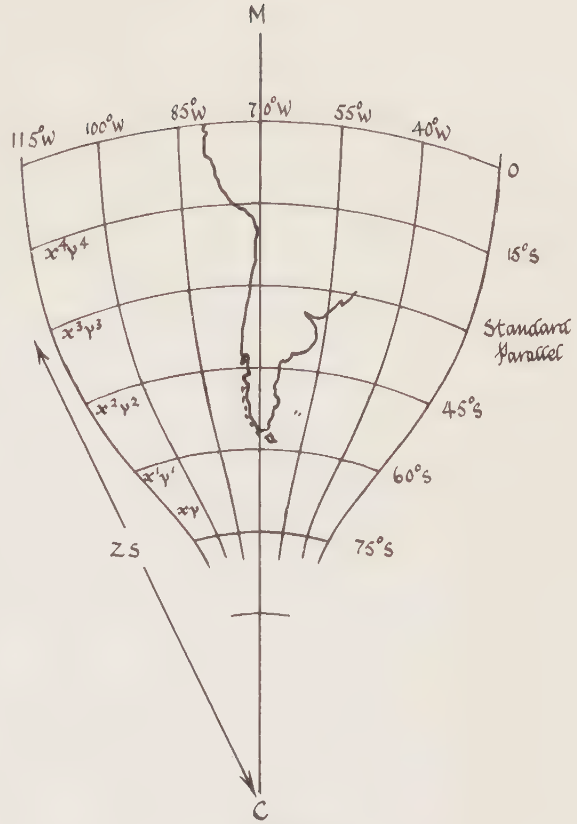


Fig. 40

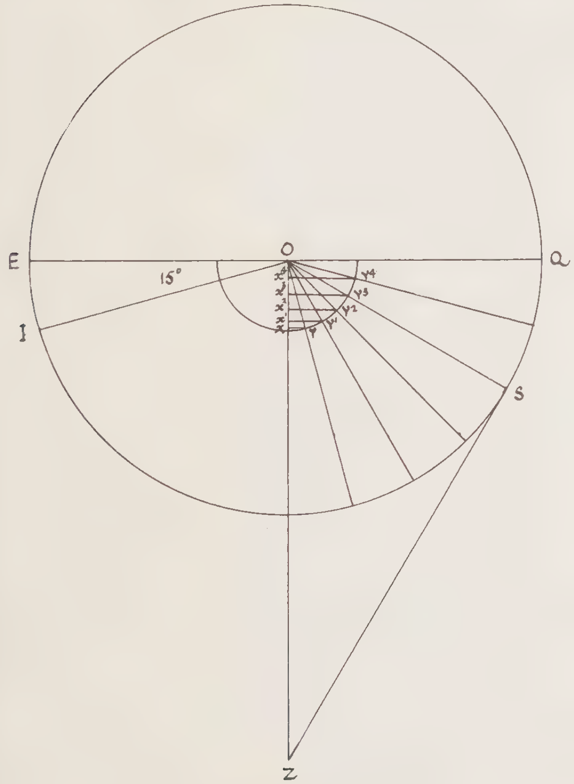


Fig. 39

BONNE'S PROJECTION

Suppose a map of Chile is to be constructed. The first step is to choose a central meridian and a standard parallel. For the former 70° W. and for the latter 30° S. will be found convenient. The size of the globe to scale must also be decided and in this example a 3 inch radius will be adopted, though in practice one much larger would be taken. As with the Conic Equidistant a generating circle and diagram (Fig. 39) is an essential preliminary to the construction of the graticule (Fig. 40). Proceed as follows:

(i) Draw a circle to scale (radius 3 inches) centre O. Put in the equator EQ.

(ii) Draw the radius OS at 30° S. to represent the standard parallel.

(iii) Construct the tangent at S and produce the polar axis to meet it at Z.

(iv) (Fig. 40.) Draw a line CM, the central meridian.

(v) With centre C and radius ZS describe an arc, the standard parallel.

(vi) Correctly divide the central meridian, commencing from the standard parallel, and through the points marked draw arcs parallel to the standard. The interval to be marked can be determined as in Para. vi of the Conic Equidistant—i.e. by drawing a radius OI at the required interval of latitude (say 15°), the required interval then being arc distance EI, although the chord distance is approximately correct on small scales.

(vii) Truly divide *each* parallel and connect the points so obtained with smooth curves to represent meridians. The intervals along each parallel are found as follows. Describe an arc centre O, radius EI. Select the interval of longitude required (say 15°) and draw radii at this interval. Through the points at which these radii cut the arc, draw lines perpendicular to the polar axis (xy, x_1 y_1, etc.). The interval to be marked along any parallel is the length of the line joining the radius representing it to the polar axis. Note that distance EI is the arc distance, although the chord distance gives a sufficiently close approximation on small scales.

7

QUESTIONS FROM PAST EXAMINATION PAPERS

C=Cambridge, L=London, N=Northern Universities Joint Matriculation Board, O=Oxford, O.C.=Oxford and Cambridge Joint Board, S.L.C.=Scottish Leaving Certificate Higher Grade, S.U.J.B.=Southern Universities Joint Board.

S=Scholarship Level, *A & S*=Advanced and Scholarship Levels.

In the case of some questions where map outlines were provided the relevant maps can be consulted in atlases using the data, printed in italics, at the foot of the questions.

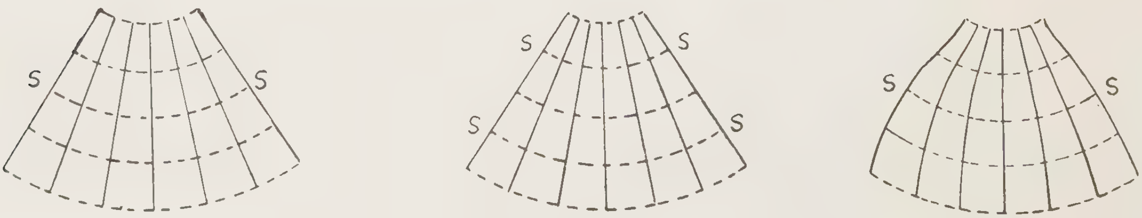
1. (*a*) Comment briefly, but critically, on the suitability of the following projections for the purposes specified: (i) polar gnomonic for a map of Arctic air routes; (ii) Mercator for a map showing the world distribution of forests; (iii) simple conical for a topographical map of Czechoslovakia.

(*b*) Draw simple diagrams of the general appearance of (i) the Mercator graticule; (ii) the Sanson-Flamsteed graticule. (Accurate constructions are **not** required.) Referring to your diagrams, show how the major properties of each projection are achieved. (C. 1956)

2. (*a*) What is the value of "equal area" maps to the geographer?

(*b*) Name an equal area map projection you would choose for a map of each of the following: (i) South Polar regions; (ii) Europe; (iii) Indonesia; (iv) the world.

(*c*) For each of **two** of the equal area projections named in (*b*), show by a sketch the appearance of the map-net and state to what extent the projection is accurate in regard to (i) shape, (ii) scale, (iii) direction. (C. 1955)



A. Simple Conic B. Two Standards Conic C. Bonne

(S=Standard Parallels)

Fig. 41

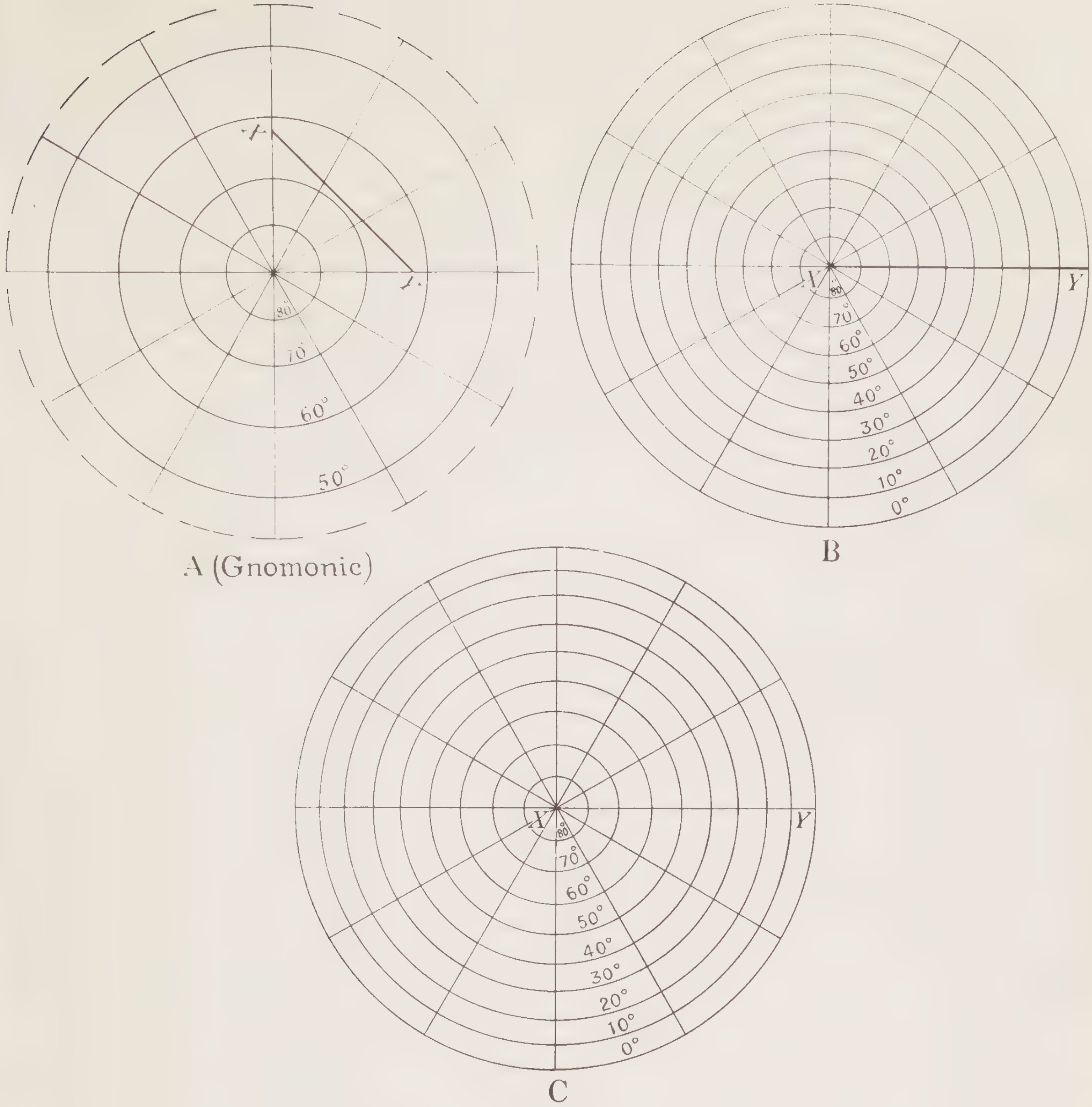


Fig. 42

3. After studying the outline map of South America:

(*a*) Name the projection on which the map is drawn stating how you distinguish it.

(*b*) What is the standard parallel of this map-net?

(*c*) Give a reasoned comparison of the accuracy on this map of the shapes of the Amazon and Plate estuaries.

(*d*) Is the scale shown on the map of value in measuring true distances between (i) *A* and *B*, (ii) *C* and *D*, (iii) *A* and *C*? Give reasons for your answers.

(*e*) State, with reasons, uses to which this map could be put by the geographer. (C. 1954)

(*The map was Sanson-Flamsteed with* 60° *W. central meridian; A was* 0° *Lat.,* 70° *W., Long., B* 0°, 60° *W., C* 20° *S.,* 70° *W., D* 20° *S.,* 50° *W.*)

4. (*see Fig. 41*)

After studying Diagrams *A*, *B* and *C*:

(*a*) On each diagram (i) draw thick lines along those Parallels and Meridians which give true scale, (ii) shade one area of maximum shape accuracy and one of minimum. Give an index to the shading used.

(*b*) Compare the properties and the uses in atlases of nets *B* and *C*. (C. 1953)

5. Study the two world outline maps *A* and *B* provided:

(*a*) Name the projections, stating briefly how you recognise each.

(*b*) Discuss the advantages and disadvantages of each for different purposes.

(*c*) What difficulties arise in giving a linear scale for Map *A*?

(*d*) Give sketches and explanatory notes of the modified form in which map *B* is frequently used in some atlases. (C. 1952)

(*Map A=Mercator, B=Mollweide.*)

6. (*see Fig. 42*) The diagram provided shows map-nets for three Polar Zenithal Projections: Gnomonic (=*A*), Equidistant and Equal area. Parallels are drawn for every 10° and meridians for every 30°.

(*a*) What property is common to all three nets?

(*b*) Show by a diagram why it is impossible to draw net *A* for a whole hemisphere.

(*c*) State briefly, giving the reason for your choice, which of *B* and *C* is the equivalent net.

(*d*) Examine the line *XY* shown on each net. State, *without comment*, whether or not in each case (i) distances measured along *XY* are correct to scale, (ii) *XY* is part of a Great Circle.

(*e*) State, giving brief reasons, which of these map-nets would be of use for the following purposes: (i) air navigation; (ii) polar exploration; (iii) showing the distribution of the Northern Conifer Forests. (C. 1951)

7. **Either** (*a*) (i) Construct the net of a Bonne's projection from 45° W. to 45° E. and from 15° N. to 75° N. Standard parallel 45° N. Scale 1/75,000,000. Draw parallels and meridians at 15° intervals.

(Radius of the earth=250,000,000 inches.)

(ii) Write brief notes on the properties and uses of this projection.

Or (*b*) Choose the most suitable projection for **each** of the following maps:

(i) surface currents in the Atlantic Ocean;
(ii) the distribution of equatorial forest;
(iii) a trans-polar air-map;
(iv) areas of cultivation in Australia.

For **each** of **two** of these, state why you consider the chosen projection to be the most suitable, and make a sketch of the graticule. (C. 1950)

8. **Either** (*a*) (i) Construct a net for a Bonne's conical projection from 30° W. to 30° E. and from 15° N. to 60° N. Standard parallel 45° N. Scale 1/80,000,000. The net should be drawn for every 15° of longitude and latitude.

(Radius of the earth=250,000,000 inches.)

(ii) Write brief notes on the properties and use of this projection.

Or (*b*) Show by means of sketches the appearance of the map-nets of any **two** forms of conical projections and compare their properties and uses in atlases. (C. 1947)

9. Using the arrangement of the parallels and meridians as straight lines or curves, map projections could be divided into the following groups:

(i) parallels and meridians straight;
(ii) parallels straight meridians curved;
(iii) parallels curved meridians straight;
(iv) parallels and meridians curved.

(*a*) Name **one** projection in each of the four categories.

(*b*) For each of **two** named in (*a*), (i) sketch its graticule, (ii) discuss its merits, defects and uses. (C. Overseas 1955)

10. After studying the outline map of Asia:

(*a*) Name the map-net used and state how you recognise it.

(*b*) Where would you place on this map the central meridian, and why? What would be the effect of selecting another central meridian?

(*c*) Do the lines *AB*, *CD* give the correct distances between these points? Give reasons for your answers.

(*d*) State *briefly* the uses, merits and defects of this map. (C. Overseas 1954)

(*Map net=Bonne; central meridian=85° E.; A=60° N., 130° E., B=30° N., 100° E.*)

11. (*a*) Illustrating your answer with diagrams, state how you would distinguish the graticules of each of the following Zenithal projections: Polar Gnomonic, Polar Equidistant, Polar Equal area.

(*b*) State with reasons which of these nets would be of use for the following purposes: (i) the consideration of international territorial claims; (ii) reaching the South Pole; (iii) plotting great circle routes. (C. Overseas 1953)

12. (*a*) Show by sketches and explanatory notes how you would distinguish between the following map projections: Simple Conical, Bonne and Sanson-Flamsteed.

(*b*) Stating brief reasons, which of the above projections could be used for each of the following purposes: (i) a general map of Africa; (ii) a map of the Canadian Pacific railway; (iii) a map to show the distribution of wheat-growing areas in Europe? (C. Overseas 1952)

13. (*a*) What is meant by an equal area projection and what is its value to the geographer?

(*b*) Name a different equal area projection you would choose for each of the following: (i) Polar regions; (ii) Middle Latitudes; (iii) Equatorial regions; (iv) the World.

(*c*) In the case of any **one** of the four equal area projections named in (*b*), show by a sketch the appearance of the Parallels and Meridians of the map-net and state to what extent this projection is accurate in regard to (i) scale, (ii) direction. (C. Overseas 1951)

14. **Either** (*a*) (i) Construct the net of a Gall's Stereographic projection for the area 60° N. to 60° S. and from 10° E. to 90° W. on a scale of 1/100,000,000. Draw parallels at 20° intervals, and meridians at 30° intervals.

(Radius of the earth=250,000,000 inches. cos 45°=0·7071.)

(ii) Write brief notes on the properties and uses of this projection.

Or (*b*) Compare the general appearance and characteristics of **two** equal area projections, and describe the method of construction of **one** of them. (C. Overseas 1948)

15. Explain why **either** the Mollweide **or** Sinusoidal projection is unsuitable for use in navigation. Suggest, with reasons, a more appropriate projection for this purpose. (L. 1957—*S*)

16. Compare the problems that arise in the construction of projections for polar and equatorial areas. (L. 1956—*S*)

17. Examine the problems of choosing projections for maps designed to show (*a*) air routes, and (*b*) meteorological conditions. (L. 1955—*S*)

18. Why is it important for geographers to study map projections? (L. 1954—*S*)

19. Describe how you would map the following, justifying your choice of projection and cartographical method in each case: (*a*) world production of coal; (*b*) the routes and frequency of air-line services from Nairobi; (*c*) the distribution of population in Australia. (L. 1953—*S*)

20. Compare the properties of the following map projections and discuss their uses for atlas maps of England and Wales: conical with one standard parallel; conical with two standard parallels; Bonne. (L. 1952—*S*)

21. Compare the distribution of distortion of shape on world maps based on each of the following projections: Mercator, Mollweide, Sinusoidal. (L. 1951—*S*)

22. (*a*) By defining the term "orthomorphic" explain fully why the statement that orthomorphic projections preserve shape is only approximately correct.

(*b*) Explain what is meant by an "interrupted" equal area projection for world maps and state the advantages possessed by such projections.

(*c*) Comment on the scale along the meridians in the polar case of each of the following zenithal projections: gnomonic, equal area, equidistant. Explain why such projections are azimuthal. (L. 1950—*S*)

23. **Either**—What are the essential differences between Mollweide's and Sanson-Flamsteed's projections? What are their advantages for special purposes?

Or—Criticise or justify the use of:

(*a*) Bonne's map-net for a map of Australia.

(*b*) Mercator's projection for a map of North America.

(*c*) A conical projection with two standard parallels for a map of the North Atlantic. (L. 1949—*S*)

24. Discuss the relative advantages for special purposes of (*a*) the Mercator, the Sinusoidal and the Mollweide map-nets of the whole world, and (*b*) the Simple Conical with two standard parallels and Bonne's map-nets. (L. 1948)

25. Which map-nets would you choose to show: (*a*) the railways of Canada; (*b*) trans-Atlantic steamship routes; (*c*) air services between London—the Middle East—India—Australia; (*d*) the distribution of vegetation in inter-tropical Africa? Illustrate by means of sketches and give reasons for your choice. (L. 1947)

26. Compare, as regards construction, properties and limitations of usefulness, the Mollweide and Sanson-Flamsteed networks (*a*) for maps of a hemisphere, (*b*) for world maps. (N. 1939)

27. Compare the construction, appearance and uses of the Polar zenithal equal area and the Cylindrical equal area map-networks. (N. 1939—*S*)

28. For what purposes are the following map projections most suitable: Bonne, Mercator, Sanson-Flamsteed, Gnomonic? State briefly your reasons, and give the chief properties of each of these projections. (N. 1941)

29. For each of the following maps choose the projection which is best suited:

(*a*) Ocean currents in the Atlantic Ocean.

(*b*) The climatic regions of Africa.

(*c*) Arctic pack ice.

(*d*) Mean annual rainfall in the Argentine Republic.

In each case show why the selected projection is the most suitable. (N. 1942)

30. With reference to the principles of construction and uses of four contrasted map-nets show why different map projections are necessary. (N. 1944)

31. Name the projections which are best suited for maps of the following: (*a*) world natural rubber production; (*b*) natural regions of Chile; (*c*) ocean currents in the Pacific Ocean; (*d*) the railway system of Canada. (N. 1945)

32. What knowledge do you consider that you should possess in respect of (*a*) distributional maps, (*b*) map projections? (N. 1945—*S*)

33. Give the most suitable projections for maps of the following: (*a*) the industrial regions of U.S.S.R.; (*b*) the oceanic trade routes focusing on the Panama Canal; (*c*) the economic products of the Dutch East Indies; (*d*) the softwood timber resources of the world. Give reasons for your choice and draw simple sketches of the general appearance of two of these projections. (N. 1946)

34. For each of the following name one projection which has the characteristics stated:

(*a*) parallels arcs of equally spaced concentric circles, meridians curved;

(*b*) parallels arcs of equally spaced concentric circles, meridians straight lines;

(*c*) parallels concentric circles spaced closer near the pole, meridians straight lines;

(*d*) parallels straight lines spaced at intervals increasing away from equator, meridians straight lines, relation of scale along meridians and parallels the same at all points.

Describe the properties and uses of each of the projections you name and show how one of them can be constructed. (N. 1947)

35. "We can keep our scale of area constant all over the map at a price. But we cannot keep the scale of distance constant all over the map at any price." Discuss this statement. (N. 1947—*S*)

36. Show fully how the property of equal area is obtained in each of the following projections: Polar zenithal equal area, Bonne, Cylindrical equal area. Giving specific examples discuss the purposes for which each graticule is suited. Explain the advantages of an "interrupted" projection for equal area maps of the whole world. (N. 1948)

37. Various considerations must be borne in mind in deciding what graticule to adopt for the construction of a map. Develop this fact on the basis of an analysis of a representative selection of graticules in common use in school atlases. (N. 1950—*S*)

38. Discuss "The first task in constructing a satisfactory map is to select a graticule suited to the purpose of the map." (N. 1951—*S*)

39. Discuss, with examples, the relevance of scale, and of position and extent of area to be represented, to the problem of the choice of map projection. (N. 1953—*S*)

40. "In map projections the two basic properties of orthomorphism and equivalence of area are diametrically opposed; the presence of one means the absence of the other." Explain why this is so, and discuss the other considerations that determine which property is preferred. (N. 1955—*S*)

41. State how you would distinguish between the two graticules in each of the following pairs:

(*a*) the Polar zenithal equidistant and the conic equidistant with one standard parallel;

(*b*) the Mercator and the cylindrical equal area;

(*c*) the Bonne and the Sanson-Flamsteed.

State the properties of and uses for one graticule in each of the three pairs. (N. 1956)

42. Select a different map projection for each of the following maps: (*a*) selva lands of the globe; (*b*) currents of the Pacific Ocean; (*c*) trans-polar air routes. State reason for the choice of each of the three selected projections and describe the construction of one of them. (N.)

43. Explain one method of constructing each of the following projections: (*a*) polar zenithal equidistant; (*b*) conical equidistant with one standard parallel; (*c*) Sanson-Flamsteed. State an area and a purpose for which each would be particularly suitable in an atlas. (N.)

44. Describe the chief distortion effects produced when a map of the world is drawn on (*a*) Mollweide network, and (*b*) a Mercator network. Show the chief purposes for which each is appropriate and inappropriate. (O. 1956)

45. List the main features, properties, and appro-

priate uses of the Mollweide and Sanson-Flamsteed (Sinusoidal) projections, and draw a sketch of each graticule. What are the chief differences between these projections? (O. 1954)

46. What considerations influence the choice of a projection for a map? Select the projection you would use to map any **three** of the following, in each case justifying your choice of projection by reference to its properties:

(*a*) distribution of cereals in the Argentine Republic;

(*b*) the principal shipping routes of the world;

(*c*) the railways of the U.S.S.R.;

(*d*) distribution of Arctic pack ice;

(*e*) world distribution of tropical hardwood forests. (O. 1953)

47. Draw sketches to show, by selected parallels and meridians, the graticules you would use to map any **two** of the following:

(*a*) the distribution of the sub-tropical crops in Asia;

(*b*) the progress of Antarctic exploration;

(*c*) the relative areas covered by the U.S.S.R., the U.S.A., and the British Commonwealth with the least possible distortion of shape;

(*d*) ocean currents in the Pacific Ocean.

In each case justify your choice of projection by reference to its properties. (O. 1952)

48. Describe the appearance, use, merits and demerits of any **three** cylindrical projections.

(O. 1950)

49. Draw figures to show by selected parallels and meridians the graticule of (*a*) one face of the globe on the stereographic projection, (*b*) the Northern Hemisphere on the orthographic projection. Why are these projections chosen in the cases mentioned? (No land-forms or mathematical explanations are required.) (O. 1949)

50. The map provided is a variation of Mollweide's projection. What advantages and disadvantages do you find in this composite map which the usual form of the projection does not share. (O. 1948)

(*The map was the Interrupted Homolographic*.)

51. Explain why map projections are necessary, giving examples to illustrate the points you make.

(O.C. 1955—*A & S*)

52. What characteristics make the following projections suitable for the purposes mentioned: Mercator—Navigation; Mollweide—World distributions; Conical—East-west communications; Bonne—Hemispherical distributions?

(O.C. 1954—*A & S*)

53. What projections are most commonly used in atlases? Explain the particular merits of any **three** that you name. (O.C. 1953)

54. Select any **three** map projections and for each state the purpose for which it is best suited, and its chief characteristics. (O.C. 1950)

55. Suggest map projections suitable for (*a*) a general navigational map for an airman, (*b*) a map to show density of population, and (*c*) one to show the equatorial part of Africa. In your answer you should clearly state the properties and advantages of the projection you mention. (O.C. 1949)

56. Name a projection suitable for each of the following purposes and describe briefly the principal properties of those you select: world distribution of a particular crop; forests in Europe; a general map of New Zealand. (O.C. 1948)

57. You are required to choose maps to show any **three** of the following: (*a*) world distribution of wheat growing; (*b*) railways of Europe; (*c*) air routes of the world; (*d*) relief of Brazil. Name two projections suitable for each purpose and explain the characteristics of each pair. (O.C. 1946)

58. Name **three** equal area projections. Give an outline account of a simple construction of any one of them. (O.C. 1945)

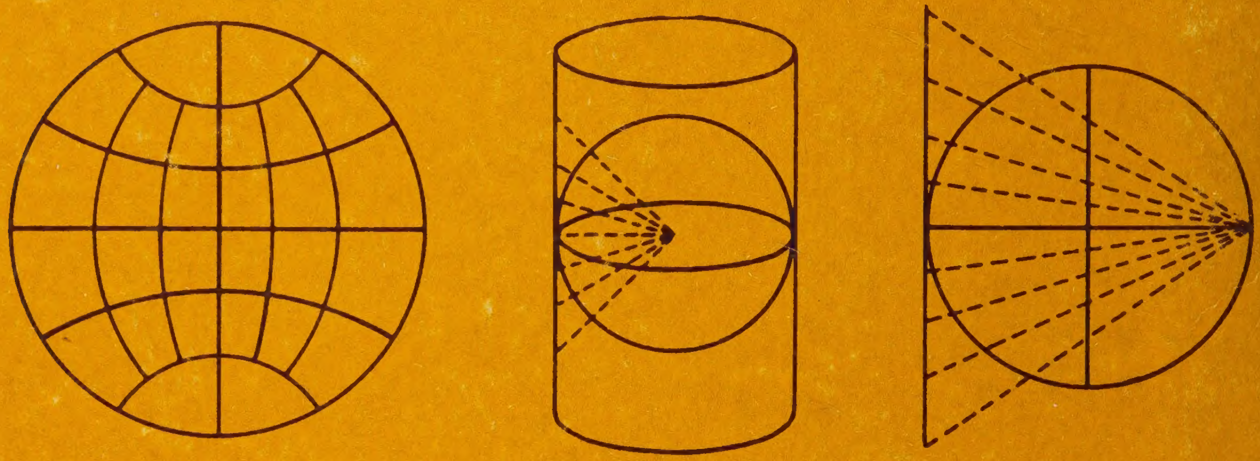
59. State the principal merits and demerits of **two** of the following projections: Mercator; Mollweide; Simple Conical. Which of these three projections would you use for (i) a map of world sea routes, and (ii) a map of the world distribution of wheat

(S.L.C. 1953)

60. State the necessary qualities required in a map projection which is to be used for a large continuous series of topographical maps at a scale 1 : 50,000 and 1 : 100,000. Do you consider that the maps of such a scale which are issued by the Ordnance Survey meet the requirements you mention?

(S.U.J.B. 1952)

This book sets forth simply and directly, for Advanced Level G.C.E. Candidates and others, the properties of the most commonly used projections. Some constructional details are also given for those who wish to go into this aspect.



The authors have wide experience of teaching and, in the case of one of them, of examining at Advanced Level. Numerous questions from past papers are included.