MAPS

TOPOGRAPHICAL AND
STATISTICAL

MAPS

TOPOGRAPHICAL AND STATISTICAL

BY

T. W. BIRCH

OXFORD
AT THE CLARENDON PRESS

Oxford University Press, Amen House, London E.C.4
GLASGOW NEW YORK TORONTO MELBOURNE WELLINGTON
BOMBAY CALCUTTA MADRAS CAPE TOWN
Geoffrey Cumberlege, Publisher to the University

FIRST EDITION 1949
REPRINTED 1952
PRINTED IN GREAT BRITAIN

PREFACE

The object of the first part of this book, which includes information about maps past and present, land and air-photo survey, and map projection, is to contribute to an understanding of topographical maps, map-reading, and the interpretation of landscape as recorded on maps. The second part of the book deals with statistical maps and diagrams, and particularly with the problems involved in their preparation.

The writer freely acknowledges his indebtedness to the authors whose works are mentioned at the end of the book, and to the various authors, publishing houses, and instrument-makers who have permitted the reproduction of photographs and figures listed on pp. xi–xiv.

Particular mention should be made of the Controller of H.M. Stationery Office and the Director-General of the Ordnance Survey for permission for the reproduction of various maps and figures, which are acknowledged in detail elsewhere.

A deep debt of gratitude is owed to many friends who have put their specialist knowledge freely at the writer's disposal. The first part of the book would have been less broad in scope and less accurate in detail without the technical criticism and valuable help of Colonel Collins, C.B.E., R.E., and much essential information could not have been gleaned without the kindly reception afforded by the Director-General of the Ordnance Survey, the Deputy Director-General and Staff, who have met every inquiry with remarkable patience and courtesy. Finally, my special thanks are due to Mr. Bickmore of the Clarendon Press for expert advice and abounding enthusiasm.

T. W. B.

Folkestone,
1949.

[illegible] from M/s Univ. Book House, [illegible] on 24/5/61 for Rs. 18/-/-

CONTENTS

Part I. TOPOGRAPHICAL MAPS

PART II. STATISTICAL MAPS

LIST OF ILLUSTRATIONS

PART I

TOPOGRAPHICAL MAPS

CHAPTER ONE

LOOKING BACK

MAPS which are described in this book fall into two broad groups which may be called respectively topographical and statistical. Topographical maps are concerned mainly with the surface of the earth, man's physical environment. By contrast, statistical maps depict to a great extent man's social and economic environment.

It is appropriate that topographical maps should be described first, because they preceded statistical maps by many centuries; and that a little time should be spent looking back over the history of mapping before proceeding to examine modern maps and methods of map making.

The record of the past is fragmentary, and such maps and plans as have survived are not necessarily the best, nor is there any guarantee that they are even typical of their time. It is known that the early Egyptians made maps and plans, and some of their work has been discovered on papyrus rolls, though the material was ill suited to stand the test of time. The Babylonians had plans made on tablets of clay, which were baked, and fragments have survived for 2,000 to 3,000 years. Such plans were probably made by direct measurement on the ground, and a scene preserved on the walls of a tomb at Thebes gives clues on which surmises can be based.

Greek cartography was aided by astronomical observations, an assumption by no means universal that the earth was spherical, and a readiness to take advantage of the extension of geographical knowledge through travels on land and sea. In the third century B.C. Eratosthenes estimated the size of the earth with an accuracy which if known to Christopher Columbus might have discouraged him in planning his memorable voyage.

Special mention must be made of Ptolemy, a Greek born in Egypt, who lived in the second century A.D. He became famous as an astronomer and geographer, and left details for the construction of twenty-six maps and a general world map, though it is uncertain whether he himself ever drew any of them. He accepted the erroneous earth measurements of Posidonius in place of the earlier ones of Eratosthenes. Errors in Mediterranean maps resulted which were repeated as late as A.D. 1700, for his work, rediscovered in the fifteenth century, long after remained a standard work of reference, as it had been for Columbus. The world according to Eratosthenes and Ptolemy is seen in Figs. 1 and 2.

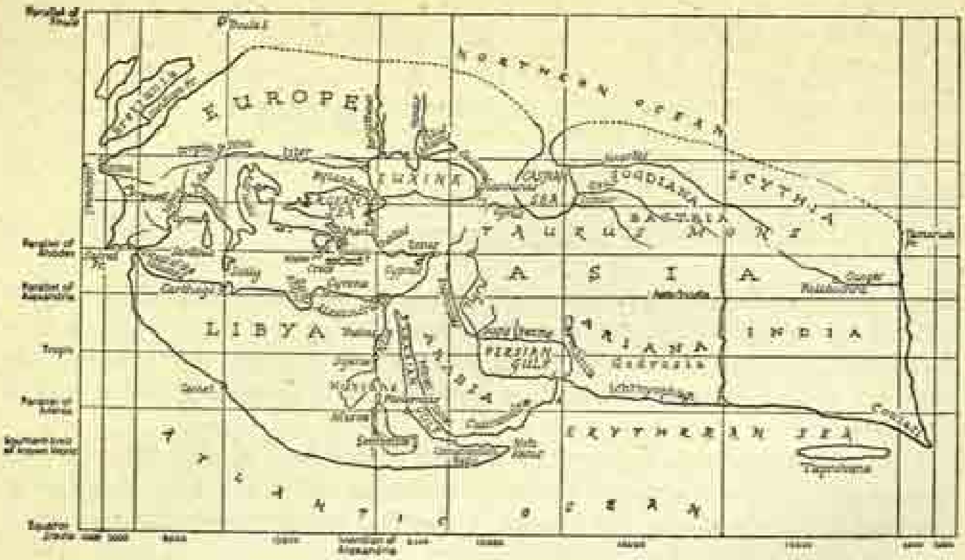


Fig. 1. The World according to Eratosthenes.

No Roman map has survived, though it is assumed that the Romans made maps as an integral part of their planning. Some of their map-making instruments have survived, and also a copy of one of their maps. This copy was drawn

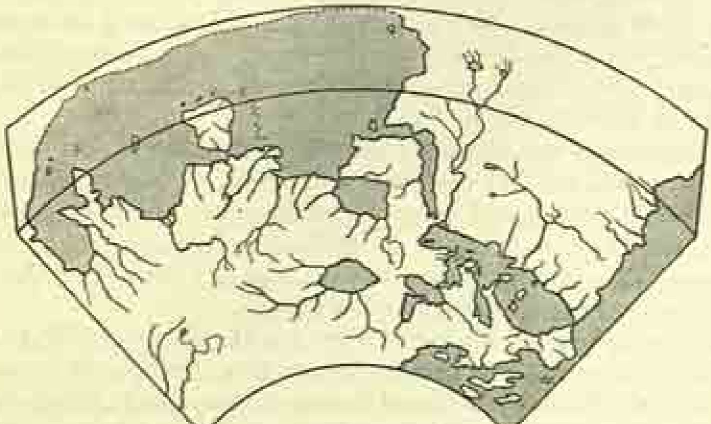


Fig. 2. Outline of Ptolemy's World.

in twelve sheets about A.D. 1230, and was discovered about three centuries later. It is referred to as the Peutinger Table, the Roman name for a map being *tabula*, and shows in diagrammatic form the main routes from south-east Britain in the west to the Ganges in the east. Plate I gives an idea of the style.

World maps of the early centuries of the Christian era, such as the Hereford Map of about A.D. 1280, a miniature sketch of which is seen in Fig. 3, reveal a good deal about the development of geographical thought and ideas, but add little to knowledge of cartographical method. During this same period Anglo-Saxons and others were no doubt making plans of their settlements and holdings in north-west Europe, but unfortunately no trace of these remains.

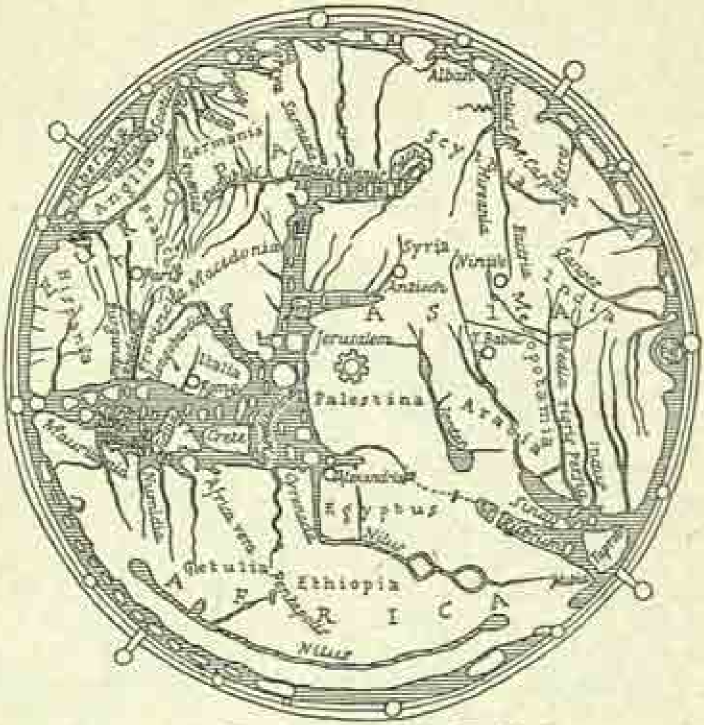


FIG. 3. Sketch of the Hereford Map of the World, about A.D. 1280.

The first notable map of England, apart from that based on Ptolemy, was produced by Matthew Paris c. A.D. 1250. Contrary to custom then prevailing, he orientated his map with north at the top. The Church had favoured putting east at the top, and the Arabs and Romans south. Paris's information probably came from other manuscript maps, manuscript accounts, and information gleaned from travellers. Directions are inaccurate to the point of suggesting that the primary purpose of the map was to show travellers the route to Dover rather than to delineate Britain.

An extremely interesting map of Britain known as the *Gough Map* comes down from about A.D. 1335. Its authorship is unknown. East is at the top, roads are shown diagrammatically as a principal feature, and the distances then

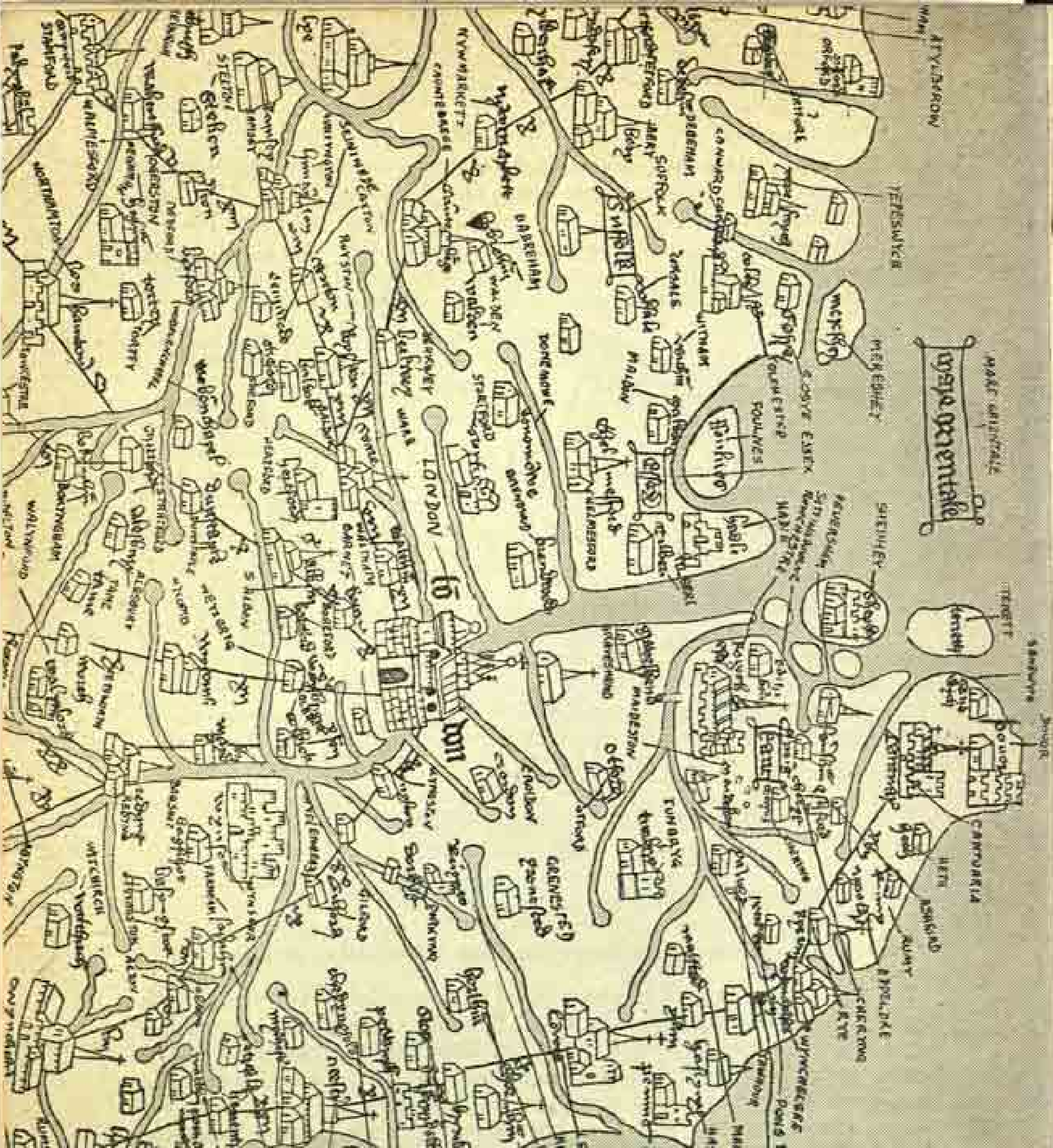


Fig. 4. Part of Gough Map, about A.D. 1335, with names transcribed. It will be seen that the map is read with East at the top.

shown were quoted for two and a half centuries. Rivers and sea are coloured green, and roofs are red. Uncoloured reproductions with names added in modern script can be bought very cheaply from the Ordnance Survey, and Fig. 4 is derived from this source. The most casual observer is struck by the accuracy of configuration, indicating that most of England and Wales had been surveyed, though nothing is known of the methods employed.

An important series of charts made chiefly by Italian and Catalan or east Spain seamen, and later by Portuguese, calls for special mention. In point of time they spread over about three centuries, from A.D. 1300 onwards, though the earliest known example represents quite an advanced stage in development. They were prepared especially for the use of sailors, and depict the coastlines chiefly of the Mediterranean and neighbouring seas, though some of the latest show the whole Atlantic coasts. These *Portolan Charts* resulted from the piecing together of numerous local surveys. Such practice contravenes a basic principle of modern survey, namely, to proceed from the whole to the part. But they were a great advance on all previous work, were quite unlike the fanciful cloister maps of the Middle Ages, and left their mark upon the shape of future world maps. They also replaced the ancient Greek word-descriptions of coasts and ports for mariners, called *peripli*, and the similar descriptions of Italian origin called *portolani*.

More than 500 of these manuscript charts are known to exist. Most are drawn in bright colours on parchment, that is, prepared skin of sheep, goats, or calves. Occasionally they were bound together in atlases. The size and natural shape of the skin often appears to determine the scale of the chart.

There is no doubt that the mariner's compass became a principal survey instrument in making local surveys, and it is significant that with rare exceptions the portolan charts are drawn with north at the top. The astrolabe was used in determining latitude. This instrument consisted of a heavy ring marked in degrees, with a sighted pointer pivoted at the centre. It enabled the sun's altitude to be determined, and this in turn could be translated into latitude. The astrolabe had been improved by the Arabs, whom more people associate with camels than with the sea or with scientific development.

Degrees of latitude and longitude were seldom indicated on portolan charts prior to A.D. 1500, and no network of lines of latitude and longitude was drawn in. Lines radiating from various points, however, form a striking feature of these charts, as may be gathered from the sketch in Fig. 5. One set of 32 lines normally radiates over the whole chart from the centre, and 8 or 16 similar sets radiate from points on the circumference of an undrawn circle about the central point. Their origin and purpose is not clear. Centre points are often elaborated into compasses or wind roses, but these lines are not true compass sailing directions, since the charts are not on a Mercator projection, nor, for that matter, on any other mathematical projection. The degree of accuracy between the lines as drawn and the true compass bearings may have matched the accuracy with which the mariners could sail their ships along a constant bearing.

Two events occurred in the sixteenth century which are notable to cartography. One was the birth of Mercator in 1512, and the other was a revolution in the method of map reproduction. Mercator combined the idea of a latitude and longitude framework with the comparative accuracy of survey observable in portolan charts. The map projection which bears his name enabled compass directions to be drawn as straight lines, and it is still in general use for navigation.

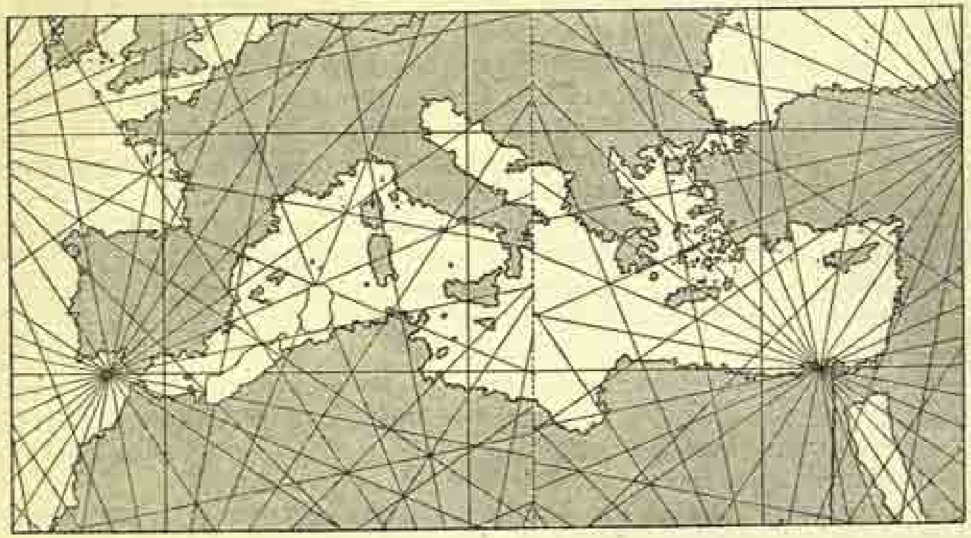
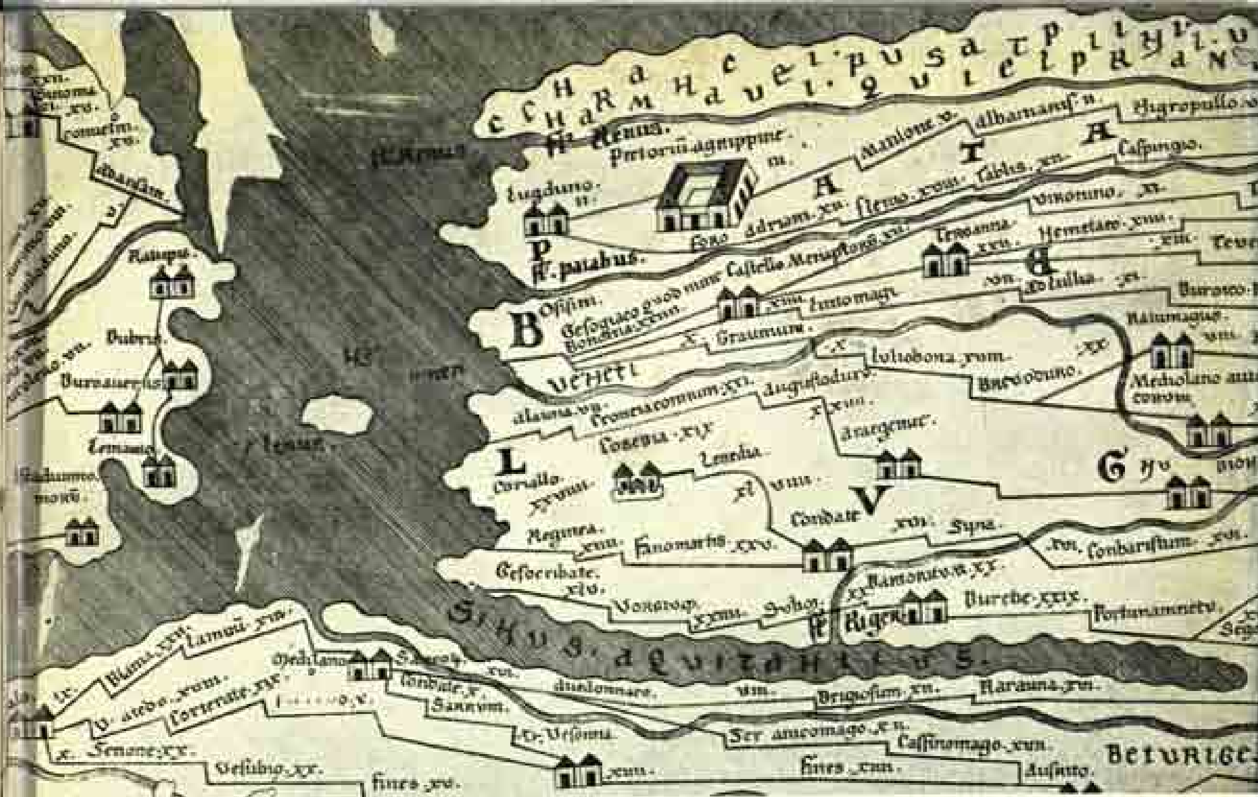


FIG. 5. Juan de la Cosa Portolan Chart, 1500.

The second event, actually begun before the sixteenth century, was map engraving. From the time papyrus rolls were used for ancient Egyptian maps and plans almost to the close of the period of portolan charts on parchment, maps had been hand copied. Thus there are in existence four copies of Paris's map of Britain, all drawn in the monastery at St. Albans but all differing slightly from each other. It does not need much imagination to appreciate that omissions and introductions were likely to occur in the process, and one is led to wonder what the original Roman map was like from which the Peutinger Table was drawn. Engraving therefore did more than increase the number of copies: it ensured identical copies, increased the chance of survival, widened the distribution, built up the publishing business, and produced wealth which went back at least in part into the making and compilation of new maps for which the spirit of exploration called.

Both wood and copper engraving had been tried as a means of map reproduc-



I. *Above*, Portion of the Peutinger Table, of Roman origin.

I. *Below*, Portion of Roy's Map of Scotland, c. 1747, full scale. *By courtesy of the Trustees of the British Museum.*

tion towards the end of the fifteenth century. It seems probable that the earliest woodcut was published in Germany, and the earliest copper engraving in Bologna, the subject appropriately enough being the maps from Ptolemy. Copper was early recognized as the superior medium, and copper engraving held the field well into the modern period of map making. The first important engraved map of Great Britain, complete with ornamental panels or cartouches, stippled sea, ships, and monsters, but without roads, was published at Rome in 1546. By 1570, when Ortelius published an historic atlas of the world, the Flemings had become skilled in copper engraving and had supplanted the Italians.

England came into the picture largely through the industry of Yorkshire-born Christopher Saxton, who was commissioned to make maps of all the English counties. Part of the map of Kent is reproduced in Fig. 6, though without the colour with which it was normally adorned. Within a few years Saxton covered all England and Wales, probably by checking and correcting such maps as existed. Some of the engraving of his maps on scales from about $1\frac{3}{4}$ to $3\frac{3}{8}$ miles to the inch was done by Flemish refugees and some by Englishmen. The first national atlas produced by any country was that by Saxton in 1579. Norden, a contemporary, was the first cartographer to show roads on county maps.

One feature common to maps whether hand drawn on pumiced skins or printed on paper, was hand colouring. Matthew Paris's map, with green sea and blue rivers, had colours made up from red and white lead, ochre, indigo, verdigris, and vegetable juices. The first issues of Saxton's maps were a blaze of colour, and though artistic decoration remained a noticeable feature of maps into the eighteenth century, the more objective scientific cartography abandoned decoration and retained colour only for technical purposes, or abandoned it altogether. The introduction of lithography in the middle of the nineteenth century reinstated colour as an important feature of modern maps, though some hand colouring, for example of English official maps, continued till 1902.

The seventeenth century was notable for the work of Dutch cartographers, notably Hondius, Jansson, and Blaeu. The Dutch republic was drawing great wealth from her overseas empire and the Dutch supplied the world with fine atlases, maps, and charts. There was opportunity for constant map revision, as shown in Blaeu's 1648 map of the world incorporating the results of half a century of exploration, but there still had to be reference back to such authorities as Ptolemy for information about the interiors of many countries. Jansson's atlas in four volumes produced in the middle of the century became famous, and enlarged editions were published in Dutch, French, German, and Latin. There was no copyright, and the maps of Saxton and others were used by a succession of publishers, sometimes with date, cartouche, and other details altered, or sometimes redrawn and engraved to look completely different.

John Ogilby made a notable contribution to cartography by an original road

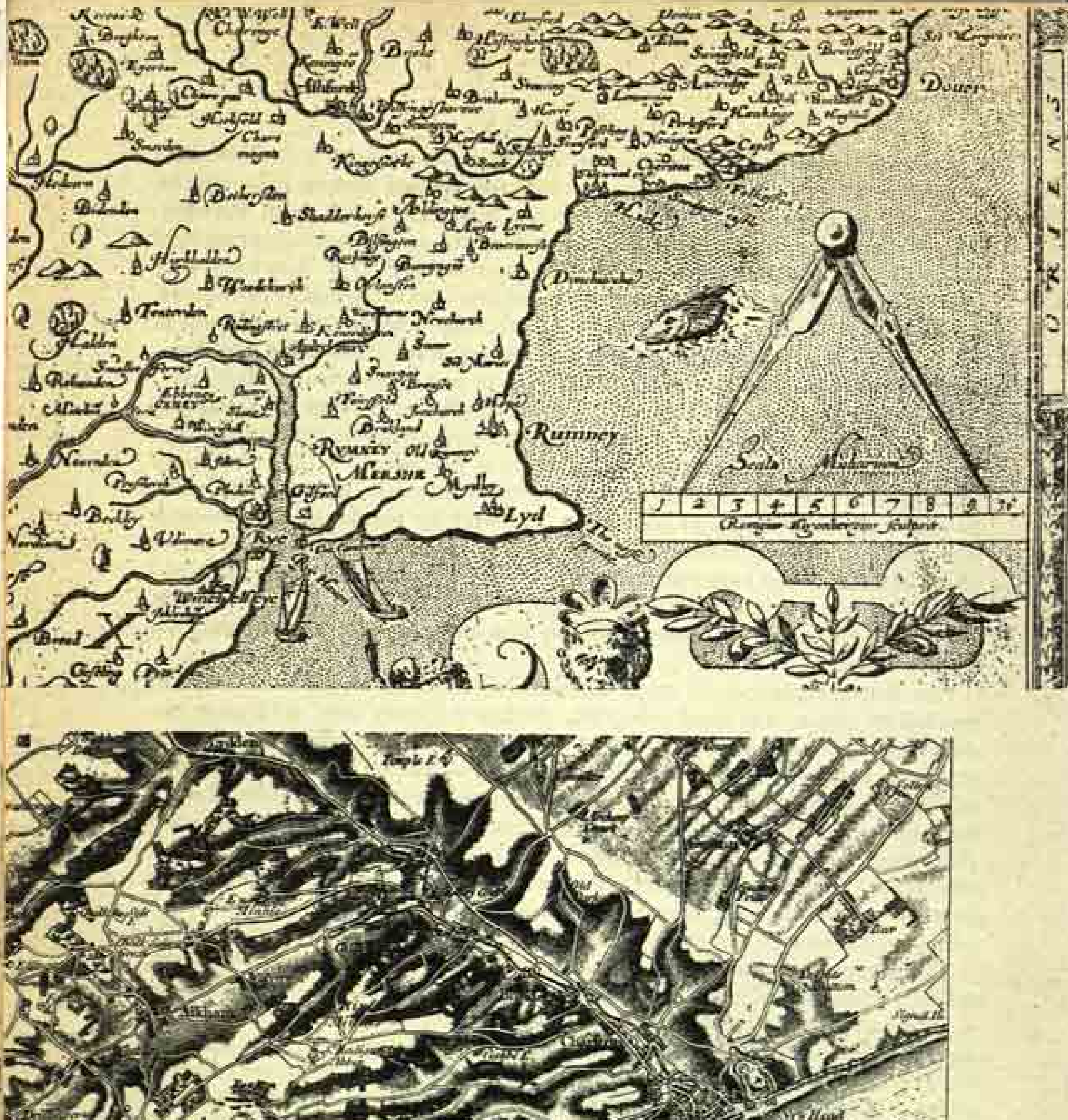


FIG. 6. Above, Part of Saxton's Map of Kent, 1577. Below, Ordnance Survey Map, 1801.

survey which resulted in the publication in 1675 of a road atlas of England and Wales in 100 plates. Many copies have survived. The roads are all drawn outward from London in strips on a scale of 1 inch to the mile. Thereafter all maps of appropriate scale had roads shown and even Saxton's atlas was republished with roads added. Lynam states that after 1675 the history of English cartography becomes to a great extent the history of publishers and of the gradual incorporation into their maps and charts of advances in geography, geodesy, hydrography, surveying, engraving, representative symbols, lettering, decorative art, and colouring.

The eighteenth century saw the foundation of modern map making and the entry of the State into competition with private map making and publishing. Several forces combined to bring this about. Nationalism developed and found expression in demands for national surveys; scientific investigations, such as the measurements of arcs of meridians, though undertaken for purposes other than map making, lent their results to that end; there was the growth of a scientific spirit which discriminated between the known and the hypothetical, and revealed the need for accurate and detailed survey; and finally there was the expense and vastness of such enterprises at what was a new level of accuracy.

In 1747 Louis XV desired Cassini de Thury to construct a map of the whole of France on a scale sufficiently large to show topographical detail. The maps were produced on a scale of about $\frac{3}{4}$ inch to the mile, actually 1 : 86,400. Points already fixed by Cassini in some triangulation in conjunction with astronomical observations formed the beginning of a framework on which to hang detail. Relief was shown by hachures. It took ten years to produce two sheets, but Cassini continued till 1793, when the Revolutionary Government took charge and finished the job. This map, the first general map of a whole country based upon extended triangulation and topographical surveys, was not fully replaced till 1914.

About the time of this request to Cassini, William Roy was making a better map of Scotland than any then in existence, though using little more than a compass, or, in his own words, 'instruments of the common or even inferior kind'. The scale was about 1 inch to 1,000 yards. The map was never printed, but the original sheets are preserved in the British Museum, and a portion is reproduced in Plate I, facing p. 6.

Towards the end of his life Cassini suggested that the observatories of Greenwich and Paris should be connected by triangulation. Roy seized the opportunity to initiate the first accurate triangulation in Britain, using what was then probably the finest theodolite in the world, specially made for the job and paid for by the King. The connexion with France was carried through under the auspices of the Royal Society, but events after Roy's death led to the adoption of the survey by the Master General and Honourable Board of Ordnance, which in turn, though not immediately, gave rise to the name *Ordnance Survey*.

The first detailed official survey in Britain with a view to map production on the 1-inch scale was over the ground of the first accurate triangulation. The first 1-inch map, copper engraved, without colour, and covering Kent and adjoining areas in four sheets, was published on 1 January 1801. Part of this is seen in Fig. 6. Roy had laid the foundation; the first Director of the Survey, in the opinion of a colleague, had played his part by taking his departure to the next world; and the second Director, Colonel Mudge, had launched the first of a series of maps which have remained unsurpassed in accuracy and unrivalled in completeness by those of any other national survey.

CHAPTER TWO

MODERN MAPS

MODERN maps are often described as either atlas maps, topographical maps, or plans, differentiation being based on scale. Atlas maps are generally on scales less than $\frac{1}{10}$ inch to 1 mile, plans on scales substantially exceeding 1 inch to 1 mile, while topographical maps are those on intermediate scales.

The chief concern of the present chapter is modern topographical maps. Their production has been a most important function of national surveys. Some idea of the extent of the earth's surface already mapped topographically is seen in Fig. 7, while an idea of present-day styles is seen in Plates II and III. A word is added about atlas maps, but plans are considered in a separate chapter.

The aim of the Ordnance Survey was at first the production of a 1-inch map of Britain. As a representative fraction this scale is written 1 : 63,360, which is another way of saying that 1 inch on the map shows 63,360 inches on the ground. Some countries use a scale of 1 : 50,000, and in the United States 1 : 62,500 is a standard scale. Both larger and smaller scales are, of course, standard in many countries, as may be seen from the table opposite Fig. 7, but scales in the region of 1 inch to the mile enable footpaths, towns, villages, railways and stations, contours, rivers, fords, streams, woods, parks, orchards, vineyards, administrative boundaries, high- and low-water marks, all to be accurately delineated. The development of colour printing has been a major factor in facilitating the representation of detail without confusion, and also the production of maps on the same scale differing widely in style. Topographical maps on smaller scales show an equivalent loss of detail, and material for these maps has to be selected with the special purpose of each in view.

Some important features of topographical maps may be noted in connexion with characteristic examples, but since there is such an array of scales, editions, and styles, only the more important maps will receive attention. Those of Britain are worthy of special note owing to their completeness and variety. The whole country is covered on each of the scales enumerated below, and samples of each in various styles are to be seen in the *Catalogue of Small-Scale Maps* published by the Stationery Office, London. (See also Plate IV, facing p. 26.)

1. ORDNANCE SURVEY MAPS OF BRITAIN

1-inch Maps. The development of modern cartography is summarized in Britain's Ordnance Survey maps on the scale of 1 inch to the mile. The field work as far north as a line from Hull to Preston probably never occupied more then twenty-five surveyors. For this southern portion work was started on a scale of 2 inches to the mile, but some areas were surveyed on a scale of 3 inches

OFFICIAL MAP SERIES

I. LARGE SCALE MAPS

LARGER-SCALE THAN 1/200,000 (EXCLUDING CADASTRAL SERIES)

Percentage cover: 1–25%, **25%–50%**, **50%–100%**—as of 1945

EUROPE			
Albania		1/50,000	
Austria	1/25,000	1/50,000	1/75,000
Belgium	1/20,000	1/40,000	1/100,000
British Isles	1/10,560 1/25,000	1/63,360	
Bulgaria	1/25,000	1/40,000 1/50,000	1/100,000
Czechoslovakia	1/25,000	1/75,000	
Denmark	1/20,000	1/40,000	1/100,000
Estonia	1/25,000	1/50,000	
Finland	1/20,000	1/50,000	1/100,000
France	1/20,000	1/50,000	1/80,000
Germany	1/25,000	1/50,000	1/100,000
Greece	1/20,000	1/50,000	1/100,000
Holland	1/25,000	1/50,000	
Hungary	1/25,000		1/75,000
Iceland		1/50,000	1/100,000
Italy	1/25,000	1/50,000	1/100,000
Latvia	1/25,000	1/50,000	1/75,000
Lithuania	1/25,000		1/100,000
Luxemburg	1/20,000	1/50,000	
Norway	1/25,000	1/50,000	1/100,000
Poland	1/25,000		1/100,000
Portugal	1/20,000 1/25,000	1/50,000	1/100,000
Rumania	1/20,000	1/50,000	1/100,000
Spain	1/25,000	1/50,000	1/100,000
Spitzbergen	1/25,000		
Sweden		1/50,000	1/100,000
Switzerland	1/25,000	1/50,000	1/100,000
Yugoslavia	1/25,000	1/50,000	1/100,000
U.S.S.R.	1/25,000	1/50,000	1/100,000
ASIA			
Ceylon		1/63,360	
China		1/50,000	1/100,000
Cyprus		1/63,360	
East Indies	1/20,000	to	1/150,000
India and Burma		1/63,360	1/126,720
Indo-China	1/25,000		1/100,000
Japan, Korea, Manchuria	1/25,000	1/50,000	

Malaya		1/63,360	
Palestine	1/20,000		1/100,000
Siam		1/50,000	1/100,000
Syria		1/50,000	1/100,000
Turkey	1/25,000	1/50,000	
U.S.S.R.		1/50,000	1/100,000
AFRICA			
Abyssinia		1/50,000	1/100,000
Algeria		1/50,000	
Belgian Congo			1/100,000
Egypt	1/25,000	1/50,000	1/100,000
Eritrea	1/25,000	1/50,000	1/100,000
French West Africa			1/100,000
Gold Coast		1/62,500	1/125,000
Kenya			1/125,000
Libya		1/50,000	1/100,000
Madagascar	1/20,000		1/100,000
Morocco (French)		1/50,000	1/100,000
Morocco (Spanish)		1/50,000	
Nigeria		1/62,500	1/125,000
Sierra Leone		1/62,500	
Somaliland (Italian)		1/50,000	
Tunisia		1/50,000	1/100,000
Union of South Africa		1/50,000	1/125,000
" [South-West Africa]			1/100,000
AMERICA			
Argentine		1/50,000	1/100,000
Brazil	1/20,000	1/50,000	
Canada		1/63,360	1/126,720
Chile			1/100,000
Columbia			1/100,000
Ecuador	1/20,000 1/25,000		
Haiti			1/150,000
Mexico		1/50,000	1/100,000
United States		1/62,500	1/125,000
Uruguay		1/50,000	
Venezuela	1/25,000		
AUSTRALASIA			
Australia		1/63,360	1/126,720
New Zealand		1/63,360	1/125,000

II. SMALL SCALE MAPS

1/200,000 AND SMALLER SCALES

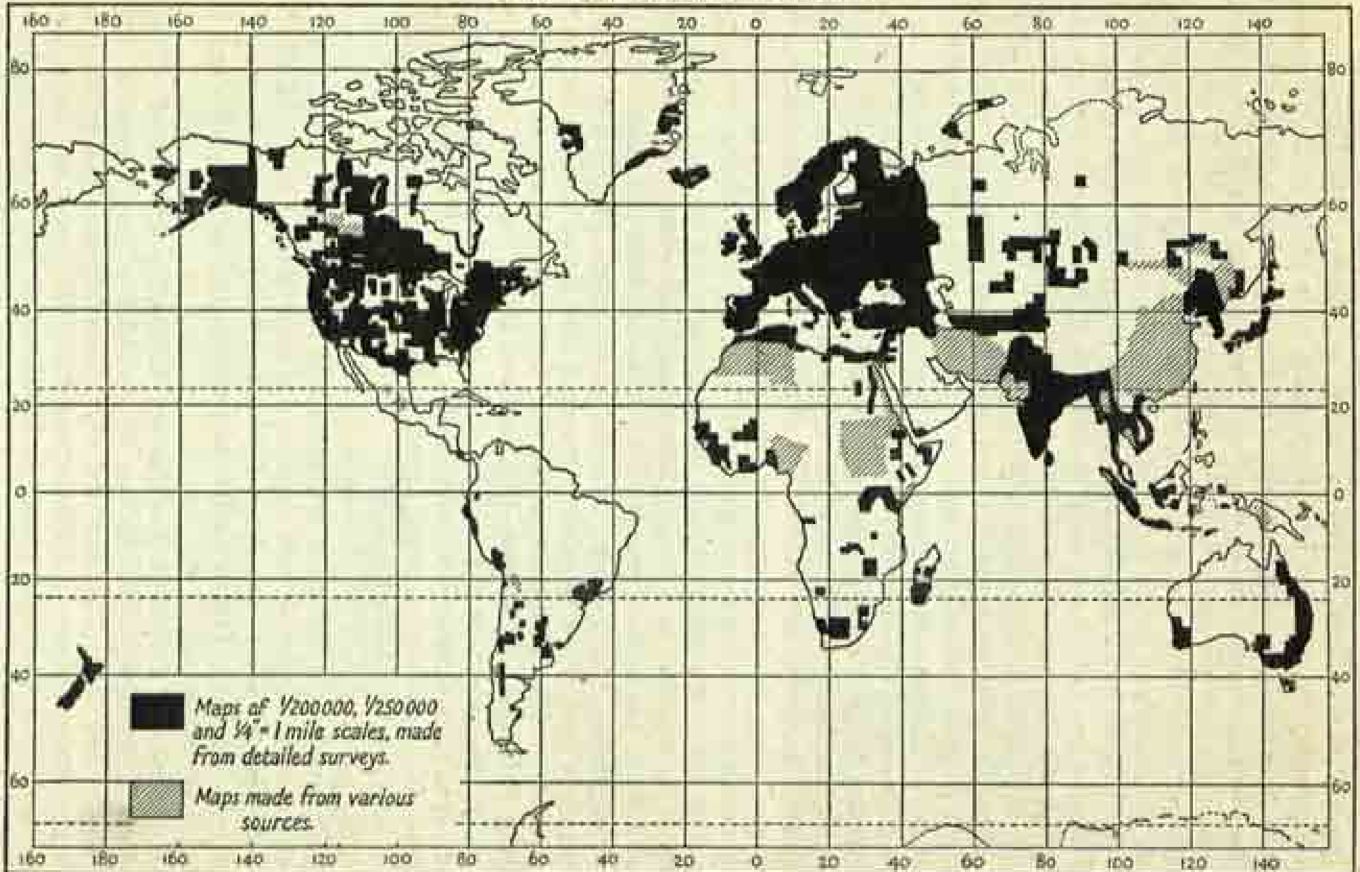


FIG. 7.

and some on a scale of 6 inches to the mile. North of the Hull–Preston line special survey for the 1-inch was not done, since north of that line first the 6-inch then the 25-inch plans made all survey on smaller scales unnecessary.

The map has not only been reduced from various scales, but it has been drawn upon various projections. Cassini's was at first used for England, and some half-dozen different central meridians were employed, later reduced to one. Scotland and Ireland were drawn on Bonne's projection, although, of course, with different origins. After the first World War, Scotland was redrawn on Cassini's projection and made to fit north of the England sheets, as part of the Popular Edition. Now all Britain is being published on the Transverse Mercator with a single central meridian.

Altitudes above mean sea-level are shown along main roads and on summits of high ground. Contours are usual at intervals of 50 feet, though this entails the use of interpolated contours which are not distinguished in any way from those instrumentally surveyed. All roads are classified by distinctive colouring, according to the nature of the surfaces and suitability for traffic, except on the *Engraved Outline Edition* which is printed in black, by transferring from engraved copper to zinc plates. No slight misfits of detail occur as may be detected when colour features are overprinted from separate plates. Contours and parish boundaries are sometimes difficult to follow. Colour printing is not possible from consecutive copper plates because the necessary fit or register cannot be obtained in a copper-plate press. But when lithography came in, originally in the form of printing from stone but later also from plates of zinc and aluminium, the necessary fit could be obtained. Details were transferred from the copper plates to separate stones or zinc plates, and printed in distinctive colours. Thus an alternative form of the 1-inch map was produced, known as the *Fully Coloured Edition*, with contours in red, hachures in faint brown, water in blue, woods in green, and roads in burnt sienna.

In 1912 publication of a *Popular Edition*, more interesting in appearance, was begun. Hachures were omitted, but there was a more careful road classification, still based on suitability for traffic.

Publication of the *Fifth Edition* began in 1931. It embodied a change in the style of writing, a change of projection, the restoration of parish boundaries, and the introduction of new symbols for such features as power cables and youth hostels. There was also a *Fifth (Relief) Edition* which covered part of southern England. It had additional printings of hachures, hill shading, and faint layer colouring.

Publication of a *Sixth* or *New Popular Edition* has commenced. It is superseding the incomplete Fifth Edition from which it is largely derived. The style is almost identical. The National Grid, described in some detail in a later chapter, forms squares of 1 kilometre a side. The size of the sheets has been standardized so that each covers 45 kilometres or grid squares from north to

II. Examples of Foreign Maps.

Top left, German map 1/100,000 (black only). *Top right*, French map 1/50,000 (coloured). *Bottom left*, Russian map 1/50,000 (coloured). *Bottom right*, International map 1/1,000,000 (coloured).

south, and 40 from east to west. Relief is shown by contours in brown. Tree signs are being omitted. Revisions arising from the 1939–45 war are being incorporated.

A last important map on the scale of 1 inch to the mile which deserves special mention is that produced and published by the *Land Utilization Survey.* Six-Inch Ordnance Survey maps were taken into the field, mainly under the direction of local education authorities, and on them the use of every parcel of land was recorded under one of six headings: Forest and Woodland; Arable; Meadowland and Permanent Grass; Heath and Moorland; Gardens, &c.; or Land Agriculturally Unproductive. The scale of the work was reduced, and colour plates prepared to show land utilization. These were over-printed on the Popular Edition of the 1-inch map.

Half-inch maps. Maps on the scale of half an inch to the mile are of use for cycling, motoring, and in administration. Various styles are published, but the features shown are substantially the same as on the 1-inch maps. It was on this scale that layer colouring in Britain was first developed, largely by Messrs. Bartholomew, and one form of the Ordnance Survey half-inch map is layer coloured. This precludes the use of green for woodland, but colour is used for road classification and for water features. With reduction in scale the contour interval becomes 100 feet, and there is some smoothing of contour form.

The sheets of Orkneys, Shetlands, and Hebrides are not layer coloured, but these provide beautiful examples of hill shading. Treatment of relief differs again on certain District Sheets, where contours, monochrome layering, and hill shading are used in combination. The Island of Skye sheet, in seven colour printings, is a beautiful example. But this apparently perfect combination of the scientific and pictorial representation of relief is less successful on the Cotswold sheet, where relief is lower and the main escarpment faces the north-west.

Quarter-inch maps. The quarter-inch to the mile maps resemble the half-inch layer-coloured edition, but special prominence is given to road classification, because these maps are much used by motorists. Contour interval is 200 feet and layer colours range from cream to brown, enabling woodlands to be shown in green. Villages appear as small clusters of black dots along roads, while larger built-up areas are cross-shaded.

An interesting version is the *Civil Air Map* on the quarter-inch scale. Details which are plainly visible from the air, such as water, railways, woods, and roads, are conspicuously drawn, while features of special interest to pilots, such as aerodromes, landing-grounds, seaplane bases, and beácons, as well as things to avoid, such as artillery ranges, are marked in red. By contrast, relief is hardly shown, only the high land which might constitute a danger being shaded brown. Purple has now superseded brown for relief on most air maps.

Ten-mile maps. There is a slight modification of nomenclature for maps on the next smaller scale, the expression 10-mile maps being used in preference to the designation one-tenth of an inch to the mile. There is a layer-coloured edition prepared on large sheets mainly for the benefit of motorists. Villages and small towns are marked by dots, as on this scale it is hardly possible to show the form of any but the large towns. One version of the 10-mile map successfully shows relief by delicate hill shading unsupported by other means.

2. Survey of India Maps

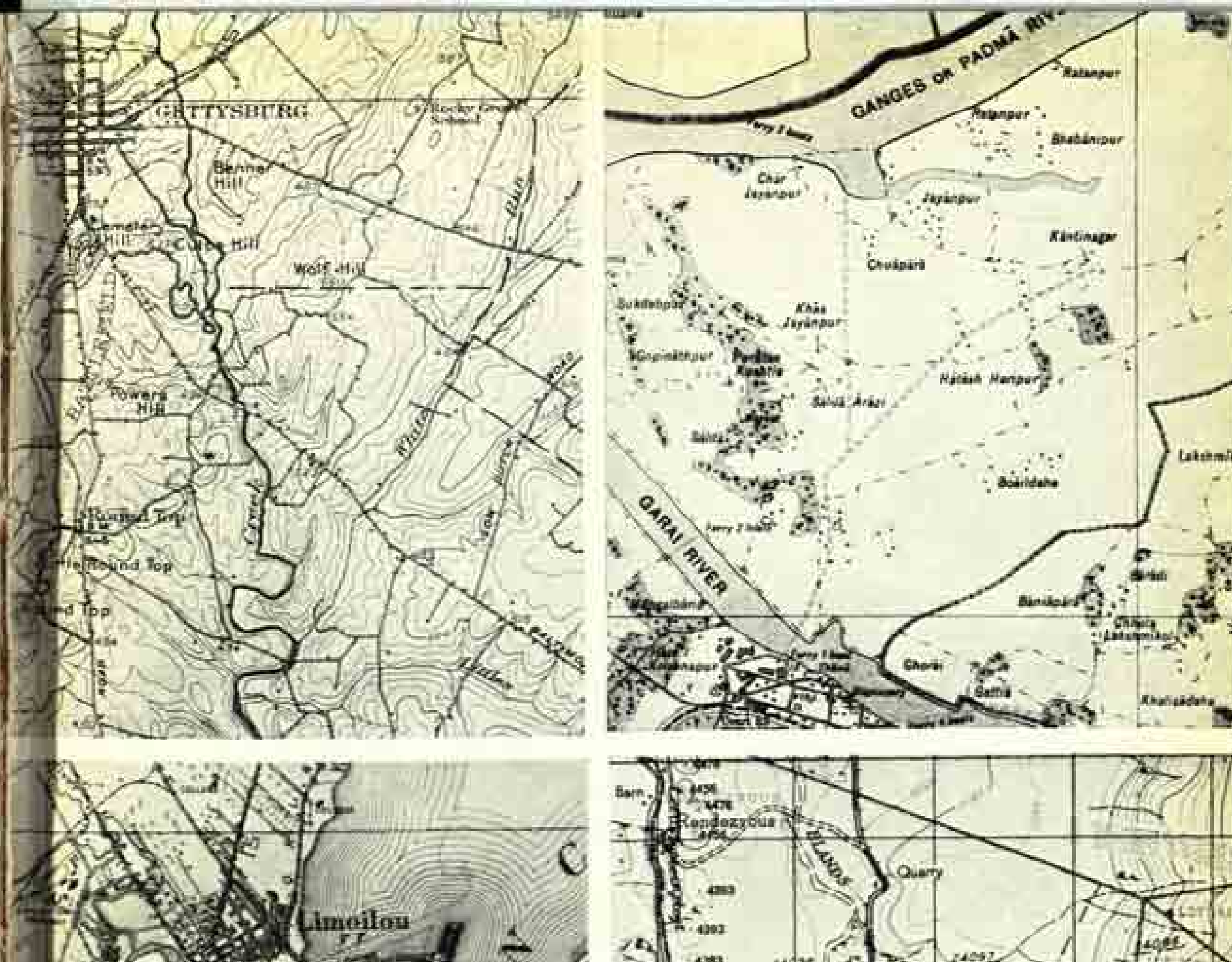
Maps in *India* are produced by the Survey of India, under the Department of Lands, though in 1947 about half the personnel in the higher posts were officers in the Royal Engineers or Royal Indian Engineers. Even the briefest of accounts should draw attention to the Survey's early start, the vast extent of the territory involved, and the high standard of the work done.

The first authoritative map of India was published by D'Anville in 1752, a compilation of travellers' routes and coastal charts. In 1767, two years after Roy had been appointed Surveyor-General of Coasts and Engineer for making military surveys in Great Britain, Major James Rennell was appointed Surveyor-General of Bengal, and this appointment may be regarded as the foundation of the India Survey.

Rennell's maps were originally military reconnaissances and latterly chained surveys based on astronomically fixed points. Though they do not pretend to the accuracy of modern maps of India based on the rigid system of triangulation, commenced at Madras in 1802 and since extended over and beyond India, the President of the Royal Society could say in 1791 that the accuracy of Rennell's surveys stood unrivalled by the best county maps in Britain.

Little need be said of the extent of the territory involved or of the variety of the landscape, ranging from the Himalayas to the Ganges Delta and from jungle to desert. A map of Great Britain can be tucked away in one corner of a page showing a map of India. The Survey spread a system of primary triangulation over the whole vast territory owing to the foresight of Colonel Lambton and Sir George Everest, who initiated this great work and so avoided the embarrassments caused in other countries where isolated topographical surveys were started before a general triangulation was available.

Apart from the astronomical observations and triangulation essential to the mapping, the Survey has undertaken precise levelling, tidal predictions, magnetic survey, and observations of the direction and force of gravity which have thrown much light on the nature of the earth's crust. Work other than the regular topographical survey is undertaken by arrangement, such as the survey of forest, irrigation, railway, city, tea-garden, and mining areas. The impetus given to development as a result of the 1939–45 war has greatly increased the demands on the Survey for such work.



III. Examples of Commonwealth and U.S.A. Maps.

Top left, U.S.A. map 1/62,500. *Top right*, Pakistan map 1 inch to 1 mile. *Bottom left*, Canadian map 1 inch to 1 mile. *Bottom right*, S. African map 1/50,000.

Until 1905 large-scale revenue maps and small-scale uncoloured topographical maps were produced. It was then decided to divorce the cadastral surveys on a scale of 16 inches to the mile from the Survey of India and hand them over to the various provincial administrations. The maps are, however, based on the trigonometrical framework of the Survey. In place of the old uncoloured topographical maps the Survey was to concentrate on a complete new series of modern maps in several colours on a scale of 1 inch to 1 mile. It was hoped to complete the series in twenty-five years. Later it was decided to publish areas of lesser importance on $\frac{1}{2}$-inch or $\frac{1}{4}$-inch scale. Even so, only about three-quarters of the programme was completed by 1939. This had involved publication of considerably more than 3,000 sheets on the 1-inch scale, 218 on the $\frac{1}{2}$-inch scale, and 23 on the $\frac{1}{4}$-inch scale, apart from compiled sheets. Sheets so far published may be seen on key maps in the Annual Reports.

The plane-table has always formed the principal instrument in India for surveying detail, though it has never been so in Britain. Increasing use is now being made of air survey.

The maps on all three scales are very alike in appearance, all decorative with brown contours and hill shading, red for roads and built-up areas, green for forests, yellow for large cultivated areas, and so on. A 1 : 1 million series, with sheets $4^\circ \times 4^\circ$, forms the basis of sheet numbering on all scales. Each million sheet is covered by sixteen $\frac{1}{4}$-inch or degree sheets; each $\frac{1}{4}$-inch sheet by four $\frac{1}{2}$-inch sheets, or sixteen 1-inch sheets. The polyconic projection is used throughout.

3. Maps of the United States

The standard topographical scale of the *United States* is 1 : 62,500. A recent report advocates the use of this scale for the final maps of all unmapped or inadequately mapped agricultural lands in the Eastern and Southern States, and of unmapped or inadequately mapped areas of moderate economic importance elsewhere, a total area exceeding $1\frac{1}{2}$ million square miles. This brings out one of the problems confronting countries of continental extent. The same report suggests the mapping of areas of minor economic importance, such as mountain and desert lands, on a final scale of 1 : 125,000. It is expected that air-photo survey will play a large part in the preparation of the maps, and though preliminary sheets may lack contours, these are to be added in the final version.

Present United States maps on a scale of 1 : 62,500 each cover an area 15 minutes of longitude by 15 minutes of latitude, and have contours in brown, water and ice features in blue, and other detail in black. The vertical interval between contours varies on different sheets from 5 feet to 100 feet, dependent on the topography. The smaller scale of 1 : 125,000 is already used for areas of lesser importance, and is in the natural series leading to the 1 : 500,000, a scale employed for a variety of maps. One of the most recently completed maps of the United States, and the first to show relief of the whole country on any scale larger than atlas size, is a sectional airways map on the scale of 1 : 500,000, which is about 8 miles to the inch. Land below 1,000 feet is undifferentiated in altitude, and the map therefore is not representative of modern topographical work.

One feature of considerable interest from a map-user's point of view is the information about the map region which is printed on the back of many United States and Canadian sheets. Sometimes a photograph is included. The practice of giving an inseparable brief memoir with each sheet seems worthy of consideration in other countries, both on topographical maps and on maps which show geology, soils, and land utilization.

4. Maps of Canada, Australia, South Africa, and New Zealand

For *Canada*, a topographical survey is in progress to cover the whole country on scales of 1, 2, 4, or 8 miles to the inch, the scale employed corresponding to the importance of the area. All the maps are in colour and are very attractive. It is significant that the chief mapping agency of Canada is designated 'The Topographical and Air Survey Bureau', for aerial photography is used very extensively in mapping the vast regions in the West that are still unsurveyed or unexplored.

In *Australia* the Department of the Army is responsible for a topographical survey of the continent for military purposes. Topographical surveys are also carried out by the Commonwealth and the various State Departments, as of Railways, Main Roads, and Water Conservation, for works of major importance, but the areas covered are small when compared with the total area of Australia. Several standard military sheets on a scale of 1 : 63,360 and about twenty-seven sheets on a scale of 1 : 25,000 had been published by 1943. Strategical maps covering a large portion of the continent on scales of 4 and 8 miles to the inch were compiled after the outbreak of the war in 1939 from State Department maps and other information. Some parish maps are produced on a scale of 20 chains to 1 inch.

Commonwealth maps are usually printed in several colours, but State maps are in black only. Standard military sheets and the International Maps alone have contours. Nine of the latter sheets had been published by 1943, and sixty more are necessary to complete the Australian series, which includes Papua and New Guinea.

In the *Union of South Africa* the Trigonometrical Survey is charged with the preparation of maps other than geological maps. Among its main functions are the air survey of the Union, and the topographical mapping of the Union on a scale of 1 : 50,000. The primary and secondary orders of triangulation are now established over the greater part of the country, and the tertiary triangulation is well advanced. The air photography of 80,000 square miles of country was completed by 1939. The scale of the contact prints is between 1 : 15,000 and 1 : 20,000. The organization of the topographical survey was commenced in 1937. Line maps to the scale of the air photographs are produced by the field parties, and copies are made available for immediate purposes pending the preparation of the topographical maps.

In *New Zealand* early surveys were conducted on a regional basis, their object being the production of maps and plans in connexion with land tenure and the requirements of a rapidly spreading population. The work served an essential purpose, but discrepancies at regional boundaries were inevitable. The observational work for a first-order triangulation has been completed for the greater part of the Dominion. Accuracy is well within the limits set by the International Association of Geodesy for work of the highest precision. A basic topographical survey is in progress, the purpose being the publication of a series of maps on a 1-inch scale, showing relief by means of contours, drainage, cultural and other features, so far as scale permits. Several thousand square miles have been covered by plane-table, principally round Dunedin, Auckland, Wellington, the Motueka Valley, Rotorua District, and North Taranaki. Recently aerial photography has been adopted for these surveys.

5. The International Million Map of the World

As early as 1891 it was suggested that an International Map of the World should be published on a scale of one to a million, often written 1 : 1 M. This scale is 15·782 miles to the inch, and therefore falls rather within the category of atlas maps than of topographical maps, but it merits consideration here.

Agreement has been reached upon sheet lines and style, and over 300 sheets, representing about one-fifth the total required, have been published, though not all are true to type. Sheets embrace 6° of longitude by 4° of latitude. They differ in shape from the traditional rectangle of Britain's Ordnance Survey, but resemble those of many other national surveys. At latitudes higher than 60°, owing to convergence of meridians, sheets may cover 12° of longitude. The map projection employed is a modified polyconic, as described in Chapter XIV, § 1. Each country is responsible for its own survey and lays down the spelling of every place-name within its borders. Sheets are produced by those countries which have the largest amount of territory in the area concerned. Brittany falls on a sheet published by Britain, and Kent on a sheet published by France. The agreed lines cause Britain to fall on parts of seven sheets, a distinct inconvenience, but one that is overcome by publication by the Ordnance Survey of two special sheets for national use.

The contribution made by different countries varies enormously. Thus by 1935 the United States had published only four sheets of its full share of forty-three, while the Engineering Club of Rio de Janeiro compiled and published between the years 1922 and 1924 the full set of forty-four sheets representing Brazil's portion, though admittedly the work was below standard.

At this stage in the world's history difficulties are bound to arise in connexion with the organization, finance, printing, and selling of an international map. But the effort has at least stimulated much mapping on this scale and has set a standard. Thus a map of the whole of Mexico, Central and South America, and the West Indies, conforming in general make-up to the International Map, has been compiled in 102 sheets by the American Geographical Society, providing a welcome map for general reference, as well as a base map for reconnaissance in the field and for detailed plotting of distributions. Each sheet has a reliability diagram showing the areas covered by surveys and the type of survey.

As well as the two sheets of Britain on the million scale, international style, the Ordnance Survey also publishes a series of other maps of Britain at 1 : 1 M. These include a Physical Map, a Distribution of Population Map in twelve colours, an International Local Aeronautical Map, and maps of Roman Britain, Britain in the Dark Ages, and Seventeenth-century England.

Air maps on the million scale were largely used in the 1939–45 war. The British Army/Air style had relief shown by purple layers increasing in intensity with altitude, water in deep blue, and main roads in solid red. Prominent lines drawn across the map showed magnetic variation for a given month and year.

6. Atlas Maps

When maps began to accumulate in the sixteenth century as a result of copperplate engraving and printing no name existed for the books into which they were collected. Ortelius, who published the first systematic collection of maps, used the name *Theatrum*, a display or show. John Speed used the English version *Theatre*. Others used the terms *Speculum*, *Geographia*, *Cosmographia*, and *Chorographia*. Mercator chose for the title of his collection the word *Atlas*, no doubt an imaginative gesture based on Greek mythology in which Atlas, with feet firmly planted on earth, upheld the sky. This title outlived its contemporaries.

To-day so many atlases are published that no attempt is made to describe them. They range in size from the genuine pocket edition to the 25-pounder. But atlas maps have characteristics which distinguish them from topographical maps, and attention can be drawn to these quite briefly.

A primary difference between atlas maps and those previously described is in scale. In atlases there are rarely any maps on as large a scale as 1 inch to 10 miles, the representative fraction for which is 1 : 633,600. The largest scales are more often in the realm of one to a million, and then only for the home country or areas of special importance. For maps of the whole world scale may be as small as 1 : 225 millions or between 3,000 and 4,000 miles to the inch.

This enormous reduction of scale entails a great loss of detail which is reflected in many ways. For example, the dimensions of the paper covered by a map set a natural limit to the number of names which can be printed upon it. An atlas map of the whole of Africa can bear no more names than can be shown upon a topographical map of like size but representing only a few square miles of territory. Relief can no longer be shown by anything meriting the name of contours, but only a generalized picture can be given showing the distribution of high and low land.

For some purposes reduction of scale is an advantage because it enables information to be given about an extensive area in convenient form. It is thus possible to see at a glance the distribution over a whole continent of rainfall, temperature, vegetation or minerals, direction of prevailing winds or movements of weather systems.

Conventional colour schemes are much employed on atlas maps. On physical maps layer colours normally show lowlands in greens, passing into browns for highland. Rainfall maps show regions of heaviest rain in purples or blues, and pass through yellows to brown with decreasing rainfall. Vegetation maps usually employ greens for forests, yellows for grasslands, and browns for scrublands. These conventions simplify map interpretation, and regard should be had for them even in sketch-maps.

The extent of the area shown by atlas maps inevitably raises the question of map projection. Earth curvature over a small area as depicted in a plan is so slight as to render projection relatively unimportant. But curvature is so considerable when a whole continent has to be mapped on a single sheet that careful consideration must be given to the scheme by which the curved surface is to be projected on flat paper. The whole problem is discussed in Chapters XI–XV. Shape or area are often sufficiently distorted to be noticeable to the most casual observer. Consequently it is desirable that the user of atlas maps should be sufficiently aware of the properties of various map projections to enable him to avoid errors about direction, distances, routes, and comparative areas.

CHAPTER THREE

MODERN PLANS

MAPS on scales substantially exceeding 1 inch to 1 mile are usually called plans. Few countries have official plans for the whole of their territory. Britain, perhaps the best surveyed country in the world, has plans of the whole of its area published on the scale of 6 inches to 1 mile, and five-sixths of its area published on a scale of 25 inches to 1 mile. A new triangulation of Britain, commenced in 1935, is in an advanced stage and will form the framework for a survey of urban areas on a scale of approximately 50 inches to 1 mile, and for all subsequent new work on this or any smaller scale.

A difficult problem naturally faces the so-called new countries, especially those of vast extent where rapid development demands maps, and where accurate geodetic triangulation cannot be waited upon. Even in the United States, less than half of the country has been mapped topographically, and only about half of the work so far completed is adequate according to modern standards. Work is entrusted to the Topographic Branch of the Geological Survey, though there are various mapping agencies, geodetic control survey, for instance, being made under the auspices of the Coast and Geodetic Survey. All the township plans of the public land surveys of the General Land Office are on the scale of 2 inches to the mile, R.F. 1 : 31,680, which is slightly out of line with the other two important United States scales of 1 : 62,500 and 1 : 125,000. The pressing need for base maps has led the Geological Survey to compile an increasing number of what are called planimetric maps, mostly on the 2-inch scale, from aerial photographs. Cultural features are shown, but not contours. Other 2-inch maps are contoured, the vertical interval varying with the terrain. Sometimes it is as low as 5 feet. More than 200 geological folios have been published, the most detailed on the 2-inch scale, and each folio has maps to show topography, geology, underground structure, mineral deposits, and economic geology. Larger scale plans are produced of special areas, and a number of line maps are compiled on scales of 1 : 10,000 and 1 : 20,000, without contours, from aerial photographs, in connexion with revision surveys of the coast.

Large-scale plans on a national basis are obviously expensive to produce, and though they are unnecessary in unproductive country, they prove an ultimate economy in highly developed areas. In Britain, before publication of official plans, large sums of money were spent on private surveys of estates and prospective canal and rail developments. Twelve thousand tithe maps were published, mainly on a scale of 1 inch to 3 chains; and though the work cost about 2 million pounds the maps were, on the whole, unreliable. No matter what care is taken, isolated unconnected surveys never prove accurate enough to join together to form a continuous whole, nor are they likely to be uniform in quality, so re-survey is ultimately involved.

Once a large-scale official survey is published it is available for town planning, development of communications, water, sewage, power, irrigation and flood control schemes, land conveyance, taxation and valuation, registration of land ownership and land grants, tithe redemption, location of national parks, and delineation of administrative boundaries. A base map also becomes available for subsequent surveys, as of geology, soils, and land utilization, or for the preparation of statistical maps so essential to much geographical and social research.

Before describing examples of modern plans it may be well to tabulate the principal scales, expressed in their two common forms, as a representative fraction and as so many inches to the mile, since constant reference is made to them in one or the other form.

Representative fractions	*Inches to the mile*
1/1,250	50·688
1/2,500	25·344
1/10,560	6
1/25,000	2·5 approx.
1/31,680	2

The first two are sometimes described as large and the remainder as medium scales. In the same way scales used for topographical maps would be referred to as small.

The work of the Ordnance Survey provides a full range of modern plans, and consequently the remainder of this chapter is devoted to publications of the Survey.

1. Background of Ordnance Survey Plans

Before describing plans published by the Ordnance Survey, a word may be said about the programme as a whole, though this anticipates explanation of such expressions as primary triangulation, central meridian, and national grid. Until the outbreak of war in 1939 the standard plans had been the 6-inch and the 25-inch. The former arose partly because of the successful work done on this scale in Ireland between 1825 and 1840. Production of the maps of Britain on the 1-inch scale had been held up to allow the survey of Ireland to proceed. When the latter was completed, the survey resumed in north England and south Scotland, but on the 6-inch scale, which rendered further work at the smaller scale unnecessary, since smaller scale maps can always be drawn from larger scales. Publication ultimately involved 15,000 sheets, each covering 6 square miles.

The survey of Ireland had shown that the 6-inch scale was too small for certain purposes. The choice of the larger scale on which all Britain was later surveyed, except mountain and moorland areas, was influenced by this and three other considerations. One of these was that on a scale of 1 : 2,500 the exact shape of every enclosure could be shown and its area calculated with sufficient accuracy from the plan itself without further work in the field. A second consideration was that a square inch on the plan conveniently represented almost exactly an acre, actually 0·996 of an acre. Lastly, the scale fell into line with suggestions at an international conference where it was hoped that natural scales, such as represented in this case by 1/2,500, would become universally employed.

The original primary triangulation of the British Isles was observed between 1783 and 1853, and was commenced to determine the relative positions of Paris and Greenwich. Subsequent checks show that while there was a remarkable degree of accuracy over long distances, there were larger local errors than would now be accepted in making plans. Thus it was considered that a new secondary triangulation was necessary on about 4-mile sides. But too few of the old primary stations could be recovered with certainty, so a new primary triangulation was necessary before the new secondary. The original plans were also published with different central meridians for counties or groups of counties, and while the survey work for each was linked with the primary triangulation, irregularities and discrepancies occurred along adjoining boundaries, revealing in effect semi-independent triangulations which cannot now be brought into sympathy with each other.

The new primary triangulation on about 30-mile sides, part of which is seen in Fig. 30, and the entirely fresh secondary on about 4-mile sides, obviating the need for a complete tertiary system, will be projected independently of county or other boundaries, on a single Transverse Mercator belt covering the entire country without discontinuity. By using this projection for all national plans and topographical maps, a National Grid can be superimposed on all of them, giving a unique reference for any point regardless of scale.

The plan programme of the Ordnance Survey therefore involves, apart from continued publication of existing plans with a certain amount of revision and, on the 6-inch plans, a superimposed grid, completion of the new triangulation, the resurvey of urban areas for a 1/1,250 plan, the overhaul of the remaining 1/2,500 plans, the publication some years hence of a new 6-inch map based on these, and finally the immediate production of a new medium-scale 1/25,000 map redrawn from the existing 6-inch plans. All new plans are to be square in shape, on the Transverse Mercator projection, and with the national grid. An idea of style is seen in Fig. 8.

2. 1/1,250 Plans of Urban Areas

The standard of control aimed at in the survey for making these plans is sufficient to produce a plan if required on a scale of 1/500. The latter scale means that 1 inch of paper would show 500 inches of ground. Lines on a plan can be drawn about 1/100 of an inch thick. Therefore this thickness on such a plan would be equal to only 5 inches on the ground. An error in position of more than 5 inches in making the survey must therefore be eschewed.

Each plan is to cover one-quarter of a square kilometre, and 150,000 sheets will be required to cover urban areas in Britain. Each is a square from the National Grid, so joining up will be possible, and names near the margins are designed to make such an arrangement satisfactory.

Contours are not appropriate to such large-scale plans especially in built-up areas. Instead there are frequent bench marks. A description of each, its height, the date when determined, and the grid reference of the mark are given in a reference list. Areas of parcels of land, which form a prominent feature of the 25-inch plans, are omitted again because of the type of area portrayed. Sufficient house numbers are inserted to enable the number of any house in a completely built-up street to be ascertained.

The usefulness of this large-scale work is unquestionable, but much will depend upon up-to-date revision. It is uncertain whether air survey will prove effective for this aspect of the work, and it may be desirable to maintain local staff to deal with it.

3. The 25-inch Plans

More can be said of the 25-inch plans since most of Britain has long been published in this series, involving 50,000 sheets. The exact scale is 25·344 inches to the mile, and the representative fraction 1/2,500. The most significant fact about the 25-inch scale is that it is sufficiently large to show every feature true to scale which is drawn in plan. Much information about important matters not visible in the field can also be recorded. Thus there are shown in distinctive lines more than twelve types of civil administrative boundaries, from county to civil parish. Until so mapped, parish boundaries were not generally recorded, hence the ancient custom of annually beating the bounds, that they should live in the memories of the inhabitants.

Hedges, fences, ditches, and other visible obstacles to trespass are marked and every parcel of land has a reference number and its area within visible boundaries recorded in acres to three decimal places, that is, to within the nearest 5 square yards.

It should be noted that in England fences rarely coincide with property boundaries. The latter are set out in title-deeds, and are often defined as running so many feet from the centre of the fence. A map showing property boundaries is termed a *Cadastral Map*, and is of primary importance in countries where fences are few or where ownership marks tend to be obliterated, as in Egypt. Nevertheless the 25-inch and the 6-inch plans of Britain are often wrongly referred to as cadastral maps.

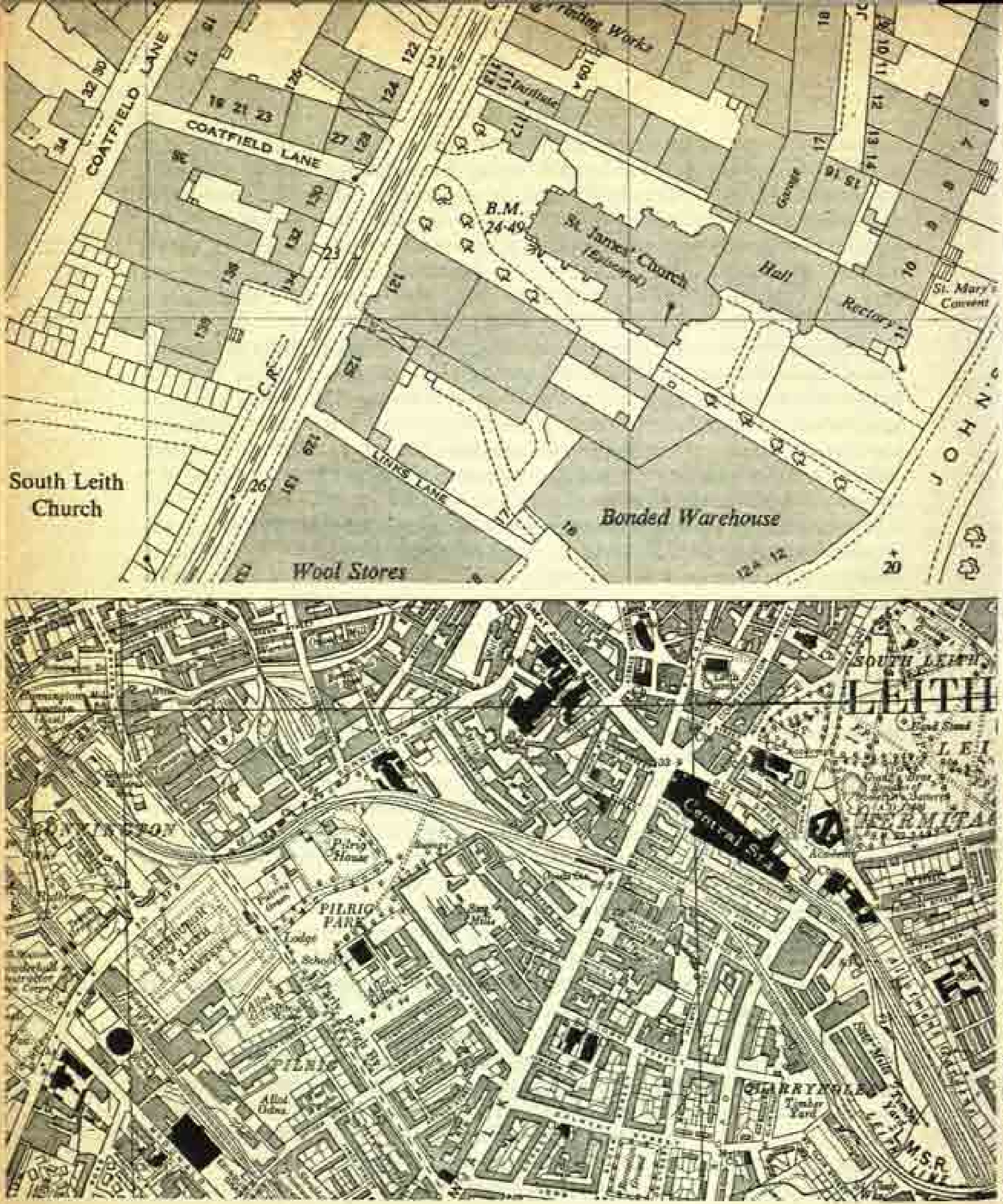


FIG. 8. Extracts from O.S. maps of Edinburgh. *Above*: at 50 inches to the mile. *Below*: at 6 inches to the mile. All four maps show the area just NE. of Leith Central Station. *By permission of the Controller of H.M. Stationery Office.*

University Press, Oxford

IV. EXTRACTS FROM O.S. MAPS OF EDINBURGH.

Above, at 1/25,000 (about $2\frac{1}{2}$ inches to the mile). *Below*, at 1 inch to the mile.

Reproduced from the O.S. Maps with the sanction of the Controller of H.M. Stationery Office.

Altitude on the 25-inch plans is shown by a generous distribution of spot heights, with bench marks and trigonometrical stations. No other means of showing relief is attempted, but it must be remembered that the area covered by each sheet is small, only 1½ square miles, and that to the users of these plans specific levels are more important than a general representation of relief by contours. Levels given on the older sheets are in feet to one decimal place, and are based on the Liverpool datum. A new and more accurate levelling has been completed based on the Newlyn, Cornwall, datum. As sheets are reissued, new levels are given in feet to two decimal places. The greatest difference shown is less than 2 feet.

Conventional signs are used with initial letters to indicate such features as electricity pylons, telephone call-boxes, springs, and wells. Uncultivated vegetation is differentiated into about ten types, and is shown by character drawings. Tree signs resemble trees in profile and not in plan, the method adopted on maps of most countries. Cultural features, from quarry to refuse heap, and cutting to embankment, are drawn graphically.

Much use is made of different styles in writing. Thus, as reference to the official characteristic sheet shows, it is possible to distinguish, for example, bogs, moors, and forests, from gentlemen's seats. Style of writing is also used to distinguish the period to which antiquities belong, namely, Prehistoric, Roman, or Saxon and Medieval.

The new 1/2,500 plans will be 1 kilometre a side, each plan covering the same ground as four plans on the 1/1,250 scale, but a greater area of Britain will be published on the smaller scale than on the larger. The old field numbers will be replaced by the four-figure grid reference of the field centre. In a later section on the National Grid it is explained how by this means every parcel of land in Britain can be given a unique reference. The acreage figure will be retained.

4. The 6-inch Plans

The existing 6-inch plans closely resemble the 25-inch, and everything shown in plan is true to scale, except narrow streets, the boundaries of which are sometimes opened to make room for names. All civil administrative boundaries are marked, but there is not the same wealth of detail relating to their exact position in relation to fences. Individual parcels of land are clearly shown, but neither reference number nor area is given.

Similar items to those on the 25-inch map are differentiated by styles of writing, and such features as cuttings, embankments, quarries, and uncultivated vegetation are similarly drawn in character, though much reduced in size.

Altitude is shown by numerous spot heights and bench marks, on the more recent sheets in feet to two decimal places, based on Newlyn. But the 6-inch can claim one feature which is lacking on the larger-scale plans, namely, contours. Perhaps the introduction of colour may be regarded as a second additional feature, for on most maps black dotted contours give way to solid line contours in red or blue. These were instrumentally determined in general at 50 feet, 100 feet, and thence by hundreds to 1,000 feet, and above this at intervals of 250 feet. Intermediate sketched contours or form lines are shown by dotted lines. There is no rigid uniformity therefore in contour style or interval, and on some maps of northern Scotland no contours at all are shown. Differences of treatment are a response to terrain and purpose.

Such large-scale plans would never be laid out to give the alleged bird's-eye view of the whole country. If an attempt were made, the 6-inch map would require a rectangle 100 yards long and 57 yards broad, and detail across various sheet edges would not fit, because, for reasons explained in a subsequent chapter, though all the plans are drawn on the same projection, Cassini's, they do not have a common central meridian.

The 6-inch map is the map *par excellence* for the detailed study of local geography. To give but one illustration, the crops of every field can be recorded, and such work formed the basis of the Land Utilization Maps of Britain finally published on a scale of 1 inch to the mile. Much use is made of the 6-inch maps for drainage, road and railway schemes, for engineering, organizing elections, and administrative purposes generally. Town-planning schemes must by law be exhibited on maps on this scale. About twenty-five town maps on the 6-inch scale have been specially published in colour.

As the new 6-inch map will be made by reduction from the new large-scale survey, and will not appear for some years, little can be said about the ultimate design. It is expected, however, to follow the general grid layout, that plans will be square in shape and cover the same area as twenty-five of the 1/2,500 plans, and that instrumentally surveyed contours will be drawn at intervals of 25 feet. Buildings may also be shown in colour.

A provisional edition is being published on the old county sheet lines, with national grid added in dotted lines at 1-kilometre intervals, together with hasty revision carried out in 1938.

5. The New 1/25,000 Map

This scale is new to the Ordnance Survey series. Production is going forward rapidly by redrawing from the 6-inch. Sheets cover an area 10×10 kilometres, with margins so designed that adjoining sheets can be assembled to form a new complete sheet. Grid lines are drawn at intervals of 1 kilometre. The map has many of the best features of both the 6-inch and 1-inch series, notably much of the detail of the former and the colour and sweep of the latter. There are four colours: black for names, outline of roads, public buildings, &c.; blue for water; brown for contours and road fillings; and greenish-grey for buildings, woods, and minor detail, such as fences. All roads below a certain width are drawn to a gauge. Contours are drawn at intervals of 25 feet, indicating interpolation. Bench marks are shown in open country, but heights are not given. These are to be found in the bench marks lists by their grid references.

In addition to the fully coloured map, there is an outline edition consisting of the black, blue, and grey plates printed in dark grey, and an administrative edition in which local government boundaries are prominent.

6. Map Summary

Large-scale plans record almost every topographical detail and cultural feature true to scale. On topographical maps some features are not true to scale, and many are omitted or shown by symbols rather than by character drawings. Street detail may disappear and town form alone be indicated, or even this may be absent and town position be shown by a dot. Contours assume the character of form lines. With still further reduction of scale the atlas map emerges. Choice of projection becomes a major consideration. There is often visible distortion of shape or area. But with decrease of scale, specialization and variety of purpose become features of the work.

CHAPTER FOUR

CHAIN SURVEY

NATIONAL surveys involve a comprehensive staff of surveyors, instrument carriers, draughtsmen, reproduction personnel, and so on, numbering in some countries upwards of 2,000 people. There are two quite different approaches to an understanding of how the field work is done. One is to follow each operation in turn, beginning with a reconnaissance survey, proceeding to a description of triangulation, and finishing with methods of filling in detail. The other is to centre description round the instruments, starting with the simplest first. This latter approach is the one employed here. The beginner may at least try a chain or compass survey, and having tried, will be in a better position to comprehend the part played by a theodolite, even though he may have little opportunity to handle the instrument. It should also be remembered that the purpose of the succeeding chapters is not to teach surveying, but to give sufficient understanding of the process to lead to a fuller appreciation of maps and plans, their limitations and possibilities.

One point in connexion with surveying calls for emphasis at the very outset, namely, that the process works from the whole to the part. A system of primary triangulation is spread over the length and breadth of the area, fixing the exact location of salient points, commonly some 30 miles apart. Secondary and tertiary triangulation fix the position of more and more points in relation to the primary stations, until the area is broken up into blocks of about 1-kilometre a side. The process of fixing points within each block continues, till eventually the detail of roads and buildings can be drawn in.

The distinction of first devising triangulation of the accurate instrumental kind is accorded to a Dutchman, Willebrord Snell, who in 1615 observed the angles of a chain of triangles between Leyden and Alkmaar. It was of course very early realized that the position of a point could be fixed by angular measurement from two other known points.

Linear measurement probably also played an important part in early surveying, based on the fact that the position of a point can be determined by its linear distance from two other points of known distance apart. In the sixteenth century land measurers used cords soaked in resin. In the next century Edmund Gunter's chain came into use, and has continued to the present day, though it may soon be superseded for Ordnance Survey work by a chain 20 metres long with links of 1 decimetre. With little but a chain, accurate plans can be made of small areas, or detail fixed within a framework of triangles determined by more elaborate survey instruments.

It seems incredible that chain work as here described should have played an important part in making national maps and plans. But much of the detail on Ordnance Survey plans has actually been fixed within the general framework by the methods to be described. In India and the United States with their smaller scale work, the plane-table instead of the chain, has been used to fix detail.

1. Chain Survey Equipment

The only equipment essential to chain survey consists of a chain, markers, pencil and note-book, a straight-edge, and a pair of compasses, for setting out lines from the field-book records.

Gunter's chain is 22 yards long and is made of links to facilitate folding, as shown in Fig. 9. Both the chain and the link are used as units of measurement. The latter includes one long and three short links, normally reckoned from one central short link to the next. There are a hundred such links to the chain, each

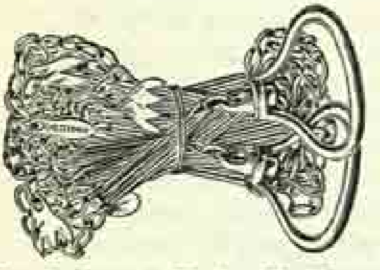


Fig. 9. Gunter's Chain with tellers.

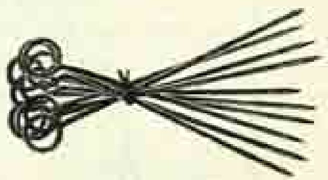


Fig. 10. Land chain arrows.

measuring 7·92 inches. Brass tags or tellers of significant shapes as seen in Fig. 9, are attached at every tenth link to simplify counting. The surveyor thinks in terms of links, and not of the equivalent in inches. A staff, ten links long, is usually carried to measure short distances. Ten square chains make an acre, evidence of decimalization of one British measure.

Engineers, unconcerned for the most part with acres, generally use steel bands wound on a reel like the familiar tape measure, and with them very accurate work is possible. They have not succeeded in displacing the chain from its old-time use, probably because of the additional care needed in handling.

Two types of markers are used. The one consists of steel skewers called arrows, used to mark the ends of chains as measurements are made. A set is shown in Fig. 10. The other type consists of slender iron-shod poles called ranging rods. These are driven into the ground or held in supports to mark the terminal stations of lines which it is intended to measure.

Measurements are recorded in a field-book, the pages of which have either one or two lines down the middle. Entries are always made from the bottom of the page upwards, starting on the last page. The usefulness of this convention is appreciated when field work is undertaken.

2. Survey of a Field

Suppose it is desired to produce a plan of a field such as the one south of Finney Farm in Fig. 20. A larger sketch is shown in Fig. 11. The chain survey is made by dividing the field into a series of triangles and measuring the sides of these. This is because the lengths of the sides of a triangle fix its shape. That is not so of all other figures. For instance, the top of a match-box is a rectangle in section. By squeezing the box a series of lozenge-shaped sections result,

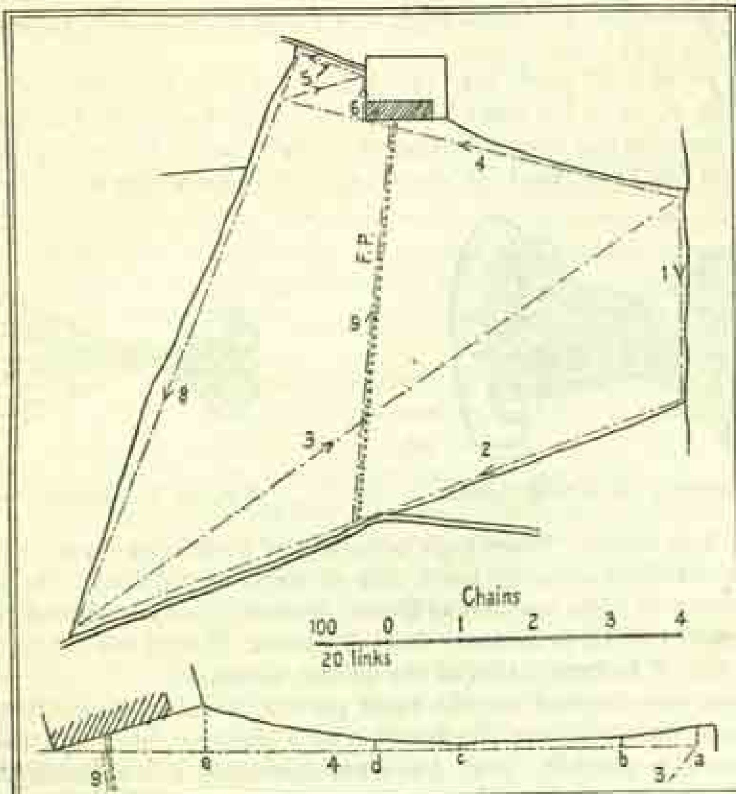


Fig. 11. Chain survey of a field. The lower figure is an enlargement of part of line 4, showing offsets at *a*, *b*, *c*, *d*, and *e*.

though the lengths of the sides remain unchanged. Few fields are triangular in shape, hence they must be conceived as a series of triangles, preferably knit together by some major straight line. It is here that the ranging rods are used. They are placed about the field to form terminal points of lines which make up a series of triangles, the ends of the numbered lines in Fig. 11. It should be noted that these are as near the fences as possible. The field splits fairly readily into two major and two minor triangles.

When the plan of campaign has been determined, a rough sketch is made in the field note-book, and chain lines are lettered or numbered in a route order which will entail least walking. The leader sets off from the ranging rod at the commencement of line 1, carrying a set of ten arrows, and dragging the chain. When the latter is fully extended, he is directed into line with the remote ranging rod by an assistant. The chain is then drawn taut and an arrow is pushed vertically into the ground touching the outside of the handle at the leader's end, while the handle at the assistant's end touches the ranging rod. The leader, or a third man, the booker, enters in his field-book the number 100 to indicate that one chain has been measured in links along line 1. The chain is then dragged forward till the assistant comes to the arrow. The leader is directed into line as before, the chain handle laid on the ground touching the arrow, the chain drawn taut, and a second arrow inserted at the leader's end. When moving on, the assistant collects the arrows *en route* and a check is made at the end of the line to see that the number of arrows collected corresponds with the number of chains entered by the booker.

It will be seen that the length measured is the distance in a straight line between ranging rods, but the surveyor wishes to produce a plan showing the fences, which are not necessarily straight. Thus, before the chain is moved forward each time, he takes his offset staff and measures the distance of the fence from the chain, at right angles to the latter, at significant points which will enable him to make a fairly accurate plan of the fence. An example is shown in Fig. 11 for part of line 4.

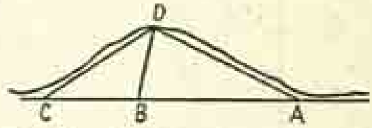


FIG. 12. An alternative to a single perpendicular offset.

Two book entries are necessary for each offset, first, the distance from the commencement of the line, and second, the length of the offset. The most accurate work results when offsets are short, and this is one reason why lines are arranged to run as near the fences as convenient. If offsets are long, it is difficult to judge when measurements are being made at right angles to the chain line, and the chain may have to be dragged round to take the measurement.

The right-angle difficulty can be overcome by using an instrument such as a cross staff, in effect a cross or box with sights at right angles. A sight is taken along the chain line and the cross sight then reveals the right-angle offset direction. Alternatively offsets to a given point can be taken from any three recorded points on the chain line, as at A, B, and C in Fig. 12, and the required position obtained by intersecting arcs. This method is recommended whenever an offset exceeds 80 links, especially if working on a scale of about three chains to the inch. Apart from its reliability, short offsets with the staff can be taken from the lines AD, CD to the fence.

It would be bad practice to endeavour to survey the field in Fig. 11 using line 3 as base and taking single offsets into the south-east and north-west corners, presuming north to be at the top of the sketch. There would be uncertainty in setting out the right angle, and there would be no check against error in linear measurement.

It is advisable to start the field entries of each line at the bottom of a new page if there is any likelihood that otherwise there would be insufficient room to complete the job. The amount of space required depends on the number of entries, as no attempt is made to keep the length to scale. Fig. 13 shows the entries set out by double- and single-line methods for line 4. The double-line method is usually considered the better. A dot in a circle represents the commencement and end of the line, and offsets are entered on that side of the page on which they appear looking in a forward direction. In this example the fence entries are on the right and line 9 is shown on the left. A line shows the approximate shape of the fence and obviates an excessive number of offsets. In addition to offset entries, full chains in links are entered as measured, hence the appearance of the numbers in hundreds with no corresponding offset entries. When the chain line is crossed obliquely by such as a path, stream, or fence, it is shown in the double-line field-book by a broken oblique line, the inner ends of which emerge from the central column horizontally opposite each other.

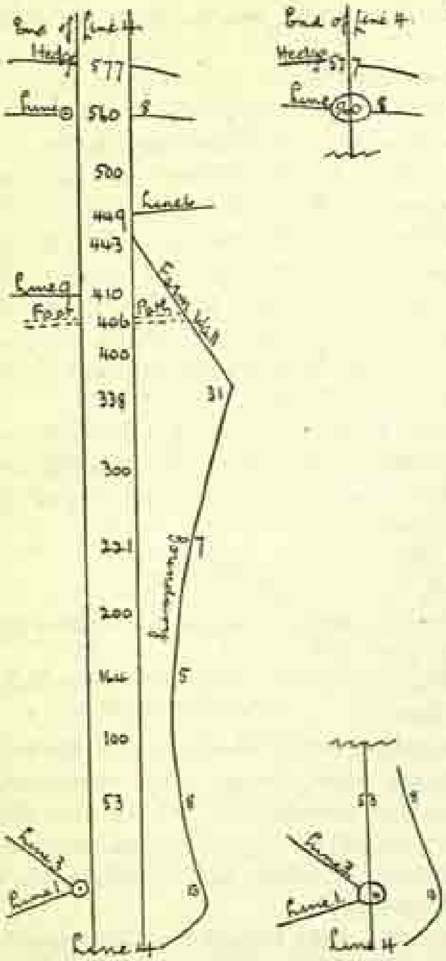


FIG. 13. Field-book entries for chain survey of line 4, Fig. 11, double- and single-line methods.

The best triangles in all survey work are those with angles each exceeding 30°, because then there is no doubt as to the point of intersection of sides when they are set out on paper. Thus the triangle bounded by lines 1, 2, and 3 is not particularly sound or well conditioned.

When drawing out the plan, a suitable scale is chosen and the lengths of the triangle sides are taken from the field-book and drawn by the usual method of intersecting arcs. Field-book entries should be so unambiguous that one surveyor can draw a plan from another's book.

Mistakes sometimes creep into the field-book, and the shape of a triangle can be distorted without discovery if the length of one side is made too short or too long, especially as there is no check on angles. It may happen that a second line crosses the triangle, as does line 9 in Fig. 11. This provides a check, for if an error has been made, this line will not fit perfectly in its assigned position. If no feature on the land requires measurement, it is essential to insert and measure such a line as check or tie. Thus another diagonal or cross line in triangles involving lines 5, 6, and 7 would minimize the possibility of error in that part of the plan. Once the triangles are drawn to scale, and tested by check lines, detail from offsets can be inserted.

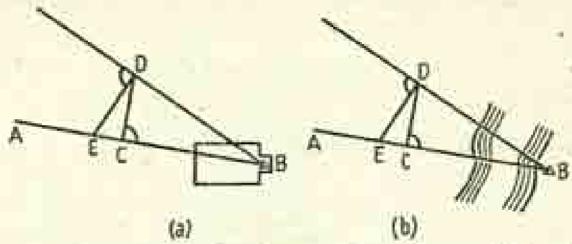


FIG. 14. To ascertain the distance to an inaccessible point.

On all surveys it is usual to insert an arrow to indicate north point. If obtained with the compass it is important to state that it is magnetic north as opposed to true north and to insert the date. A scale line should also be drawn. Scales of three or four chains to the inch are common. It might be noted that sufficient accuracy is obtained when such scales are used by measuring lengths to the nearest link. On a scale of two chains to the inch, one link is only one two-hundredth of an inch, so fractions of links are imperceptible.

Chain survey need not be limited to a single plot of land. The same procedure could have been followed had the area in the figure been divided into a number of fields. Chains can be dragged through hedges, and obstacles overcome. But there is a fairly obvious limit to the area that it is desirable to survey with the chain. A large estate would prove very unwieldy and would tend to an inaccurate result because of the difficulty of binding the whole together on a single major line or series of lines. For the same reason a number of chain surveys cannot be pieced together to form a map of an extensive area, no matter how carefully the work is done. By using a theodolite, to be described later, an accurate framework of triangles can be laid down and the detail filled in with the chain.

A station used in theodolite work, as on a church tower, may be inaccessible for chaining purposes, but its distance away may be determined by the following method. Suppose the direction of chaining in Fig. 14 (*a*) to be from A towards the inaccessible point at B. At any convenient point C a line CD is laid off perpendicular to AB. At D the line DE is laid off perpendicular to the direction BD. Then because BDE is a right-angled triangle with CD perpendicular to the hypotenuse, $EC.BC = CD^2$. That is, the required distance $BC = CD^2/EC$.

This method is equally applicable if it is necessary to find the width of a river. A point is noted on the far side, as at B in Fig. 14 (*b*), and lines are laid off as before at C and D, and the length BC is calculated. The point C need not be on the river edge, since the distance from C to the river may be chained and subtracted from CB.

An alternative method to find CB is shown in Fig. 15. Perpendiculars are laid off AB at convenient points such as F and C, and the points B, D, and E are alined. Then because triangles EXD and DCB are similar,

$$CB/CD = XD/EX.$$

That is,

$$\begin{aligned} CB &= CD \times XD/EX \\ &= CD \times FC/EF - DC. \end{aligned}$$

All these are measurable with the chain on the ground.

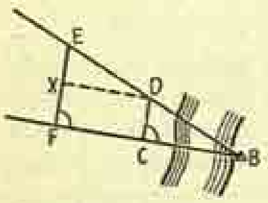


FIG. 15. To find the width of a river.

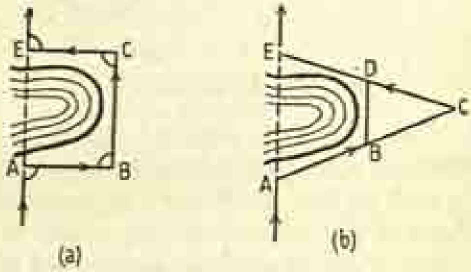


FIG. 16. Diversion round pond: (*a*) rectangular, and (*b*) triangular.

Should the obstacle be a pond as in Fig. 16, it may be easier to measure the broken length of chain line by making a rectangular diversion round one side as in Fig. 16 (*a*), where AE equals BC; or better, a triangular diversion as in Fig. 16 (*b*), where AB equals BC, CD equals DE, and where, therefore, AE equals twice BD.

Chain survey is generally unsuited to enclosed, built-up, or bush-covered areas, while broken ground makes chaining slow and difficult. It is therefore necessary, as with all other forms of survey, to consider in advance whether it is suited to the job in hand.

3. Distances and Areas

One point must be made clear about all plans and maps, namely, that distances are represented on them as though measured on the level, or to put it another way, as though hills had been planed off and hollows filled in. A moment's reflection will show that this is absolutely essential. If topographical measurements were accepted without adjustment, hills and hollows would cause local distortions impossible of absorption into the scheme as a whole. Consequently, when surveying even a limited area of sloping land, the distances entered should be the horizontal distances, not those measured up or down slopes. It is not always possible to avoid setting out chain lines on sloping ground, so either the chain has to be stretched as nearly horizontal as possible against a vertically held ranging rod, or allowance must be made for slope. The chain is likely to sag if the first method is adopted, but there is less error from this source if twenty-five- or fifty-link lengths are measured at a time. Alternatively the degree of slope can be measured with an instrument such as a clinometer, and the corresponding horizontal distance calculated, obtained from a table, or a section drawing to scale. It will always be less than the slope distance. The surveyor often inserts numbers at various spots on the plan which show differences of level, but these are not determined with a chain alone.

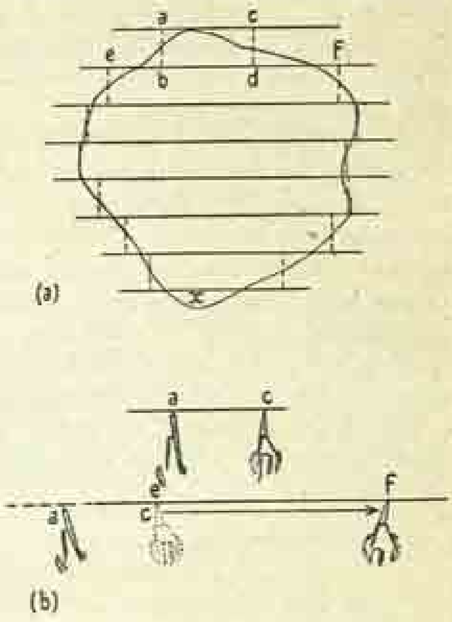


FIG. 17. To find the area of an irregular figure. (*a*) Parallel lines solid, give-and-take lines dotted; (*b*) Totting length of strips with dividers.

It follows that areas shown on a plan do not strictly conform with land surface areas, unless the land is flat. Except in the case of canyons, ravines, or hills like the Sugar Loaf, the difference is not as great as might be supposed. On land with a slope of 10°, which is considerable, slope distances exceed horizontal distances by 1·54 per cent. and areas exceed horizontal areas by slightly more than 3·1 per cent.

There are two simple methods of finding areas of irregular shape on plans. One is to trace the figure on squared paper, count the number of squares, and convert this into area from the scale of the plan. Along the edges of the figure where squares are cut by the bounding lines, those squares which have half or more within the figure are counted as whole ones, and those with less than half are discounted to balance. It is convenient to remember that on the scale of 1/2,500 or 25·344 inches to the mile, an acre is represented by just about one square inch, actually 1·0018 square inches.

Another method to find areas is illustrated in Fig. 17 (*a*). Parallel lines are ruled across the plan at a convenient distance apart, such as that represented by one chain. Give-and-take perpendicular lines are then drawn as shown, so that the area enclosed within each rectangle is estimated by eye to equal that enclosed by the corresponding strip on the irregular figure. The area is computed by summing the lengths of the rectangles and multiplying by the breadth *ab*. Allowance must be made for any small additional area such as that marked *x*. If parallel lines are drawn on tracing-paper, the paper can often be turned about till lines coincide with extremities, and any small residual area is thereby eliminated.

The total length of the strips is most conveniently found with dividers. The points are first opened to coincide with points *a* and *b* as sketched in Fig. 17 (*b*), then moved to the second line so that the right-hand point is at *e*, and the left point on *fe* produced. The left point is secured by sticking it into the paper, and the dividers are then opened till the right point is at *f*. The process continues, using the dividers as an adding instrument, and finally the total length is measured against the scale line. This tends to minimize accumulation of small errors which would result from measuring each strip separately with a ruler or scale, and adding the lengths together.

The easiest method of all to find areas is with a special instrument called a planimeter, which does the job mechanically.

CHAPTER FIVE

THE PRISMATIC COMPASS

THE origin of the compass is unknown, but it seems to have been in use in the Far East in very early times and in its most primitive form, that of a needle magnetized with lodestone and floating on a piece of wood or cork in water. It was probably in use in Europe in the thirteenth century, and is thought to have been a principal instrument in making the Gough map of Britain in the early fourteenth century. It is also thought to have been used by Saxton in the sixteenth century, and was certainly used by Roy when making his map of Scotland in the eighteenth century. It is useful to-day especially for making rapid sketch-maps of extensive areas, and is used in exploratory surveys.

1. THE INSTRUMENT AND ITS RESPONSES

The prismatic compass, as seen in Plate V, is about the size of a large pocket watch. It consists essentially of three parts. There is a small bar magnet which swings on a central pivot, and which swings with it a circular card graduated in degrees from 0 to 360 in a clockwise direction, that is, increasing from north through east, south, and west back to north again. Next there is a sight, consisting of a slot on one side and a vertical hair-line or wire diametrically opposite, usually fixed in a hinged glass lid. Thirdly, there is a prism built into the slot sight, which enables numbers on the dial immediately below the prism to be read when the eye is looking through the slot.

To take a bearing, the sights are first raised as in the figure and the card set free to swing. A finger is then threaded through the compass ring and the compass raised to the eye. The free hand steadies the compass and operates the brake plunger to check excessive card swing. Practice enables the observer to see comfortably and clearly at the same time the object on which he is taking a bearing, the hair-line sight superimposed on it, and the reading on the compass card, which shows the number of degrees by which the bearing differs from magnetic north, measured in a clockwise direction.

The force to which the compass is always responding is the earth's magnetic field, and this has an axis other than that of rotation. Consequently magnetic north is not the same as true north. Further, magnetic north varies over a period of years, so that the angle between true and magnetic north, called the magnetic variation or angle of declination, is constantly increasing or diminishing. Official maps normally mark magnetic north with date and the annual change at that period. There is also a daily variation, but this is too small to worry the compass sketcher. The compass also responds to magnetic elements in the earth's crust, and these are very unevenly distributed. In parts of South

Africa magnetic rocks occur in sufficient quantity to render the compass almost useless.

Not all magnetic elements are within the earth. Steel-rimmed glasses, despite gold camouflage, rucksack frame, bicycle, fountain-pen clip, or the dog's metal lead, all these disturb the compass when they come in close proximity to it.

2. Initial Practice

Three cricket stumps stuck up in a field, as in Fig. 18, might form the basis of a first exercise once the feel of the instrument is obtained. From A take a

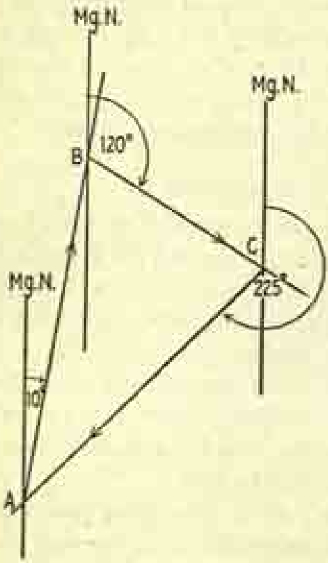


Fig. 18.
Practice with the prismatic compass.

Fig. 19.
The measuring-wheel.

reading on B, in this case 10°. Sketch this direction on a piece of paper with angular measure recorded, then measure or pace the distance to B, and from there take a reading on C, here 120°. Pace to C and then take a reading on A, here 225°. After measuring CA draw the triangle to scale, working carefully with ruler and protractor. If the triangle closes, work is satisfactory. If the triangle does not close, go over the work again. This time introduce checks. For instance, if the forward bearing of B from A is 10°, when at B take a *back bearing* on A and see whether this reads 190°, as it should. If not, consider whether some magnetic object is creating a disturbance. Or again, when at A, take a reading on B and then on C. The difference should give the angle BAC. When the three internal angles are measured in this way they should add up to 180°. If they do, and still something is wrong when the drawing is made, check the measurement of sides. A method to deal with unavoidable inaccuracy is described in section 4.

3. The Compass Traverse

Having attained facility in handling the compass and plotting bearings, it is a simple matter to make a compass traverse. Suppose we are in the district

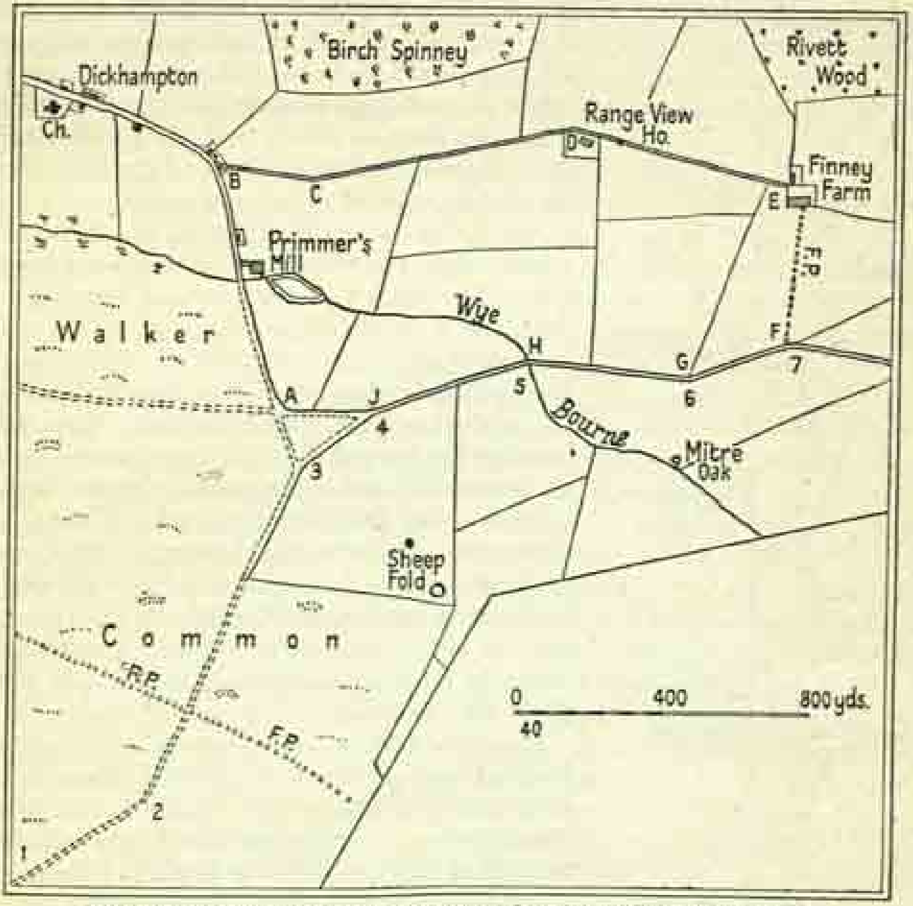


Fig. 20. Sketch-map showing route to be traversed with compass.

shown in Fig. 20, at the point numbered 1. A bearing can be taken along the road as far as the bend marked 2. Assume that magnetic north is parallel to the side edges of the plan. The compass bearing of point 2 from 1 is then 56°, and the distance, which can be taken by paces, revolutions of a wheel, or by tape is 415 yards. At point 2 it is possible to see as far as point 3, the compass bearing being 25° and the distance 1,230 yards. In this way the bearing and length of each leg can be noted and later drawn to scale. The date of the traverse should be recorded and a line inserted to show magnetic north. It is advisable to draw the traverse without undue delay, for it is often helpful to have a clear mental picture of the route.

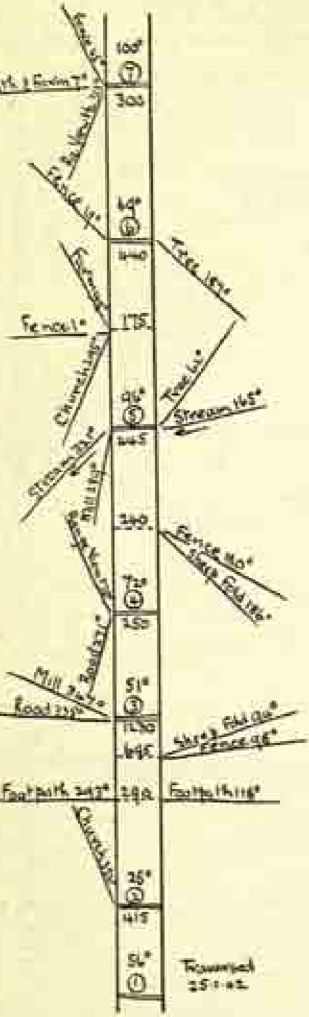


FIG. 21. Field note-book entries of prismatic compass traverse from Points 1 to 7 in Fig. 20.

It is at once obvious that there is no need to confine attention simply to the road. The bearing of other objects of interest can be recorded, with this reservation, that if their precise positions are to be fixed in the sketch, bearings must be taken on each from at least two places *en route*. Rays can then be drawn and the points where they intersect fix the positions of the objects on the sketch, without so much as a visit.

Now let us go over the route again. At point 2 a good view is obtained of Dickhampton Church spire. The bearing is 352°, that is, it is almost due north. At the fence which meets the road between 5 and 6, another good view is obtained, and another bearing taken, this time 295°. When the route has been drawn to scale, these two bearings are set out from the appropriate points on the traverse and so the position of the church is fixed. Some discretion is necessary in choosing points from which to take bearings. If they are too close together, the result will be a very acute angle, with an indefinite intersection point of rays. A very obtuse angle is equally vague. The best rays are those that intersect at angles from about 60° to 120°.

Provided that a clear system of recording bearings and distances is adopted, there is no need to go over a route more than once. In some circumstances it is impossible. A conventional method of entry, which it is desirable to acquire, is shown in Fig. 21. Resemblance to the chain-survey field entries will be noted. Remember that one does not have the map, only the compass, the landscape, pencil, paper, and memory. Station No. 1 is entered at the bottom of the last page in the central or chain column, and the bearing of the next station immediately recorded. The distance to station 2 is measured and entered in the chain column and double cross-lines close the information about the first leg. At station 2 a forward bearing is taken on station 3 and recorded in the chain column. Before moving forward, a bearing is taken on the church which appears in the left foreground. Consequently this bearing is recorded on the left-hand side of the chain column, in the left offset column, and a freehand line is sketched indicating the approximate direction as seen when looking towards station 3. Along this line the word *Church* is written. At 290 yards from station 2 the bearing of the foot-path on either side of the road is recorded, and at 695 yards from station 2 the bearings of the fence and sheep-fold are recorded, appropriately in the right offset column. At 1,230 yards from station 2 the leg is complete and double lines close the record. The same process is continued for successive legs, as shown in Fig. 21.

Attention might be drawn to one or two points. Dotted lines with numbers in the chain column indicate points at which intermediate offset bearings are taken. Distances recorded are always those from the previous traverse station, and not from intermediate stopping-points. Direction of freehand offset lines is the approximate direction in relation to the direction of the leg which is being traversed. The distance apart of entries in the chain column is not to scale, but depends solely on the amount of writing space required.

Occasionally only one bearing may be taken, say, on a nearby barn, and the distance to the barn along the bearing measured and recorded. A small sketch-plan of the barn with measurements inserted would then appear in the appropriate offset column, ready for incorporation in the traverse plan.

Over a limited area magnetic north can be regarded as a constant direction and represented by a series of parallel lines through stations. It is on this principle that the compass traverse rests. Consequently, it is very convenient when drawing the traverse from the field note-book to have a series of parallel lines or zero lines on the drawing-paper to represent magnetic north. The protractor is then easily alined by these. If the traverse is drawn on tracing-paper, squared or lined paper can be pinned beneath to serve the same purpose.

Useful practice can be obtained by entering in field note-book form a supposed traverse made up from a map as from *A* through *B*, *C*, &c., to *A* again on Fig. 20. Relevant offset bearings should be included. Directions can be extended by lines so that angles are measurable with protractor. The note-book entries can then be reconstructed in traverse form on tracing-paper, and by laying this on the original map, diversions and errors are observable.

Exploratory compass survey differs from that described, in scale rather than in method. Bearings may be taken on the most distant recognizable objects in the line of march. Distance is recorded by a wheel fitted with a counting mechanism and called a perambulator, one pattern of which is seen in Fig. 19. A bicycle with a cyclometer attachment would do almost as well over certain types of country, and would prove more useful than the perambulator in getting back to tea.

In such work offset bearings are taken *en route* and the character of the ground recorded. In a traverse across Fig. 20 the change from common land to enclosed pasture or plough land would be the subject of appropriate entry.

The compass is sometimes fitted on a tripod in an attempt to obtain more accurate readings. Even in the most favourable circumstances, however, errors accumulate and an occasional careful check on latitude and longitude are desirable, together with determination of true north. The necessary operations are described in connexion with theodolite work. It must be remembered that magnetic north differs in different places, and even at the same place at different times.

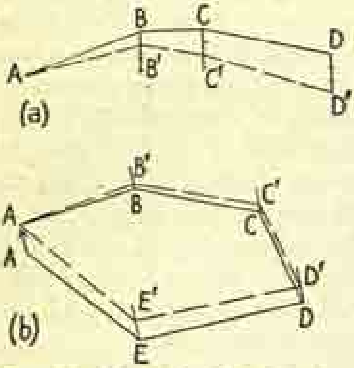


FIG. 22. Method of distributing error in a traverse. (*a*) Open traverse. (*b*) Closed traverse. The error shown in the figure is unduly great.

Summarizing, a compass traverse is extremely useful to provide a record in prospecting, exploration, or reconnaissance. It may help to fill in detail following a theodolite triangulation. But traverses can never be pieced together really satisfactorily to produce a map. This can only be built upon a framework of triangles accurately determined with the theodolite, or less accurately but more quickly with the prismatic compass itself.

4. DISTRIBUTION OF TRAVERSE ERROR

Sometimes a traverse is made between points whose distance apart and bearing are marked on a reliable map, or between trigonometrical stations determined in a theodolite triangulation. On drawing the traverse, it may be that the ends do not coincide with the known positions. If the difference is not serious, the error may be distributed between the legs as shown in Fig. 22 (*a*). $ABCD$ represents the traverse drawn from the field note-book. Now suppose it is known that D ought to finish at D'. A line from D to D' represents the total error. Draw lines parallel to DD' through B and C. To share the error between the three legs, move stations along the parallel lines, B one-third of the whole error to B', C two-thirds to C', and D three-thirds to D'.

A refinement of the method which is calculated to give a better distribution is as follows. Each point is moved an amount which bears the same ratio to the total error as the back portion of the traverse bears to the whole traverse. Thus since in the figure AB is two-fifths of $ABCD$, B is moved two-fifths of DD'. C is moved three-fifths of DD', because ABC is three-fifths of $ABCD$. The method is equally applicable to a closed traverse which refuses to close when drawn from field-book details, such as $ABCDE$ in Fig. 22 (*b*).

5. Compass Sketch-maps

A very useful sketch-map of an area can be made simply with prismatic compass, a protractor and ruler, or a protractor of service pattern, which is in effect a ruler with a scale of degrees marked upon it, a piece of smooth board, paper with zero lines to represent magnetic north, a sharp hard pencil, and a rubber.

There is little need to give an elaborate account of the procedure since it differs very little from that used in making a compass traverse. Instead, however, of making a route the basis of the sketch, stations whose positions have been determined from the ends of a single base-line are in turn occupied and used to fix the positions of new points. The whole area is thus covered by a series of triangles forming a rigid framework.

In order to make explanation as plain as possible, let us examine procedure in respect of the area shown in Fig. 20, although this hardly exploits the possibilities of the method.

The first step is to select a base-line, preferably one that is fairly level, easy to measure, and with intervisible ends which command a view of prominent features on the surrounding landscape. If the base-line is somewhere near the centre of the area, so much the better. Suppose that the leg between numbers 4 and 5 on Fig. 20 offers all these advantages. Occupy point 4 and from it take a bearing on point 5. Put a dot in a suitable part of the paper to represent point 4, and draw a ray in the compass-bearing direction of point 5, using the zero lines on the paper to represent magnetic north. Then note two prominent points, one on either side of the base, and about the same distance from point 4 as the base is long. Take bearings on these and draw the rays, labelling each. In this example the sheep-fold might be taken as one, and the south-west corner of the field in front of Range View House as the other. Next proceed to point 5, carefully measuring the base *en route*. Mark point 5 on the sketch at a suitable scale distance from point 4. From point 5 take bearings on the sheep-fold and the field corner. The intersection of rays fixes their position in the sketch. These two *ruling-points* should then be occupied in turn and bearings taken from them to such prominent features as Range View House and the Mitre Oak beside Wye Bourne. The procedure continues till the whole area is covered by a system of triangles, drawn on the paper in the field. There are no entries like those made for a traverse or chain survey.

Measurement of the base-line is the only linear measurement made, as all other points are fixed by intersection of rays determined by angular measurement. Consequently, if an error is made in that part of the work, all distances will be affected, but not the relative positions of points. In other words, the scale of the plan will be wrong, but no other fault will result.

It will be appreciated that more than two bearings can be taken from each ruling-point if convenient. For instance, when at the field corner and the sheep-fold, bearings might be taken not only on points to the east, but also on Dickhampton Church and on the signpost, if any, at the intersection of the road and the footpath across Walker Common. If rays are lightly drawn

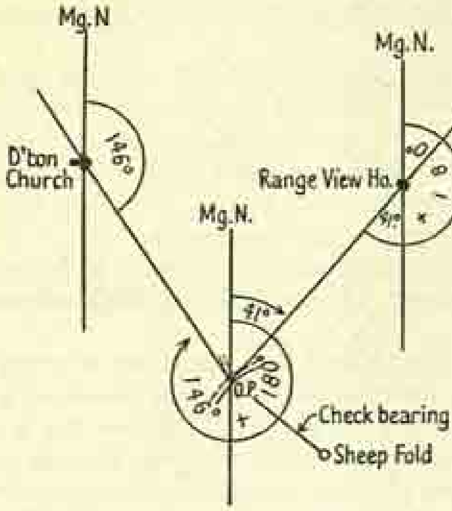


FIG. 23. Resection with compass to fix observation-point. The observation-point is station 3 in Fig. 20, where the church, sheep-fold, and house are shown.

and neatly labelled, there is little to fear from confusion. The usual care should be taken to see that triangles are well conditioned, the more nearly equilateral the better.

It should be kept in mind that at least a number of the ruling-points have to be occupied to extend the triangulation. It is far easier to take a bearing on the chimney of a house than to climb the chimney to take new bearings. The sites of factories can rarely be occupied, and buildings block the view in one direction at least. Some prominent features, such as electric pylons, statues, and bridges with girders are unsuitable because of their magnetic reaction, and there is of course always the possibility of disturbance through magnetic rocks, or concealed water mains. When trouble is suspected it can often be revealed by taking a bearing on some distant point, then walking directly towards the point, and taking the bearing again. The two should read the same. Back bearings likewise help to detect local disturbances.

Ruling-points and the position of other objects fixed by intersection are not likely to provide enough detail to enable a sketch to be completed with roads, fences, streams, farms, and bridges. The position of other important but inconspicuous points must be determined, most conveniently by *resection*. This consists in occupying the point whose position it is desired to determine, and from it taking bearings upon two or more other points already marked in the sketch. Back rays are then drawn through the known points, and their intersection fixes the observer's position.

Suppose, for example, that it is desirable to fix the position in the sketch of the road junction marked 3 in Fig. 20. Bearings are taken in turn upon Range View House, Dickhampton Church, and the sheep-fold. The compass bearing of the house reads 41°, as shown in Fig. 23. The back bearing from the house to O.P., the observation-point, would therefore be 180° plus 41°. Similarly the forward bearing on the church reads 180° plus 146°, and the back bearing would be 146°. The intersection of these back bearings when drawn on the sketch indicates the position of the observer. But error is likely to creep in unless resected positions are confirmed by at least a third back bearing from some other fixed point. Hence a back ray from the sheep-fold is similarly drawn to check the position.

No confusion need arise nor rule be memorized if in plotting back bearings it is noted that the ray is a transverse line cutting parallel zero lines, so that interior opposite angles are equal. Alternatively the sketch can be roughly alined in the field and the direction checked. With experience it will be found possible to fix much detail as triangulation proceeds. It might be noted that by the process of resection, error is not cumulative, positions being determined from ruling-points fixed in triangulation.

Once the position of enough well-distributed detail has been determined, the map can be completed by freehand sketching with the surrounding country as guide. On occasion it may be deemed desirable to run a traverse across the district, for instance, to enable a road to be sketched in. Such a traverse should begin and end on ruling-points so that correction can be applied.

It is highly desirable that apart from inking in, all compass sketch-maps should be completed in the field. Unwanted lines, including rays, and even ruling-points that do not merit a place in the final sketch, are rubbed out, though their position might well be indicated by a dot in a circle. The date, scale, and magnetic north should be shown.

CHAPTER SIX

PLANE-TABLE SURVEY

THE plane-table, possibly known since Roman times, may be used to survey as extensive an area as the prismatic compass, and the resultant work is far more accurate. It has been widely used in various countries for original surveys on scales of 2 or 3 inches to the mile, but it is not the proper instrument for large-scale work, and that may account for the fact that it has never been widely used in Britain.

In the present chapter some account will be given of the equipment used in plane-tabling, of plane-table sketching as it may be practised to pick up the basic principles, and finally a brief indication of methods employed in plane-table survey in the British Empire as contrasted with methods in America and various other countries.

1. EQUIPMENT

The equipment necessary for a plane-table survey consists of the table itself, a spirit-level, sight rule, chain or measuring tape, paper and pins, a hard pencil, and a rubber. To cut the latter into many pieces and to put at least one piece in each pocket is an indication of cunning rather than of good practice. A box compass is usually regarded as part of the outfit, and a pair of field-glasses are sometimes useful for recognition of distant objects.

The plane-table shown in Plate V, facing this page, consists of a flat board about 2 feet square, mounted on a tripod in such a way that the board can be levelled, twisted round, or clamped in any position. The table must be rigid when set up on either sloping or flat ground. Metal parts must not be of iron or steel or they affect the compass. The spirit-level is simply to assist in levelling the table top when setting up.

The sight rule is variously called a sight vane or an alidade. In its simplest form shown in Plate V it is a boxwood ruler with raised sights, a slot at one end and a hair-line at the other, giving a sight line parallel to the edge of the ruler. More elaborate patterns have a bar attached to the straight edge, enabling lines to be drawn parallel to the edge and at various distances from it. For the most accurate work an attached telescope takes the place of open sights, as in Plate V.

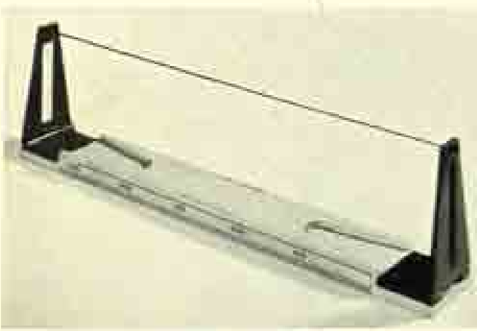
For plane-table sketching a chain or tape is necessary to measure the base-line as in the compass survey. Any inaccuracy in base measurement is reflected only in the scale of the map, but it is desirable that no avoidable error should be introduced. All work is transferred directly from the landscape to the paper by direction.

Box Compass

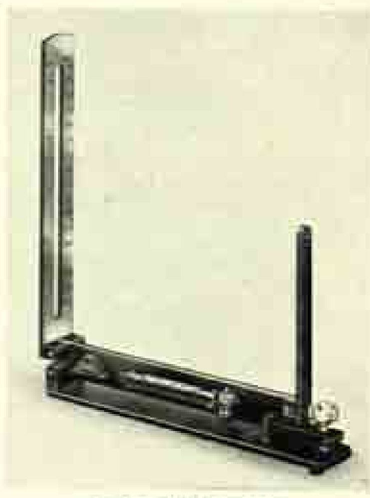
Prismatic Compass

Plane Table

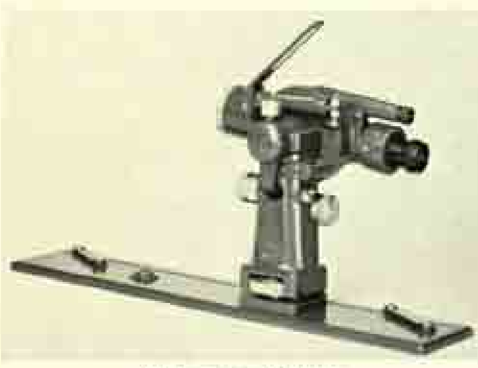
Aneroid Barometer



Simple Alidade



Indian Clinometer



Telescopic Alidade

V. Surveying Instruments.

By permission of Messrs. Hilger & Watts, Ld.

Changes in the amount of moisture in the atmosphere cause paper to shrink and expand, and errors are thereby introduced which are greater than errors inherent in the method. It is therefore desirable to mount the paper in such a way as to minimize changes. The following process may be tried. A piece of linen or calico rather larger than the table top is soaked in water for a quarter of an hour and then stretched evenly over the board. Edges are pasted and pinned underneath. A neater job results if the overlap at the corners is cut away. The drawing-paper, which should be of good quality, is then moistened with water on both sides and stuck to the linen with cornflour paste. Overlap is smoothed out and pinned under the table as with the linen. On drying, the paper should be smooth and taut. It must be remembered that if sheets are torn or damaged, there is no field-book record to fall back on.

Some paper is obtainable already backed by muslin or linen, and this can be seasoned by exposing it alternately to damp and dry atmospheres for about a week. In mounting this paper only the sides need be damped before pinning. Drawing-pins on top of the board obstruct free movement of the sight rule. Special frame tables have been designed which carry an aluminium-sheet top. Over this is pasted first linen and then paper, secured at the edges and strained by springs. A fresh aluminium sheet is necessary each time, but the record is more permanent. In Alaska, where climatic conditions are very unfavourable to the use of paper, celluloid sheets have been tried.

The box compass, known also as a trough compass or declinatoire, consists of a compass needle about 5 inches long housed in a small box, as shown in Plate V. The needle is pivoted in the centre, so has only a small swing to right or left. At each end of the box is a short arc scale, graduated so that a line joining the central or zero marks is parallel to the long edges of the box. Thus, when the box is turned until the needle comes to rest at the zero marks, the long edges of the box are parallel to the needle and therefore in a due magnetic north-to-south direction. These edges can be used as a ruler to draw magnetic north–south lines upon the plane-table sheet. Once these lines have been drawn, the table can be set up elsewhere and oriented, magnetic interference excepted, by placing the edges of the trough along the lines and turning the table top till the needle points to the zero marks on the scale. The north end of the needle is usually marked, and this enables a beginner to avoid attempting to get the needle to swing freely when the compass is the wrong way round.

2. Principles of Plane-table Sketching

For various reasons detailed description of how to use the plane-table is rather long and tedious, though in practice the work is comparatively simple and by no means slow. A general idea of basic principles is given in this section, by reference to the area shown in Fig. 20, already used as the basis of explanation of compass sketching.

Suppose that in Fig. 20 points 5 and 6 are intervisible and offer good views to surrounding features, and that the stretch of road between them is fairly level, simplifying determination of length. This piece of road is then suitable to act as base in making the plane-table sketch. The table is first set up at point 5, and the top levelled. The box compass is placed on one side of the table and the top slowly rotated till the compass needle comes to rest at the zero marks of the scale. The table top is then clamped in that position. Lines drawn along the edges of the box indicate magnetic north. The north end should be marked to distinguish it from the south. If it is considered desirable to follow a common convention and get north at the top, the box is placed with its edges parallel to one edge of the table before rotating, so that the magnetic north line is parallel to the edge of the paper. Once the table top has been clamped, a dot is placed in a suitable part of the paper to represent point 5. The sight rule is then placed with its edge on the dot, and twisted round till point 6 is seen through the sights. A pencil line is then drawn in the direction of point 6 along the edge of the sight rule from the dot representing point 5.

Some difficulty may be experienced at first in moving one end of the sight rule without shifting its position away from the dot. Many surveyors place the unsharpened end of the pencil on the paper against the dot and use this as a fulcrum or pivot to swivel the ruler into line. Some use the finger-nail and others a pin, though the latter may damage the paper. When drawing the ray, the pencil point should be placed in the dot and care taken not to alter the angle at which the pencil is held while completing the ray. The advantage of a parallel-bar attachment is now seen, because so long as the sight rule is alined in the vicinity of the dot, the bar can be moved till it occupies a convenient drawing position touching the dot.

Rays are next drawn by the same process from point 5 towards all outstanding points which may serve as subsequent ruling-points, as in the prismatic compass survey. Each ray is suitably labelled for subsequent recognition.

The table is then moved to point 6 and the distance between points 5 and 6 on the ground carefully measured. This distance is marked off to scale along the ray which was drawn first. The end mark represents point 6. Scales from 2 inches to ¼-inch to the mile are common, while a base-line ½-mile to 1 mile is as long as can be measured conveniently. In organized plane-tabling, when base stations follow from theodolite triangulation, there is no need for preliminary measurement as in this case.

The problem is now to orient the table over point 6 on the ground, with magnetic north in the same direction as before. There are two ways to do this. The box compass can be placed in its original position on the table, the top unclamped and rotated till the needle comes to rest at the zero marks, and the top again clamped. The other way is to place the sight rule along the ray representing the base-line and slowly rotate the table top until point 5 on the ground appears in the sights. The top is then clamped. From what has already been said it will be appreciated that the latter method is more accurate. Rays are then drawn from point 6 to ruling-points previously sighted from point 5. Intersection of rays will determine the position of each on the plan.

The usual precaution should be taken to see that triangles are well conditioned, especially those fixing the position of sites to be occupied for extension of the triangulation. There is no need to draw a continuous ray from the station occupied to the edge of the paper. Practice will enable the approximate position of a ruling-point to be estimated, and only a portion of the ray in that neighbourhood need be drawn, provided it is clearly labelled. Sometimes it becomes necessary to extend a ray or place the straight edge accurately along a previously drawn ray, as, for instance, in orienting the table by a back-sight along the base-line. This may be difficult if only a short length of ray has been drawn. Consequently, whenever such may become necessary, it is advisable to draw a small extension line at the edge of the paper, and to name it. Such extensions are called *repère marks*. They are sometimes usefully accompanied by a sketch of the object sighted, to aid recognition when taking sights from new ruling-points.

Procedure is almost identical with that for prismatic compass survey and the initial object the same, namely, to cover the whole area with a network of triangles which give a framework upon which detail is hung. Ruling-points fixed by well-conditioned triangles are in turn occupied, the table oriented, and rays drawn towards new points whose positions will later be fixed by intersection of rays from other determined points.

The first ruling-points to be occupied away from the ends of the base will be fixed by intersection of two rays only, but after that the position of no point should be considered adequately determined unless a third ray intersects at the same point. For example, if Fig. 20 in the sheep-fold is occupied as the first ruling-point away from the base, the position of the Mitre Oak should be determined by intersection of rays from the sheep-fold and both ends of the base.

The table is oriented at each new station by sighting back to another station whose position has already been determined. It is good practice of course to check by placing the sight rule along other rays to see whether the appropriate ruling-points can be seen in the sights. Thus, when setting up at the Mitre Oak in Fig. 20 by a back-sight on the sheep-fold, the ruler might also be placed along the ray from the oak to point 5 and a check taken to see whether point 5 in the field appears in the sight as it should. The position of prominent objects, no less than of ruling-points, can be determined by intersection, all to assist in completion of the work by sketching detail about points so determined.

At times it may be difficult to set the table exactly over a ruling-point, for example, if this is a tree or a large cairn. On a scale of 2 inches to the mile, 10 yards is represented by little more than one-hundredth of an inch, so on this or a smaller scale there is little to be gained by insistence on centring the table precisely over the ruling-point. On the other hand, if the scale is 200 feet to the inch, then it is desirable to centre the table within a foot or so of the ruling-point. When such precision is essential to the accuracy of representation, it should be queried whether the appropriate instruments for the survey in hand have been chosen.

One point sometimes gives rise to unnecessary misgiving. The beginner notes that the line of the sights is parallel to the edge of the ruler, and not coincident with it. How far then is a line drawn along the edge of the sight rule really directed at the object seen in the sights? Strictly speaking, the line of sights should lie directly over the edge of the rule, and indeed it does in some sight rules. Suppose a ray is drawn from a dot on the paper to an object half a mile away. With sights along the centre of the ruler, the ray drawn on the edge, if continued, would miss the object by half the ruler's width, say, half an inch. The error in direction is therefore half an inch in a ray half a mile long, an imperceptible amount when reduced to the normal scales of plane-table work.

3. Resection and the Triangle of Error

The process of *intersection* will only determine the position of conspicuous features in the plan, but will not fix equally important but inconspicuous features. These must be determined by *resection*. The process is not quite as simple as with the prismatic compass, the chief difficulty being to orient the table accurately. Suppose for a moment that the positions of Primmer's Mill, Range View House, and the sheep-fold have been determined by intersection, but that the position of point 4 has not been fixed. The table can be set up at point 4 and oriented by trough compass as before and then clamped. The sight rule may then be pivoted against the point on the plan representing Range View House, and swivelled round until the house itself appears in the sights. A back ray is drawn from the house towards the observer's position at point 4. If the map is correctly oriented, this ray will pass precisely through point 4. Another ray is drawn by alining the actual mill with its position as marked on the paper. The intersection fixes the position of the observer. The principle is obviously akin to resection by prismatic compass illustrated in Fig. 23. For check, a back ray must be drawn through another point, such as the sheep-fold. But whereas three rays fixing points by intersection can normally be expected to meet in one point, three rays in a resection rarely do. This is because of inaccuracies inherent in orienting the table by compass. Hence determination of position by resection based on compass orientation alone cannot be regarded as satisfactory, and in new country the compass is always suspect. Errors, however, are not cumulative, as each point is fixed independently by resection on fixed ruling-points.

A second method to determine position, and the one most used, consists of drawing back rays from three points, as described above, and then eliminating any error caused by inaccurate orientation with trough compass. When the table is inaccurately set, the three back rays intersect to form a triangle, commonly called the *triangle of error*, as shown in Fig. 24. The method of solving the problem takes longer to follow in words than to effect in the field, or plane-tabling might have been given up long ago.

A choice of points already fixed by intersection should be made, if possible so that one is distant and two are near to the observer. For beginners matters are

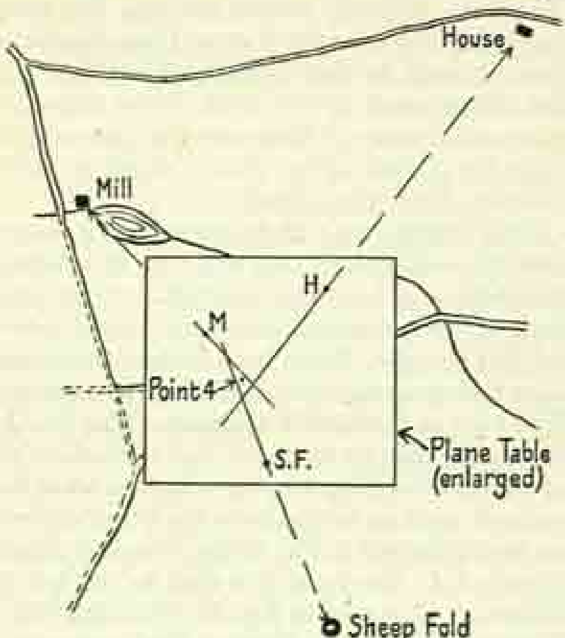


FIG. 24. Triangle of error. Observer's position at point 4 is within the triangle formed by points used in resection. The size of the table top is vastly exaggerated.

simplified if lines joining the three points on the ground enclose the observer's position, as when two are in front of him and one behind. The table is oriented by compass, or by alinement on the most distant point, as on the house in Fig. 24.

Back rays are drawn on the plan from all three points, by pivoting the straight edge on each in turn, and swivelling till the actual field station comes into view. Consider first the case shown in Fig. 24, where the observer's position at point 4, marked also in Fig. 20, is inside the triangle of stations used in resection. The observer's true position on the plan is then inside the triangle of error. The precise position is at a vertical distance from each ray proportional to the length of the ray. Thus it is nearest the mill ray and farthest from the house ray. The position as judged by eye on this basis is marked by a dot. To check, the sight rule is first alined on the plan by the newly determined position and the point representing the most distant station used in resection. The table is then unclamped and rotated till the station in the field comes into the sights. The table is then reclamped, and back rays drawn once more from the three stations. This time they should meet in one point, or the triangle of error should be much smaller and may be dealt with again as before.

If a resection has been properly carried out and the method of solution carefully applied and still the triangle of error is no smaller, error should be looked for elsewhere. It may be that confusion has arisen through failure to distinguish a given ruling-point in the field. New ruling-points might be chosen, but it is more satisfactory to determine the cause of the trouble even if this means going over the ground again. Always where possible, a fourth point should be employed as a check in resection.

When the three initial points form a triangle outside the observer's position, as in Fig. 25 (A), where the position of Point 2 of Fig. 20 is being determined by sighting on the same stations as previously used, the correct position on the plan is outside the triangle of error. Correct orientation should result by turning the table slightly to the left or right. There is no harm in experimenting with this method, but it is slow and uncertain compared with the usual graphical method. Suppose that a slight turn to the right is necessary. This has the effect of moving all three points on the plan to the right, and the correct position is therefore to the right of all three rays, right being defined as when facing the station in the field. The correct position cannot lie to the left of any of the rays, so the left side of each has been ruled out in Fig. 25 (B). The only possible sector is that without shading, marked *d*. Similarly, if a turn to the left is necessary, the same reasoning eliminates all sectors in Fig. 25 (C) except that marked *a*. The precise position is again at a vertical distance from each ray proportional to the length of the ray. In the example shown, this must be a point most distant from the house ray. This determines that the correct position of the observer is in section *a* and not in *d*. The estimated position is marked by eye and checked by trial as before.

Once familiar with the process, it will be realized that every case can be covered in a single sentence, namely, that the observer's position is either to the right or left of all rays, at a vertical distance from each proportional to the length of the ray.

There is one case in which wrong orientation fails to produce any triangle of error. This arises when the observer's position and the three points used in resection lie on a circle. In such circumstances, no matter how wrongly the table is oriented, the three rays will always meet in a point, though different orientations give different meeting-points. Thus the three points used above would be unsuitable in determining the position of the Mitre Oak in Fig. 20 and shown as inset *D* on a smaller scale in Fig. 25. Such a choice of points on this danger circle should be assiduously avoided.

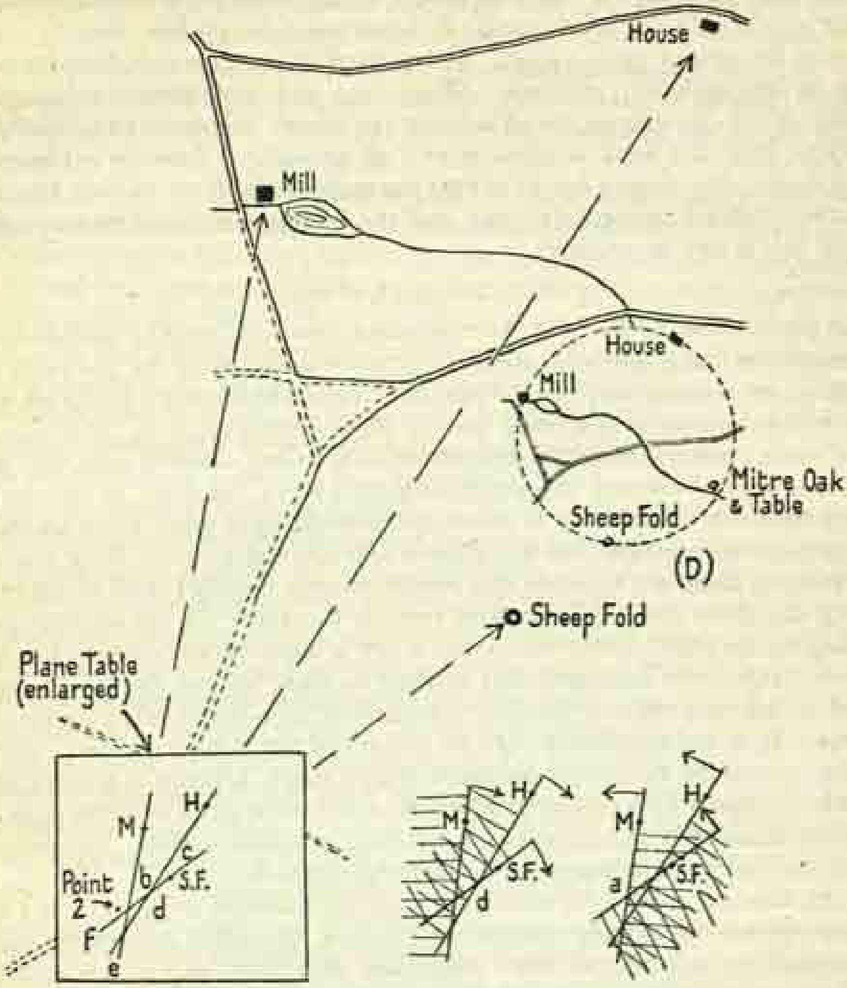


FIG. 25. Triangle of error. Observer's position at point 2 is outside the triangle formed by points used in resection. The size of the table top is vastly exaggerated. Inset *D* shows case in which triangle of error fails.

At times it may be difficult to determine the position of a point by more than two forward rays in intersection, or two back rays in resection. Provided that the table can be oriented with some confidence that the degree of error is at most small, that such rays make well-conditioned intersection, and that the ruling-points are not far distant, then for the purpose of filling in detail such a position may be accepted. But an object whose position has been determined in this way should not subsequently be used as a ruling-point.

One of the arts of plane-tabling, no less than of compass sketching, is to fix detail as triangulation proceeds. Much time and unnecessary walking are thereby saved. As enough detail is fixed, the sketch is completed by freehand drawing. Essential work is inked in and all unrequired lines are rubbed out. If it is desirable to keep a record of how the map was built up, the ink fair copy might be obtained by careful tracing, and the field copy retained for inspection, though this is rare in practice.

4. Plane-table Traverse

The plane-table, no less than the prismatic compass, may be used to run a traverse from one point to another, to produce a sketch of the route, to add details to an existing map, or to draw in a route which cannot easily be fixed by resection or intersection, as in thickly wooded country.

If a route sketch is required without relation to any existing map, the table is set and a point marked in some convenient part of the sheet, as the start of the traverse. A forward ray is drawn towards the next point to be occupied. The distance is measured on the ground and marked to scale along the ray. The table is then set up over the second station, levelled, and oriented by placing the ruler along the ray and turning the table till the starting-point appears in the sight. After clamping, a ray is then drawn towards the next station, its distance measured and marked to scale, and so the job proceeds. Detail to left and right is fixed by intersecting rays drawn when at traverse stations. It is not essential to invoke the aid of the trough compass, though there is something to be said for using it as a check, because if a single error is made in setting by back ray, the whole of the subsequent traverse is slewed round, whereas error in compass setting has no cumulative effect. The compass should be used to draw magnetic north on the traverse.

If the traverse is done in connexion with the mapping of an area and conspicuous points are already marked on the sheet, the initial orientation can be determined by one of the ways previously described, and at each station orientation can be checked by sighting fixed stations in addition to the back one in the traverse. In such circumstances, however, determination by resection rather than by traverse would normally be employed.

5. Organized Plane-tabling

The plane-table is used in topographical surveying, usually on a scale of 3 inches or less to the mile, to fill in detail after an accurate triangulation has been made with a theodolite. The *trigonometrical points* or *stations* determined by theodolite are accurately plotted on the plane-table sheet, and each is marked with a dot surrounded by a triangle. Each corresponds to a station clearly marked in the field, as by specially built beacons, church spires, chimneys, or flag-poles securely tied to trees. A written description of each aids identification. These trigonometrical stations should be both frequent enough and well enough distributed to enable detail to be fixed accurately.

In organized work the plane-table sheet covers an area of so many minutes of latitude and longitude. Outside the marginal lines trig points are plotted as far as the edge of the plane-table.

In the British Empire the largest plane-table scale is usually the 1-inch. Many trig points are provided, and all topographical detail relevant to the particular survey is fixed graphically. Distant points are fixed by intersection and the surveyor's own position by resection. Each plane-tabler usually works separately. When satisfied of his own position, rays are drawn to all points likely to be of value in controlling further work, and map detail of the nearby country is drawn in. To assist in this the surveyor has points fixed by intersection, and may supplement these by noting the direction of other detail, measuring the distance to it, and then scaling the distance along the appropriate ray. Training enables a man to estimate 200 yards within an error of 6 yards by pacing, and this is negligible in plotting on the 1-inch scale. Contouring is carried out at the same time usually with the Indian pattern clinometer as the map detail is drawn in, but consideration of this part of the work is deferred to a later chapter. The pencil work of each day, covering about a square inch of paper, is inked in each evening. The sheet is finally checked by visiting some high viewpoint and taking rays at random throughout the area.

The normal practice in various other countries is to have fewer trig stations determined by theodolite, and scales around 1 : 20,000 are commonly employed. The lone plane-tabler is replaced by a team of at least four. This is necessary because positions are not only fixed by intersection and resection, but much is determined instrumentally. A telescopic alidade is used, fitted with vertical arc and level for measuring vertical angles. The diaphragm has engraved upon it one vertical and three horizontal lines. A wooden rod about 10 feet long and 4 inches wide is graduated so that the upper and lower marks correspond in position to those on the alidade diaphragm when the rod is viewed through the alidade at a convenient horizontal distance, say, of 100 metres. If the whole of the graduated stadia rod is seen to be intercepted between the upper and lower horizontal lines of the diaphragm at 100 metres, half of it will be seen to be intercepted at 50 metres, and other lengths proportionately. Thus by having one man to carry, set up, and guard the table, and two rodsmen to occupy salient points of detail, the topographer can fix and draw in his detail and contours fairly rapidly. The latter aspect of the work is dealt with more especially in Chapters IX and X.

CHAPTER SEVEN

AIR-PHOTO SURVEY

The proverbial bird's-eye view of landscape is now a commonplace to many people, and those who hitherto regarded a map with suspicion pour with interest over an aerial photograph. If the camera has been held vertically above the landscape, thereby obtaining a vertical photograph, objects are not always easy to recognize, but if the camera has been tilted, recognition is not so difficult. This type of photograph is termed an oblique.

1. Development of Photo Surveying

It was early apparent to surveyors that both vertical and oblique photographs could be of assistance in surveying, though verticals were little more than an idea until the aeroplane was developed. The photographs first used, about a century ago, were ordinary ground photographs taken with the camera mounted horizontally on a tripod at points whose positions and heights had been established by normal ground survey. Knowing the focal length of the camera, and either the direction in which it pointed or the precise position of recognizable objects appearing in the photo, it was possible to plot additional data from the photograph to the map.

Most use was made of these ground photographs in difficult country such as the Rockies and Alps, and indeed they are still used in very inaccessible country for large-scale surveys.

The next stage in photogrammetry or photo measurement came about the beginning of the present century, when pairs of photographs taken some distance apart but in parallel direction were studied stereoscopically. By this arrangement, familiar to nearly everyone, the pair of two-dimensional photographs come to life as a single three-dimensional model, aiding recognition of objects, distances, and relative heights. Instruments were perfected which enabled vertical and horizontal measurements to be made on these apparently three-dimensional models. In some cases they even incorporated a plotting mechanism which records these measurements in the form of map detail or contours.

That this plotting is at all possible may be appreciated by regarding camera stations as setting-up points of the plane-table, intersecting rays from the two known positions determining new positions. A pair of movable optical marks brought to coincide at any point of the landscape take the place of the plane-table visible rays, the necessary movement of the marks motivating a plotting arm. Similarly, contours are plotted when the coincident optical marks are made to move in a horizontal plane while apparently in contact with the surface of the stereo model, the necessary movements being recorded mechanically in plan.

Aerial photography was taken up in earnest during the 1914–18 war, though at first cameras were simply held in the hand and photographs taken over the side. These enabled new detail to be added to existing maps. Bushes which appeared overnight were suspect. Even with improved cameras and photographing arrangements, the problems of aerial surveying were obvious, namely, the difficulty of ascertaining the exact height and position of the craft at the time of exposure, and of dealing with inevitable tilt.

The stereoscope once more provided a line of development. Photographs were taken so that consecutive exposures possessed an overlap of about 60 per cent. The two points of view essential to stereoscopic inspection were provided

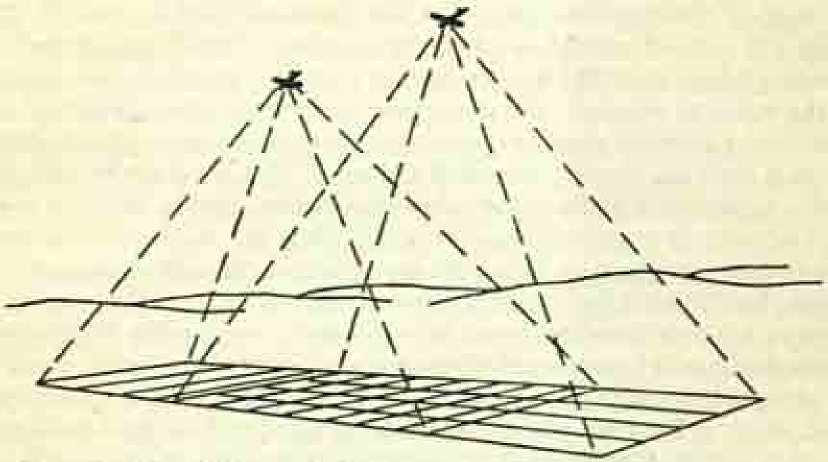


FIG. 26. Plane taking vertical photographs to give stereoscopic overlaps.

through the movement of the plane, while the pairs of photographs were provided by the common overlap, as shown in Fig. 26. A third photograph would make use of the forward portion of the second photograph, and so on. The old ground photo stereoscopic plotters were gradually adapted to automatic plotting from the vertical photographs.

2. Scope and Limitations of Air-photo Surveying

A truly vertical photograph of level ground taken from a known height gives a true perspective picture of the ground, but such ideal conditions never obtain. The old problems still have to be reckoned with, namely, distortions due to variations of ground level, uncertainty of scale due to uncertain height of aircraft, changes of aircraft height from one photograph to the next, and random tilts through which the photographs are neither true verticals nor uniformly tilted. Automatic pilots now help to reduce flying defects to a minimum.

Points fixed by ground survey, both in position and altitude, and known as ground control points, are essential to the preparation of accurate plans from the photographs. As expressed by one who has done much to develop air-photo survey, the air photo can replace the clinometer, the plane-table, and, to a large extent, the chain, but it cannot as yet replace the spirit-level and the theodolite. Ground control points assist in correcting for tilt, plotting to scale, contour determination, and the insertion of fresh control points by elaborate plotting-machines, which in turn enable detail plotting to be carried out with simpler instruments and more personnel. Plotting from individual photographs is rather like independent chaining or plane-tabling. A tolerably good plan can be made of a limited area, but a number of such plans will not fit to make a map. Inaccuracies appear at the edges, as may be seen in photo-mosaics. If ground control is of geodetic order, so much the better. The elaborate plotting-machine will fix further control, and so the process moves from the whole to the part, and from point fixation to detail sketching.

Probably the outstanding feature of air-photo survey as compared with the traditional methods already described is speed. This is especially valuable in virtually unsurveyed lands where economic development is likely to outpace ground survey. It is also of importance in regions like the Laurentian Shield, where distances are long and the field season short, for enough ground can be photographed in a few days to keep plotters busy the rest of the year.

Even in a highly developed and fully surveyed country like Britain, large-scale plans adjacent to centres of population are constantly becoming out of date, and aerial photography can be used as a means of rapid revision of the 6-inch and 25-inch plans. It has been established that with photographs of the best quality, accuracy is sufficient, and that there is a substantial saving of time and money.

The air photo also records a vast amount of detail of value in a survey of vegetation, soils, agriculture, archaeology, and geology. After training, a forestry officer is able to make a fair estimate of forest types and tree heights: the geologist the prospects of successful mining operations. Consequently it is not only topographical mapping which benefits and makes more rapid progress, but economic development can be pushed forward with more speed and certainty.

At the outbreak of war in 1939 Canada had a library of over three-quarters of a million photographs, used by the Topographical Survey, Geodetic Survey, Hydrographic Survey, Dominion Water Power and Reclamation Bureau, and the Forestry Department, and they were also available to the public. In the United States a million and a half square miles had been photographed, and contracts let for another half-million. The 1939–45 war has led, moreover, to photography of even wider areas of country previously unknown, and the Royal Air Force Library in the United Kingdom now contains many millions of photographs. In some regions, such as tropical deltas, conditions may make survey by any other means impossible.

More use has been made of oblique photographs in Canada than elsewhere. They are especially useful to cover vast areas of low relief as found in the Arctic and Canadian Shield. The area covered by a single photograph is much greater than in the case of verticals. The making of small-scale topographical maps, in the region of one-quarter of an inch to the mile, then consists of drawing an appropriate perspective grid over the photograph, and transferring detail from this to a grid of squares. The photograph may be regarded as a chess-board seen in perspective, and the problem is to redraw it in plan.

One of the problems in undeveloped countries of vast extent, especially in the application of vertical photography, is that of cost. This becomes a question of maintenance of either field parties of plane tablers or the provision of aircraft within suitable range. In general, modern facilities are showing that it is both quicker and cheaper to do the work by air photography. This is particularly so in jungle or uninhabited country where not only is travel difficult for the plane tabler but his outlook is often very restricted.

Modern vertical photography is taken from between 15,000 and 30,000 feet with cameras of focal lengths between 6 and 36 inches. These photographs are 9 inches square, so each photograph taken 30,000 feet above the ground with a 6-inch lens will cover nearly 80 square miles of country. They bear a titling strip which gives the focal length of the lens, and the date. In some instances the height of the aircraft and the time of day are also given. The focal length and the height taken in conjunction enable the scale of the photograph to be determined with sufficient accuracy for general purposes. A knowledge of time assists in photo-interpretation, enabling, for example, confusion to be avoided between the long shadows cast by early or late summer sun from shadows of similar length cast by midday sun in mid or high latitudes in winter.

Although aerial survey may reveal things which are not visible to the naked eye when walking over the land, such as geological faults and concealed dikes, and matters especially of archaeological interest such as ancient tracks and sites of buildings, some features important to topographical mapping remain unrecorded. Vegetation may conceal parts of paths, roads, and rivers. On large-scale work even overgrown hedges may prevent the accurate delineation of what the Ordnance Survey delightfully calls visible obstacles to trespass. Broad eaves of buildings conceal ground-floor plans. The oldest inhabitant, at least in this present generation, can usually be consulted about parish boundaries and spelling of place-names only on the ground.

3. Simple Plotting from Air Photographs

Elaborate plotting-machines are exceedingly useful to assist correct orientation, to extend control, and to prepare the way generally for detail plotting.

But there are much simpler instruments used in conjunction with these, and which indeed may be used alone with tolerably good results. Modern stereoscopes are available, by which one of the photographs of a stereoscopic pair can be contoured especially if the levels of a number of points are known. On looking through the stereoscope, relief is clearly seen, and by apparently pencilling form lines on this, as one would on a solid model, it will be found that the lines are actually being drawn upon the photograph adjacent to the hand holding the pencil.

An elaborate form of this is employed for work of a high standard in the Multiplex Aeroprojector, in which the two images are projected through coloured light filters on to a table, and observed through coloured spectacles which match the complementary colours of the filters and give stereoscopic effect. It is thereby possible to contour a model illusion, just as later a simple method is described of creating a model illusion by vertical spacing of prepared contours.

If there is very little tilt, and in modern work this rarely exceeds 2°, and there is not a great variation in level, a straight tracing of one photograph with contours added makes an excellent sketch-map. A plan without contours may be seen in Fig. 73, which should be compared with the photograph in Plate VIII, facing p. 148.

Even without a stereoscope and with only one air photo, information can be added to an existing map. Suppose that the area is fairly flat and the photograph vertical or only slightly tilted. A point which does not appear on the map can be plotted from the photograph by noting first of all two other points common to photograph and map. These two points are treated as a base-line to determine the direction of rays to the third point. The photograph directions drawn on the map from the appropriate points given an intersection fixing its map position, as in plane-tabling. This automatically corrects for scale, but not for differences in altitude or tilt.

If proportional dividers are available, the method of intersecting arcs can be applied. The points of one end are set by the photograph, and the others by the map. Several points may be fixed from the original two bases. Further detail may be sketched about these by eye.

If a line is drawn through a pair of points on a photograph, and another line to intersect this is drawn through another pair of points, their intersection marks a fifth point. If the same pairs of points are identifiable on the map, and lines are drawn through them, their intersection will occur at the point corresponding to that on the photograph, no matter how tilted the latter may be, provided there is no great variation of relief. Should a point be required which does not lend itself to this method, the nearest plottable point should be fixed, and the final point plotted by one of the former methods from the nearest suitable pair of points.

Detail may also be sketched in from a tilted photograph, by choosing points about the detail, and joining these up to form a pentagon. The corners of the

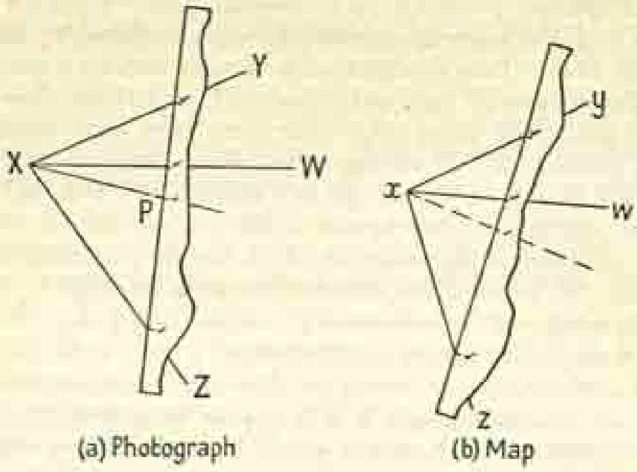


FIG. 27. To fix the position of additional points on a map when only four points are identifiable as common to map and photograph.

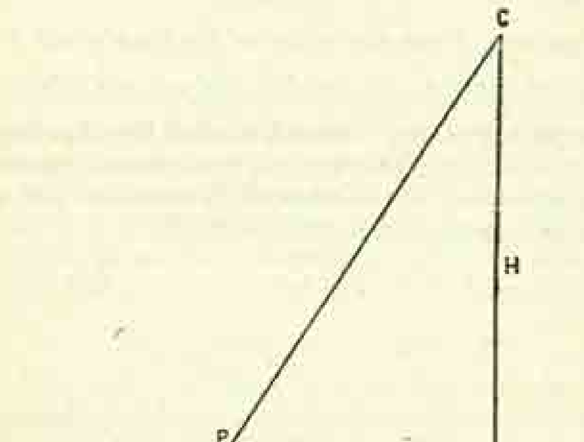


FIG. 28. One effect of relief on a vertical photograph.

pentagon are joined, dividing the whole into a series of figures. Corresponding points are marked and joined on the map. The framework obtained enables detail, as of drainage, to be copied fairly accurately from the photograph.

If only four points can be identified on map and photograph, it is still possible to fix others from photo detail. Reference to Fig. 27 explains the method. W, X, Y, and Z are four points on the photograph and P a point it is necessary to transfer. w, x, y, and z are corresponding points on the map. Join the points as shown in Fig. 27 (*a*). Take a straight edge of paper and lay it across as shown, marking the intersection of rays and paper edge with ticks. Now join x to y, w, and z, and move the paper edge over these rays until the ticks occupy corresponding positions to those in Fig. 27 (*b*). Mark the required position of the p tick, for p will lie somewhere on the ray through this tick and x, shown in Fig. 27 (*b*) by a dotted line. The precise position is obtained by repeating the whole process from one of the other points. A further repetition acts as check. A slow business, but an adequate skeleton can soon be clothed.

The effect of relief may be considered in relation to Fig. 28. C represents the camera, H its height above general surface level, and h the height of a point P above general surface level. P would be shown in a map vertically below its position, but on the photograph it will appear at p instead. Therefore in plotting the position of P adjustment should be made. From similar triangles having hypotenuses Cp and Pp, $\frac{d}{D} = \frac{h}{H}$, therefore d, the amount of displacement, is $\frac{D.h}{H}$. Suppose that the photograph is taken so that H is 12,000 feet, and that h is 1,000 feet. From the centre of the photograph D proves to be 4 inches. Then the amount of photographic displacement in inches is $\frac{4 \times 1,000}{12,000}$, which equals one-third of an inch. Correction would therefore bring it one-third of an inch nearer the centre. The effect of a depression, as shown to the left of the hill, may be calculated as an independent exercise. The problem of air photo interpretation is dealt with in Chapter XXI.

CHAPTER EIGHT

THEODOLITE TRIANGULATION

THEODOLITE triangulation forms the basis of all accurate surveys of extensive areas. The process is usually slow and expensive, requires a high degree of skill, and a considerable knowledge of mathematics. Nevertheless, the principles of the triangulation are straightforward and an attempt will be made to explain these in outline, indicating something of the care that is taken to avoid errors. It will be assumed that previous sections on survey are already understood.

The theodolite survey in unmapped country resolves itself into at least five distinct operations, namely:

1. Preliminary Reconnaissance Survey.
2. Measurement of a Base-line.
3. Theodolite Triangulation.
4. Defining the Positions.
5. Determination of Azimuth, Latitude, and Longitude.

Although the work is done in order from 1 to 4 and is best so described, it is not necessary to wait for the completion of one part before commencing work on the next.

1. PRELIMINARY RECONNAISSANCE

A preliminary reconnaissance of the area is undertaken to produce a sketch-map which will be of use in determining the best trigonometrical stations. Much time is thereby saved, because intervisibility is determined in advance of theodolite work, and from the many ruling-points in the sketch, those only are chosen which will yield well-conditioned triangles with sides of a predetermined approximate length. The work is carried out with the plane-table ahead of the theodolite, and beacons are built as work proceeds.

2. MEASUREMENT OF A BASE-LINE

For the plane-table sketch, the length of a base-line is measured only approximately, as the purpose of the sketch is not affected by inexactitude in that part. But the measurement of the base for the theodolite work must be as accurate as possible, since accuracy is the keynote of the work. One method of checking is to measure a second base-line and compare the result with the length as computed from the triangulation. Unless measurement were accurate, such a check would be of little value. Further, the geographical position, that is, the latitude and longitude of each station, is calculated from the triangulation after determination of latitude and longitude of an initial point. All would be wrong if calculated from an inaccurately measured base.

If possible a base is chosen on fairly level ground where ends are intervisible and from which sights can be taken on to other stations suitable for base extension. The length varies from about 5 to 10 miles. The Atlanta base in Georgia, U.S.A., was about 6 miles, the principal bases in Britain, measured between 1784 and 1849, were 5 to 8 miles long, while the five bases used in the Geodetic Survey of the Transvaal and Orange River Colony were between 10 and 22 miles. All distances on Ordnance Survey maps of Britain depend upon the accuracy of measurement of bases near Loch Foyle and upon Salisbury Plain, for all are derived from the weighted mean of these two.

The apparatus used has varied with the date and the country. Wooden rods, glass rods, and special compensating bars, made of two metals to counteract temperature changes or enable length to be calculated accurately, have been used. A compound bar of iron and brass, 6 metres long, was used in the United States, and also a steel bar immersed in melting ice. In Britain and India a bar of brass and steel 10 feet long was used. These bars were usually set up in wooden troughs in a series of about four, and the distance apart determined by microscopes or wedges. Alinement was maintained by theodolite. The process was very slow, taking several weeks, but the error made probably varied only from one part in two hundred thousand to one in a million, or less than one-tenth of an inch in a mile.

Nowadays measurement is usually made with invar tapes or wires, either 100 feet or 24 metres long. Invar is an alloy of nickel and steel and varies less in length with changes of temperature than does any other metal. This minimizes the possibility of error from the hitherto most fruitful source. The tapes are stretched by weights on tripods. The end tripods have marks against which marks on the tape can be read. Consequently the exact distance between tripod marks can be ascertained by simultaneous readings at each end of the tape.

Correction is made for tension, slope, sag, and temperature, and for variation from true length peculiar to the particular tape.

One other adjustment is made. The base-line measurement of the theodolite triangulation is reduced to what it would be at sea-level, a simple calculation since the radius of the earth is known, and the height of the base-line above sea-level can be ascertained. The point is appreciated by drawing a capital V with two arcs across it. The upper one represents the base-line as measured, the lower one as reduced to sea-level. Since the base-line is the only linear measurement made, this adjustment has the effect of reducing automatically all subsequent calculated lengths to what they would be at sea-level.

3. Theodolite Triangulation

The handling of a theodolite can only be learnt with practice in the field under enlightened guidance, and consequently little more than the principles involved are considered here. A precise type of theodolite is shown in Plate VI, facing p. 72.

All consist essentially of a telescope so mounted that it will rotate in either a horizontal or a vertical plane. The degree of rotation in the horizontal plane is measured by means of a pointer which rotates with the telescope round a clamped horizontal circle graduated in degrees clockwise from 0 to 360. Vertical movement is recorded by a vertical circle graduated in quadrants from 0° to 90° upwards and downwards. The instrument is normally mounted on a tripod. Its size is stated in terms of the diameter of the horizontal circle. For the primary triangulation of the United States a 2 ft. 6 in. theodolite was used and for that of Britain and India 3-foot theodolites. By improved design and manufacture very accurate work is now possible on a 6-inch instrument, some patterns reading to single seconds of arc. All readings are made by means of verniers or micrometers. Transit theodolites are those designed so that the telescope can be turned through a complete circle in the vertical plane, an arrangement which assists the surveyor in eliminating error.

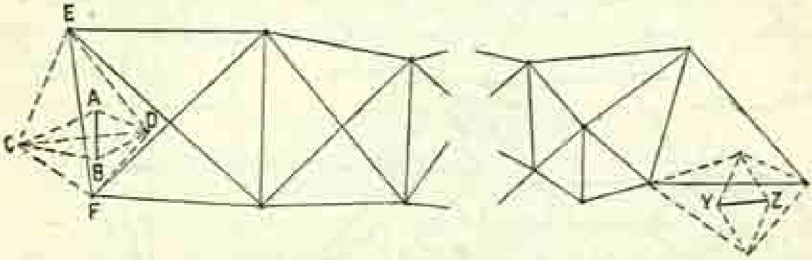


FIG. 29. Theodolite triangulation. *AB* original base, *YZ* base of verification. Dotted lines build up to the principal triangulation.

The size of triangles in a primary triangulation varies a good deal. In Britain the average length was about 35 miles a side, but one triangle had sides each exceeding 100 miles in length, the apices being respectively in England, Wales, and Ireland. In India sides varied from 11 to 30 miles, the longer ones in the hilly regions where there is good intervisibility. By using illuminated beacons much work is done at night.

The base-line is rarely long enough or suitably situated to form one side of a major triangle, so triangles are set out to subsidiary stations to build up to the main triangulation, as shown in Fig. 29. *AB* is the measured base, *CD* stations used to build up to the main triangulation on *EF*. One or more bases such as *YZ* are subsequently measured and their lengths compared with those computed from the triangulation as a check on accuracy. Lengths in the first triangulation of Britain were computed on a mean value, as found between the Loch Foyle and Salisbury Plain bases, 350 miles apart. Several check bases were employed to make sure that no important errors had crept in.

To commence triangulation the theodolite is set up and accurately centred by plumb-line over one end of the base *A*, as seen in Fig. 29. The telescope is directed first on B and then on C. The difference in pointer readings gives the angle BAC. By setting up at B and C in turn the remaining angles of the triangle are measured. Since the length of the base AB is known, the lengths of the sides AC and BC can then be calculated. They can be used in conjunction

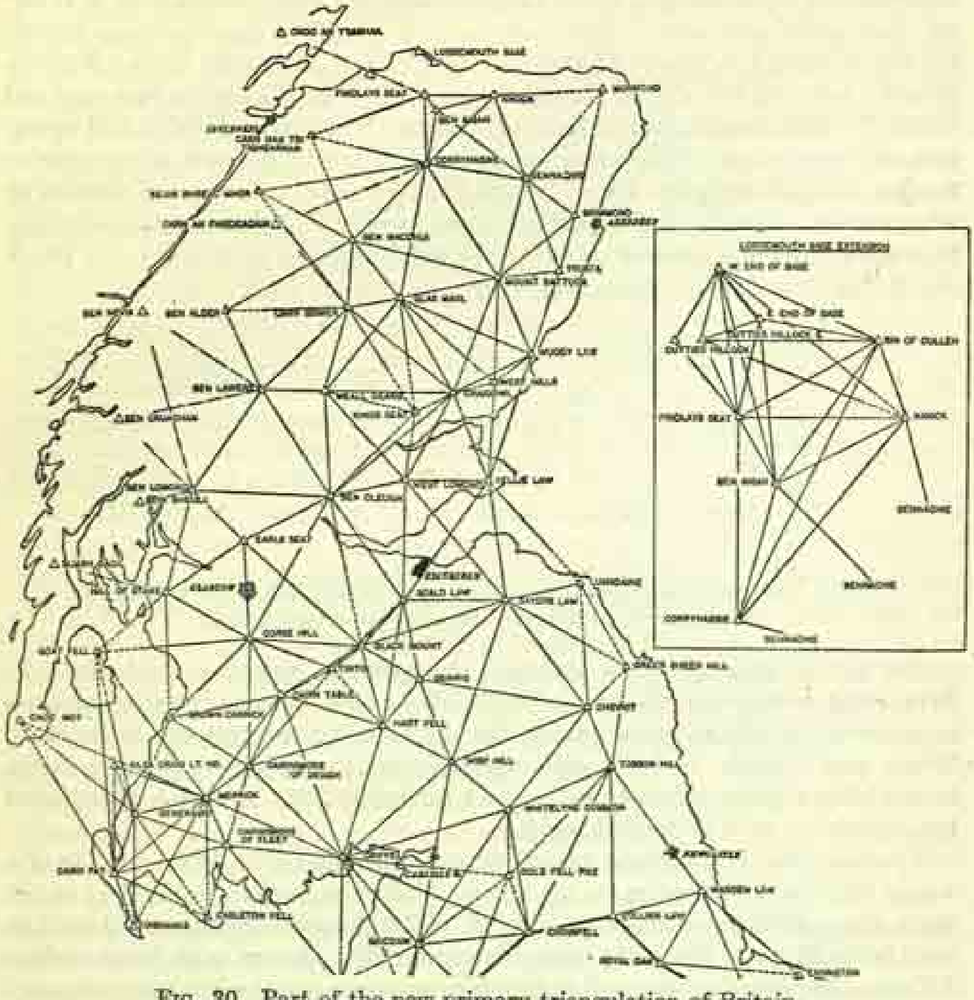


FIG. 30. Part of the new primary triangulation of Britain.
(*By permission of the Controller of H.M. Stationery Office.*)

with angle measurements to solve triangles CAD and CBD and so provide two results which should be identical for the length of CD. The work is built up on these lines to the main system of triangles, which may completely cover an area if of limited extent like Britain, or form chains of triangles or interlacing polygons at right angles to each other across a country the size of India. In the latter case the intervening space is filled with secondary triangles of smaller size, their accuracy being checked by contact with points fixed in the primary triangulation. The sites of all trigonometrical stations should be marked in some permanent way on the ground. In Britain the primary triangles were subdivided into secondary triangles about 5 miles a side by the use of a 12-inch theodolite, and these in turn with smaller theodolites into tertiary triangles of 1¼ miles a side. Consequently the position of more than 150,000 points was accurately determined, the work taking about seventy years to complete. Fig. 30 shows part of the new primary triangulation of Great Britain, including the Lossiemouth base extension on an enlarged scale. The place of this triangulation in the present survey of Britain is described in Chapter III, § 1.

Without going into instrumental details, it may be said that every possible check is taken in the primary triangulation to reduce probable error in a triangle to less than 1 second, while in tertiary triangles error may amount to 20 seconds without rejection.

4. Defining the Positions

One point should be made clear, especially after the space already devoted to graphic triangulation. In the latter, points are fixed on the plan by drawing intersecting rays from field data, or by direct transfer to paper in the field. In trigonometrical survey this is not so. A higher degree of accuracy is aimed at. Certain earth dimensions have to be adopted as a basis of calculation in the solution of the theodolite triangulation, for the precise shape and size of the earth are still a matter of uncertainty despite elaborate investigation by determining astronomically the position on the earth of pairs of points, and then measuring the length of arc between them. It is at least common knowledge that the earth is not truly spherical, and that the polar diameter is shorter than the equatorial. If the earth were a sphere of known radius, the distance between any pair of points whose positions had been determined astronomically would be a matter of elementary calculation. As early as the middle of the eighteenth century it was established that for the northern hemisphere, the farther north one went, the longer became the length of a degree of latitude, and hence the flatter the earth.

In an original survey, not already governed by a primary triangulation, it is obviously necessary to know just where on the earth's non-spherical surface the triangulation has taken place. This means that an initial point must be fixed in terms of latitude and longitude, and that the direction or azimuth of one side of one of the triangles must be determined. The first pins the triangulation to the earth at one point, but leaves it free to swing round. Azimuth determines orientation. Neither is complete without the other.

Once an initial latitude and longitude are known, and azimuth determined, the triangles can be solved, based on the assumed earth shape and dimensions, and the positions of all points relative to each other are fixed. The draughtsman can then plot these either from data in the form of rectangular co-ordinates on the chosen projection, or from geographical coordinates, namely, latitude and longitude, on any desired scale.

5. Azimuth, Latitude, and Longitude

Nothing more than the general ideas involved in the determination of azimuth, latitude, and longitude are discussed in this section. Furthermore, the easiest methods to describe and understand are not necessarily those most usually employed, nor the most accurate to practise. Details of these are set out in the *Text Book of Topographical Surveying*, and to this the student who wishes to go farther is referred. He will find such terms as apparent, mean, and sidereal time fully explained, and examples of numerous calculations involving the *Nautical Almanac*, a statistical compendium which is part of the outfit of field astronomy.

With the above qualifications in mind, consider first the principle of one method by which *azimuth* of a station B could be determined from an initial station A. The main problem is to determine true north at station A, and then to measure the angle between this and station B. The North Star or Polaris is approximately due north as seen from any point at any time of year in the north hemisphere. Observation will show that as the earth rotates on its axis, all stars appear to revolve in circles round Polaris. Some are above the horizon the whole time and are called circumpolar stars. Others dip below the horizon on their courses.

To ascertain azimuth, the theodolite is set up at station A and directed on station B, and the horizontal circle is read. Then as a circumpolar star moves round the pole to a position on its downward path, it is centred in the theodolite telescope by swinging the telescope along the horizontal circle to X', as seen in Fig. 31, and tilting it an amount $X'AX$. The vertical circle is clamped to keep the telescope at that angle. Some hours later, when the star is rising, the telescope is again swung round and the observer waits till the star appears at Y in the centre of his field. Its height above the horizon is the same as at X, because the vertical circle has remained clamped. The horizontal swing $X'AY'$ is read.

Fig. 31 helps to show what has happened. A line joining X and Y is in reality a chord across a circle with the heavenly or celestial pole as centre. Thus a line bisecting this chord from the observer's position passes through the pole and is a true north line. The only angles necessary to determine the direction of B from A have been read on the horizontal circle, namely, angles BAX' and $X'AY'$, though the telescope was tilted to centre on X and Y. The point N^1 on the horizontal circle corresponds to N. The direction of B from A differs from true north by the angle $N'AB$.

It is obvious that a second method to determine azimuth is to ascertain with the theodolite when a star or the sun reaches its maximum altitude, for reference to Fig. 31 shows that this is the observer's true north. The angle $N'AB$ can be observed and again gives the azimuth of B from A. It is difficult to determine the exact point when a star is at maximum altitude, and choice must be made so that any slight error will have least effect, as of a star making a wide sweep across the sky, rather than one which moves in a small circle about Polaris.

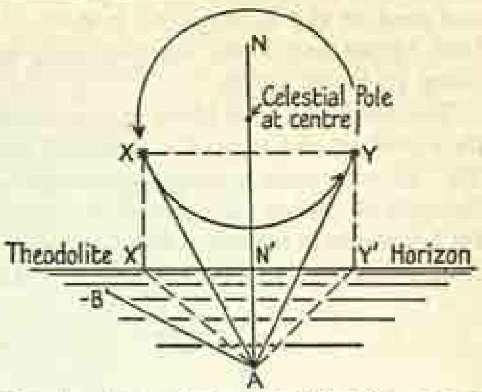


FIG. 31. Determination of direction or azimuth by circumpolar star. In the south hemisphere apparent rotation about the South Pole is reversed.

The *latitude* of a place is defined as its angular distance from the plane of the equator measured at the earth's centre. In Fig. 32 (a) this is angle x. But this angle is the same in magnitude as y, the angle between the horizon of the observer at A and the celestial or heavenly pole. The latter is so distant that in the diagram it appears in a line parallel to the earth's polar axis produced.

In determining azimuth, a method was described of finding a true north line through the observer's position. A vertical plane through this line passes through the celestial pole, but does not define its precise position or elevation. Reference to Fig. 31 shows that the celestial pole will be at the centre of the circle, midway between lowest and highest points, or lower and upper culminations or transits, as these are called, of the circumpolar star. The lower culmination can be found with the theodolite by following the movement of the star in the telescope until it ceases to dip and begins to rise, evidenced by the need to cease depressing the telescope. The upper culmination can be found in a similar way. Bisection of the angle between lower and upper culminations, corrected for refraction, gives the position of the celestial pole and hence the observer's latitude. This is shown diagrammatically in Fig. 32 (b) as angle y.

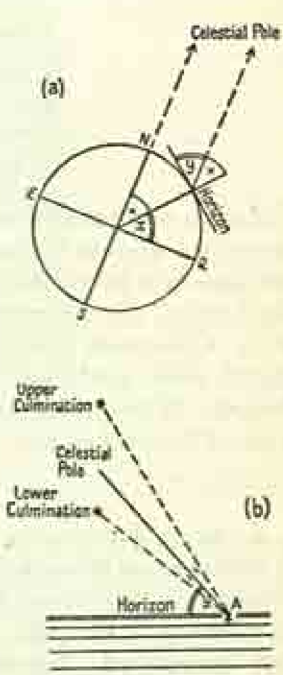


FIG. 32. Determination of latitude shown in diagrammatic form.

If the observer's longitude is known, the time of culmination can be predicted and read at the appropriate instant. Tables render it unnecessary to observe both upper and lower culminations, and this is often impossible since they occur 12 hours apart.

The *longitude* of a place is the angular measurement between the plane of its meridian and that of a standard meridian, usually of Greenwich. Suppose Fig. 33 represents a polar view of the earth. Then the plane of the meridian through A makes an angle of 90° with the plane of the Greenwich meridian. Its longitude is therefore 90°. Angles are measured in degrees east and west of Greenwich round to 180°, which is neither east nor west.

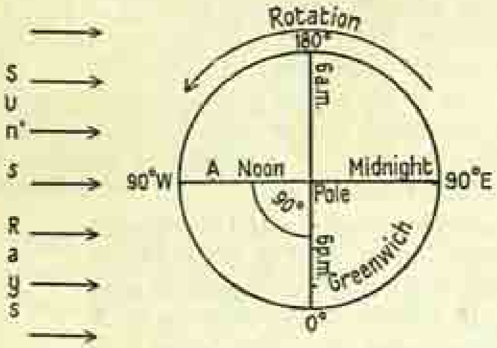


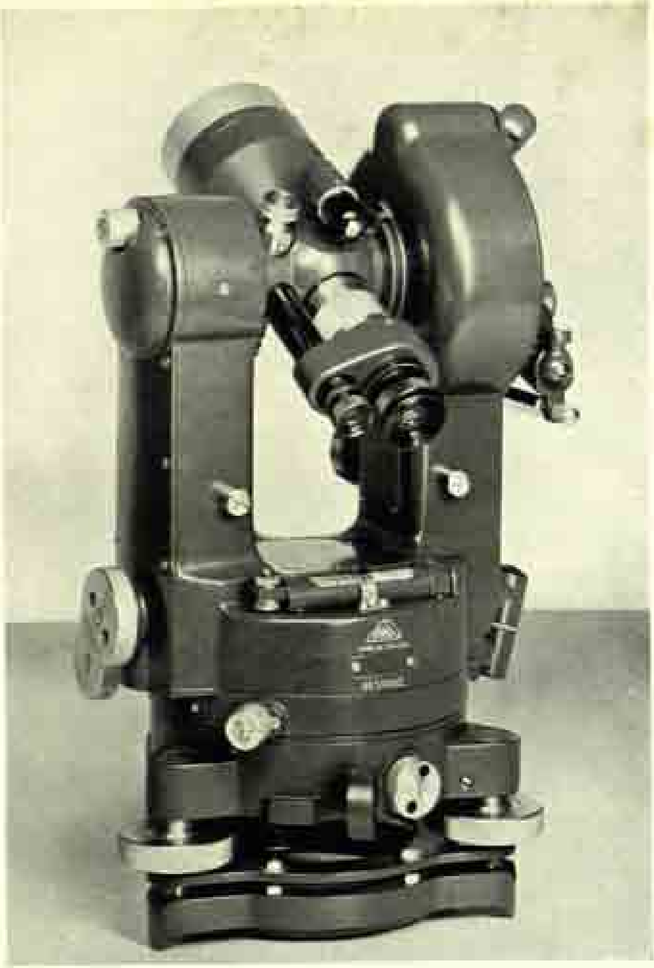
Fig. 33. Determination of longitude.

As the earth makes one rotation on its axis each 24 hours, longitude can be expressed also in terms of time. The place A in Fig. 33 is one-quarter of a rotation or 6 hours behind Greenwich. Thus if Greenwich time and local time are known, the difference between them can be translated into terms of longitude. Greenwich time may be taken from a chronometer checked by wireless signal, while local time can be determined by ascertaining the time of the sun's transit. If the latter occurs when it is after noon at Greenwich, the place is west of Greenwich, and if before Greenwich noon the place is east.

6. Time

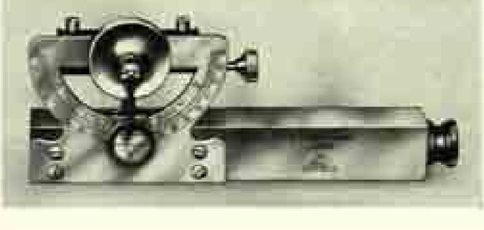
So much depends on an understanding of *Time* in accurate surveying that it merits some space here. Consider first Fig. 34. The earth is represented as rotating on its axis and moving forward on its orbit simultaneously. Point A is in transit with the sun. By the time the same point is again in transit, one solar day has elapsed. The earth has made one complete rotation as seen from the sun, but owing to its movement along its orbit, it has made more than one rotation in space, actually one rotation plus angle XPA. The net result is that although in one year the earth makes $365\frac{1}{4}$ rotations as seen from the sun, it makes $366\frac{1}{4}$ rotations in space.

Although A rotates slightly more than 360° each solar day, actually about



Theodolite

Level



Abney Level

VI. Surveying Instruments.

By permission of Messrs. Hilger & Watts, Ltd.

361°, the two factors which must be taken into account in converting time to degrees and vice versa are (*a*) the interval of time between sun transit and sun transit, and (*b*) the degree of rotation as judged by the sun, namely, 360°.

Next consider Fig. 35. The earth's orbit is elliptical, and the sun is not at its centre. The earth rotates at a constant speed and also moves forward on its orbit at a constant speed. Consequently the angular speed varies at different parts of the orbit, for example, angle O is greater than angle P. The result is that the time interval between sun transits varies. It is greater between

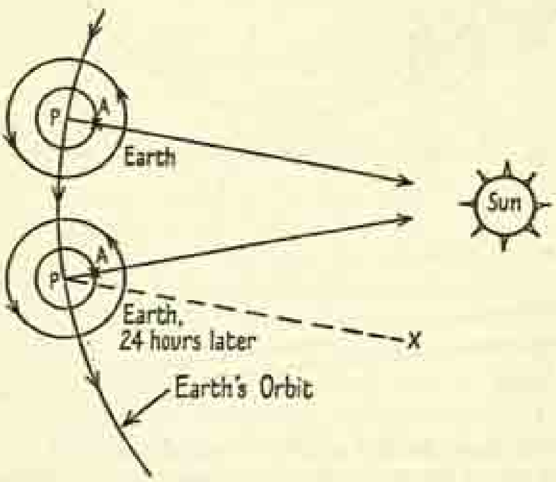


FIG. 34. Diagram to illustrate effect of earth's rotation about its axis and revolution about the sun.

positions 1 and 2 than between positions 3 and 4. This means that the sun is not an ideal time-keeper and only provides us with *apparent time*. Irregularity in the length of the solar day is further introduced by the slope of the earth's axis. The mean interval between transits is 24 hours, and this time, to which clocks and watches are regulated, is termed *mean time*. The difference between mean time and apparent time is termed the *equation of time*, and this varies between about 16 minutes positive and negative.

Fig. 36 shows that in relation to the stars things are different. Since even the nearest star is at an almost infinite distance from the earth, lines marking its direction are virtually parallel despite movement of the earth on its orbit.

Part of this diagram is enlarged in Fig. 37. By comparing this with Fig. 34 it will be seen that the time interval between transits of the star will be slightly less than between transits of the sun. Time taken from the stars is called *sidereal time*, and each sidereal day is shorter than a solar day. In a whole year there are 366¼ sidereal days, for any point on the earth, such as A, will rotate once more as seen from the star, than as seen from the sun.

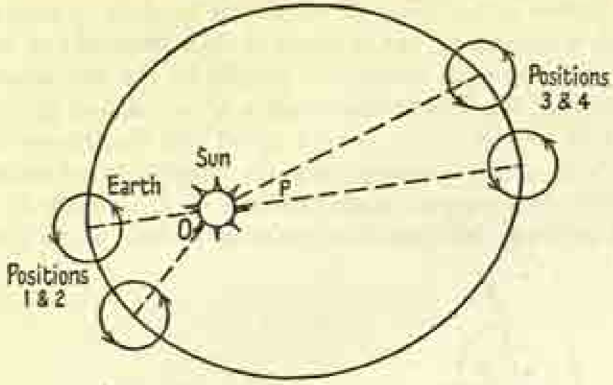


Fig. 35. Diagram to illustrate effect of earth's elliptical orbit.

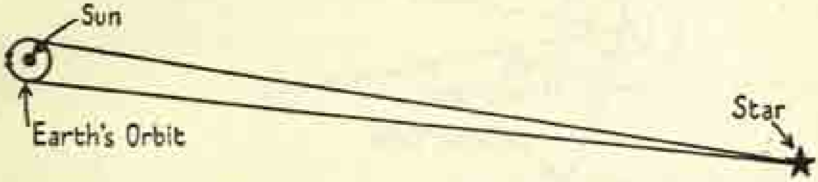


Fig. 36. Diagram to illustrate why transit directions in Fig. 37 are shown by parallel lines. Based on the size of the earth's orbit, the nearest star should be 5,000 times as far away as in this diagram. This would make the lines from the star to the extremities of the earth's orbit virtually parallel.

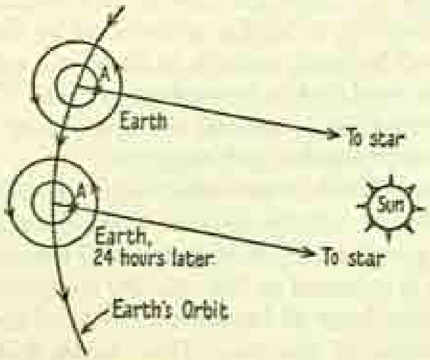


Fig. 37. Diagram to illustrate transits of a star at an infinite distance.

If, in determination of longitude, apparent time is taken from the sun, it can be converted into mean time by reference to the *Nautical Almanac*, which sets out the value of the equation of time for all days in the year. Comparison with Greenwich mean time then shows the longitude. Since much astronomical observation is based on the stars, the *Nautical Almanac* also sets out information enabling conversions to be made from mean to sidereal time and vice versa. It is unimportant which time is used in the determination of longitude, but evidently the times of Greenwich and of the place in question must be of the same kind.

7. Theodolite Traverse

Finally, to return once more to the theodolite, for it is used not only in triangulation but also as a traverse instrument where triangulation is extremely difficult or expensive, as in forested country or in flat tropical grasslands. It may also be used to run traverses between trigonometrical points. Traverse stations should be as far apart as possible, say, a mile or so, distances being measured by tape or chain. Each time the theodolite is set up, the telescope is directed on the previous station, the horizontal angle noted, and then the telescope is swung clockwise till it points at the next station to be occupied. The difference in the two readings gives the angular change in the direction of the traverse at the station occupied. A check may be taken every fifty or sixty legs by testing azimuths astronomically. If the traverse closes, a further check is provided. On the Ohio River Survey, commenced in 1911 for maps to a scale of 500 feet to the inch, a control base was run in duplicate along each bank. A steel tape 200 feet long was used for linear measurements and the two traverses closed every 10 miles. The error of closure was not more than 1 in 20,000. On traverses connecting triangulation points of the Topographical Survey of Cincinnati, using the theodolite and a 150-feet tape, the average closing error was 1 in 3,000.

CHAPTER NINE

DETERMINATION OF ALTITUDE

So far, survey has been treated very largely as though concerned with a plane surface. Length and breadth have been taken into account, but the third dimension, height, has received no more than passing reference. The only steps taken in connexion with altitude have aimed at its elimination in the finished map. In so far as the map has to be shown in two dimensions on paper, slope must still be eliminated and all distances recorded as though measured on the level, but this does not preclude determination of height and its representation in some form upon the map. A map which fails to show relief fails to show one of the most significant features of the earth's surface.

Determination of altitude is the final surveying process requiring explanation, but it will be appreciated that in map-making the surveyor works in an order quite different from that employed in this elementary account. He starts with triangulation, follows this by determination of height, and thereafter deals with topographical and detail surveying by appropriate methods as described in previous chapters.

1. Datum Line

Before relief can be shown, altitude must be determined, and altitude of any spot can only be expressed with reference to some other spot, line, or plane as datum. The most significant level on the earth is sea-level, and this forms a suitable reference. Some surveys adopt mean high-water level, others, as of Britain and India, take mean sea-level as determined by tide gauges over a period of years, in the case of these countries at Newlyn and Karachi respectively. All recorded heights are then relative to the adopted initial level.

2. Use of Barometer and Hypsometer

Approximate differences in height can be determined with a *Barometer*. The higher one ascends, the lower becomes the atmospheric pressure. If a barometer at mean sea-level is read at the same time as one on a mountain top, the difference in pressure will indicate the height of the mountain, a difference in pressure of 1 inch corresponding to a vertical difference of about 1,133 feet, or 30 millibars to 1,000 feet. There are various adjustments to make in the readings, as for temperature and latitude, which are set out in appropriate tables. Common sense is essential also, because pressure varies from place to place at a given altitude and sometimes fairly rapidly in a single place. The best conditions would obtain in settled weather, with simultaneous readings. If these are impossible, a barometer can be carried from the base station to the required station, its reading noted, and an allowance made for any change in pressure which has occurred at the base on return. In some circumstances the barometer is useful to determine intermediate heights between pairs of stations whose altitude is already known. Under good conditions errors may not exceed 10 to 20 feet.

The *Hypsometer* also depends upon differences in pressure, but this time by the effect pressure has upon boiling-point. The lower the pressure, the lower the temperature at which water boils. Consequently the apparatus consists of a thermometer and vessel in which water is boiled. The temperature of the steam is recorded, as it is more constant than that of water which varies with impurities as well as with pressure. Again, tables which take into account various conditions are necessary. But since a difference of 1° F. corresponds to a difference of about 500 feet, accuracy is almost impossible. Eight determinations to ascertain the height of Lake Tanganyika showed a range of

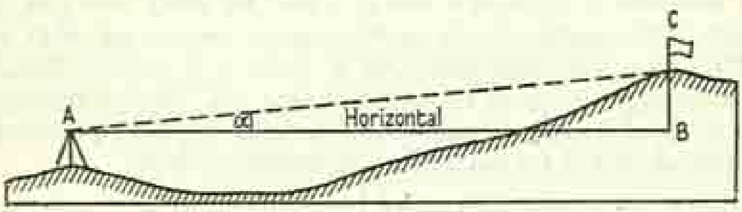


Fig. 38. Determination of relative altitude by theodolite.

328 feet, and the mean was probably 170 feet too high. The hypsometer may have been a more convenient instrument to carry round than the mercury barometer, but it is inconvenient as compared with the modern aneroid barometer, an example of which, scaled to read changes of altitude in feet as well as changes in pressure, is shown in Plate V, facing p. 48.

3. Theodolite or Trigonometrical Levelling

In the description of the theodolite mention was made of the vertical circle for recording angles of elevation or depression. If the theodolite is set up at a station *A* of known altitude, as in Fig. 38, a sight can be taken on any other station *C* and the vertical angle read. The difference in altitude is calculated from this angle and the distance away of the other station, which is represented by the horizontal line *AB*. The distance from *A* to *B* would be shown by the map or recorded in the horizontal triangulation. Allowance must be made for the height of the theodolite tripod, and if possible check readings should be taken from *C* towards *A*. Refraction, which is at a minimum around midday, tends to make readings unreliable when taken from one end only. Another check is possible by reading on the same summit from various stations. The heights of many inaccessible peaks in mountainous regions have to be determined by this method.

4. The Alidade

The telescopic alidade, shown in Plate V, can be used in much the same way as the theodolite to measure vertical angles. It is necessary to ensure that the plane-table, with which the instrument is used especially in the United States, is properly levelled. When the plane-tabler is fixing his position by resection from known points, he can at the same time determine his height, if the heights of the known points are shown on his sheet. This will normally be so if he is filling in detail in a systematic survey. He measures the angle of depression or elevation of the station, determines its distance from the scale of the map, and hence calculates the elevation of the site occupied.

The amount of rise or fall is known as the vertical interval, and the horizontal distance as the horizontal equivalent. It will be found that when the angle of elevation measures 1° there is a rise of 1 foot for every 57·3 feet measured horizontally. This relationship is approximately true for all other angles up to 20°. Thus when elevation measures 5° there is a rise of 5 feet for every 57·3 feet distance, or a rise of 1 foot in 57·3 feet ÷ 5. The relationship can be expressed in the following forms, using *HE* for horizontal equivalent, *VI* for vertical interval, and *D* for the number of degrees of slope:

$$HE = \frac{VI \times 57{\cdot}3}{D},$$

or, rearranged,

$$VI = \frac{HE \times D}{57{\cdot}3}.$$

It should be noted that the formula presumes that *VI* and *HE* are both in the same units of measurement, such as feet, yards, or metres. If not, as may often happen in practice, due allowance must be made in the calculation.

The plane-tabler will usually have a diagram or ready reckoner from which he can find vertical interval given degree of slope and horizontal equivalent. For rough work done mentally 57·3 is often counted as 60, but this introduces an error of nearly 5 per cent. If the *VI* is in feet and *HE* in yards, the two forms then become respectively

$$HE = \frac{VI \times 20}{D},$$

and

$$VI = \frac{HE \times D}{20}.$$

5. The Clinometer

There are various other instruments designed to measure vertical angles, collectively known as clinometers. Only two patterns need be referred to.

The first is very simple and effective and is used with the plane-table. It is known as the Indian Clinometer and is shown in Plate V. In effect it is a simple sight rule, but instead of having two slotted sights, the near one has a pin-hole sight, while a scale of degrees is marked along the slot of the remote sight. Thus when the table has been levelled, a station can be sighted through the pin-hole and its angle of elevation or depression read from its position in the slot sight. The zero mark is at the same height as the pin-hole. The degree scale only occupies one side of the slot sight. On the other is what is known as a tangent scale, that is, a scale which shows vertical interval divided by horizontal equivalent. Thus opposite 1° on the degree scale would be 0·017, that is, 1÷57·3. The surveyor then simply multiplies the horizontal distance by the tangent scale reading, and obtains his vertical interval. If his tangent scale reading is 0·041 and the object is distant 1,000 yards, the *VI* is 0·041× 1,000, namely, 41 yards or 123 feet. Allowance must be made for the height of the table if the object is very near. The maximum distance for observation is about 3 miles.

The second pattern of clinometer which might be mentioned is the Abney level, seen in Plate VI. It consists of a small telescope with semicircular protractor. A pointer with spirit-level attached is hinged to move round the protractor. An object is sighted in the telescope and unless on a level with the observer, the bubble is thrown out of centre. It is brought back to centre by turning a screw, still keeping the object in sight. When the bubble comes to the middle of its run, it can be seen in the telescope. The pointer then reveals how much the telescope was tilted from the horizontal, and hence the degree of elevation or depression from observer to station is read and vertical interval calculated.

6. Spirit-levelling

By far the most accurate way to determine height is with an instrument known as a spirit-level or simply a level. It consists essentially of a long spirit-level mounted on a telescope which when properly adjusted swings in a horizontal plane. The instrument is used in connexion with a staff or staves. Of these, there are two principal patterns. The first, used mainly in England and India, is 10–14 feet long, and is graduated from the base upwards, in feet, tenths, and hundredths of a foot. Alternate hundredths are filled in with black. Readings are taken on the staff by the observer through the telescope. The other pattern, used largely in the United States, has a movable circular target with lines marked upon it. The target is raised or lowered by the assistant until the observer, looking through the telescope, indicates that it is at the desired height. The actual reading, which shows the height of the target, is then made by the assistant, who is aided by vernier scale reading to thousandths of a foot. The staff may be graduated alternatively in metres subdivided to centimetres or 2-millimetre divisions. (An accurate level is shown in Plate VI).

The most accurate levelling is done with two staves, usually along roads. One is placed in front of the level, and one the same distance behind, as shown by *A* and *B* in Fig. 39. The distances are never great. The maximum length of sight allowed in the precise levelling of New York City was 150 metres. The Ordnance Survey records 50 yards as a maximum. It is apparent from the figure that the reading on staff *A* and staff *B* will differ by the same amount as the height of the ground differs on which they are resting. This is the figure required. Having ascertained this, the level is moved to position 2 and staff *A* to position *C*. Thus the difference in level between *B* and *C* is measured,

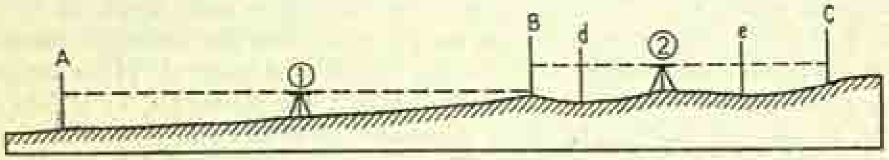


FIG. 39. Levelling with a spirit-level and a pair of staves.

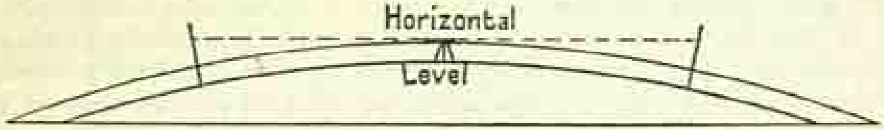


FIG. 40. Elimination of earth curvature in levelling.

and from this and the first result the difference between *A* and *C* can be ascertained. Any slight variations of slope between instrument and staff, as at *d* and *e*, may be obtained by a single reading, comparing, say, the reading on *d* with that on *B*, and of *e* with that on *C*. Any slight errors on *d* and *e* are not carried forward and do not accumulate.

There is a twofold purpose in using two equidistant staves. In the first place, instrumental errors cancel themselves out, for should the telescope be reading slightly higher or lower than true horizontal, it will give readings equally too high or too low on both staves. On subtraction, this error is eliminated. The second purpose is to cancel apparent differences of altitude due to refraction and earth curvature. The latter, though the lesser source of trouble, amounts to 8 inches in a mile, so error far too serious for precise work would accumulate. The effect of curvature is seen in exaggerated form in Fig. 40. Readings are too high on both staves, the amount, on level ground, depending on distance from the spirit-level. When staves are equidistant, the excess due to curvature is automatically cancelled on subtracting one reading from the other. The figure brings out the difference in meaning between the words horizontal and level. The work in hand is concerned with the latter, which, if the earth is regarded as spherical, follows the curvature at a constant distance from the centre.

The degree of accuracy can be checked most easily by levelling a closed traverse, as the altitude should be the same on return as on setting out. In New York one traverse of 74 miles showed a closing error of 0·012 feet. An error of 1 millimetre in a kilometre indicates a very high degree of precision, while 5 millimetres error in a kilometre is regarded as below precision standard. It is obvious that changes of level of a few inches in an area can be detected and measured. They are commonly associated with earthquakes or subsidence due to mining.

By connecting through to the datum line, the precise height of various spots can be determined. In Britain there is a network of precise levels about 25 miles apart, marked with concealed fundamental bench marks based on solid rock. Second-class bench marks, discernible on relatively permanent structures and buildings in the form of broad arrows, are about a mile apart. Third-class bench marks take the form of copper rivets let into horizontal surfaces about 400 yards apart. As in theodolite triangulation, so in levelling, the utmost precision is attached to the primary work. Longer sights are permitted for the secondary work, while for the tertiary fewer readings are taken on the staves, and they are placed only approximately equidistant from the spirit-level.

As bench marks are shown on all fairly large-scale official maps, and their height is either given or may be looked up in bench-mark lists, any route can be levelled or land contoured relative to the national datum line, simply by connecting up with the nearest bench mark. Connexion with more than one provides a check. And in all surveying, every measurement *must* be checked either by repetition or by alternative path.

CHAPTER TEN

REPRESENTATION OF RELIEF

MOST features are readily shown on maps either by drawing them to scale or arbitrarily out of scale, by characteristic drawings, or by conventional signs. Relief offers a peculiar problem because it involves the third dimension. Saxton and other early cartographers drew hills in profile; and though useful in its day, the method had obvious disadvantages and limitations. With improved means of determining altitude, the possibilities provided by colour-printing, and a good deal of experiment, new methods have entirely superseded the old, as may be seen by reference to Plates II, III, IV and VII. Present methods deserve special notice and may be summarized under the following headings:

1. Spot Heights.
2. Contours.
3. Form Lines.
4. Layer Colours.
5. Hachures.
6. Hill Shading.
7. Shadow.

The first two are exact methods, the remainder pictorial.

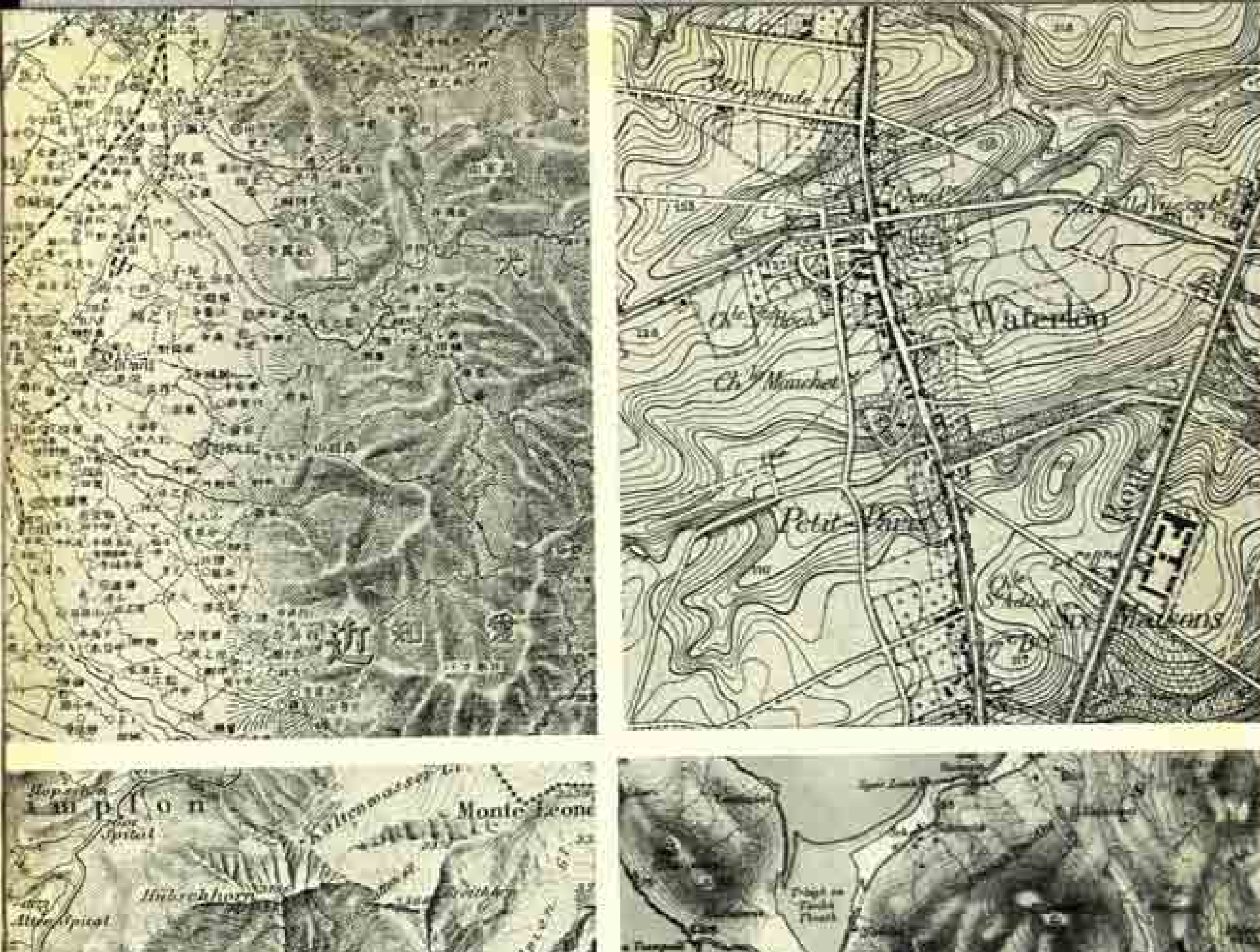
1. SPOT HEIGHTS

From the previous description it is evident that the altitude of any number of points can be determined and their position and altitude marked on the map. Alone, they fail to give any general idea of relief, though helpful in revealing the heights of hill summits or points along a road. On large-scale plans they are frequently the only indication of relief.

2. CONTOURS AND CONTOURING

There is much misconception about contours and contouring, probably owing to the way the matter is first presented. Early in life one receives a piece of paper liberally sprinkled with dots and numbers which are said to be spot heights. A perplexing half-hour ensues steering a pencil with high numbers to left and low ones to right, or vice versa. The result is said to be a contoured map, and various definitions are evolved about imaginary lines at a constant height above sea-level. Consequently people grow up with the idea that contours are drawn this way. The only case where the method applies is in drawing under-water contours from soundings. Incidentally, the frequent reference to imaginary lines in cartography is somewhat curious, since they are usually no more imaginary than the lines which go to make up the diagrams in this book.

The method used in contouring depends to a great extent on the scale of the



University Press, Oxford

VII. METHODS OF SHOWING RELIEF.

Top left, Japanese map 1/200,000. *Top right*, Belgian map 1/40,000. *Bottom left*, Swiss map 1/100,000. *Bottom right*, ½ inch to 1 mile O.S. map of South Harris. *With the sanction of the Controller of H.M. Stationery Office.*

work. Consider first large-scale engineers' plans, and suppose that from precise levelling the height of a given spot is known. The surveyor sets up his level near by so that a rod resting on the known spot can be seen. A target or other indicator is moved up or down the rod till it comes into the telescope sight. The assistant then moves forward a reasonable distance. In response to signals he moves up or down slope until the indicator on the rod again comes into the telescope sight. This means that the foot of the rod is on the same level as before. The position is marked on the ground with a peg. The assistant moves forward again, and the process is repeated. As often as necessary, the surveyor moves the level forward. The position of the pegs is marked on the map by traverse plane-tabling, or by some other method already described, as by taking into account direction and distance. For this purpose, distance may be measured with a stadia rod as described in the section on plane-tabling, or by offsets from chaining lines. The contour is drawn by passing a line responsive to intervening terrain through the peg marks on the map. Other contours are similarly run at chosen vertical intervals.

The work is obviously fairly slow and tedious, but by a discriminating choice of peg stations, as on spurs and in valleys, much time is saved without sacrificing accuracy. This will be realized if the hand is placed flat on the table, fingers outspread. The only marks essential to contouring the fingers or spurs, table as datum, would be near the tips and bases of the fingers. Comparatively few levelled points would enable the back of the hand, representing the flattish hill-masses, to be contoured, since the drawing is done with the area in view.

As the surveys of Britain were done on a large scale, the main contours were accurately levelled. But practically all contouring on maps made initially on a small scale, and hence that on the national maps of most countries, is drawn in on the plane-table sheet as work proceeds. Heights are thrown to distant points of detail or brought in to the observer's position from points of known height. All are checked by observation from at least two places. The India pattern clinometer is usual in British work, and the telescopic alidade is standard for American. The plane-tabler develops an eye for sketching in the contours between his spot heights, always *with the land before him*, but it is obvious that their accuracy of position cannot compare with that of other surface detail.

It is remarkable that contouring as a means of showing relief was little known or used until a century and a half ago. Various people apparently fell on the idea, as they described their experience, and developed it independently in Europe and the United States.

As an exercise in contouring, rays may be drawn from a station outward in the direction of significant slopes, as along spurs and valleys. Having measured a particular slope in degrees, this may be converted into terms of rise or fall from tables or from the formula $HE = VI \times 57{\cdot}3/D$. If the station is at 1,000 feet, the ground sloping away in one direction at 5°, and it is desired to contour at intervals of 50 feet, this gives $HE = 50 \text{ ft.} \times 57 \cdot 3/5 = 573$ feet or 191 yards. By scaling along the ray lengths of 191 yards outward from the station, the position of the contours 950 feet, 900 feet, 850 feet, and so on, may be marked, so long as slope is constant. Where slope changes, it is necessary to set up again, resect for position, and measure the new slope. After enough contour marks have been made, and with the landscape as guide, one contour after another may be sketched in.

It is evident that something of the same sort would be possible with the aneroid barometer, by walking along significant slopes, and stopping to mark the point on the map at which the pointer indicated a fall or rise of a chosen vertical interval. The aneroid might be the most convenient instrument to use in a deeply wooded gorge. There is little error when working between stations of known height.

In the *Textbook of Topographical Surveying* the following generalizations are made as to methods by which contours would be determined so far as scale is concerned, though of course the purpose of the map, as well as the time and money available, would be taken into account.

Scale: Inches to the mile	*Method of contouring*
Exceeding 4	Level, theodolite, or water-level.
„ 2	Water-level or clinometer.
„ 1	Water-level, clinometer, or aneroid barometer.
„ ½	Clinometer, aneroid barometer, or sketch-contours by eye.
¼ and smaller	Sketch-contours by eye.

Where contours are determined by level or theodolite, detail is surveyed before contouring is commenced. Where the contours are approximate and put in by the other instruments or by eye, contouring is carried out during the survey of detail. Methods of contouring in connexion with air-photo survey have already been mentioned, and need not be repeated.

3. Form Lines

At times contours are drawn in by eye when a surveyor has few or no fixed heights to control the work. Such lines are meant to show the form of the land, and are called form lines. The degree of control which differentiates between form lines and contours is laid down in the terms of each particular survey.

In Britain, contours were accurately levelled over most of the country at 50 feet, 100 feet, 200 feet, &c. to 1,000 feet, and then upwards at intervals of 250 feet. On the present 1-inch maps, the contour interval is almost always 50 feet, this being achieved by the addition of sketched contours. These are based on a very dense net of levelling, and on hill sketches made with great care for the original hachuring. They therefore rest on a surer foundation than the original contours of most other national maps. In any case it should be remembered that contours are used not so much to show the height of a particular spot, as to give a sound impression of relief. On the present 6-inch maps instrumental and sketched contours are differentiated, though as a rule only the former are shown. On the new 6-inch maps contours will probably be at 25-feet intervals, all instrumentally surveyed.

On small-scale maps, such as one-quarter inch to the mile, instrumental contouring would largely be a waste of time. Form lines are as accurate a representation of relief as is consistent with small scales.

4. Layer Colours

One way to aid visual interpretation of relief is to colour between contours. This system, known as layer colouring, is therefore not an independent system, but is inseparably linked with contours. Since many more contours are used than the number of colours which could be conveniently and economically printed upon a map, one colour often has to cover the same range of altitude as several contours. Certain detail tends to be obscured, especially on higher ground where darker colours are used. Fortunately it is here that there is usually least of human activity to record. Probably because layer colouring was developed in temperate lands, lowland is shown in greens, highland in browns. This convention would prove less graphic in certain desert regions where lowlands are actually brown and the highlands show a little green, and less convenient in areas like Peru, where most indications of human activity would have to be printed over the dark browns of the highlands, and little on the desert lowlands. There are also extensive flattish plateaux in areas like South Africa and Tibet that appear a monotonous brown against which features in black do not show up clearly.

5. Hachures

Another way to aid visualization of relief is by using hachures. These are short lines drawn down the slope of the land, an amplification of the hairy caterpillars of a century and a half ago. The lines are thickest and most crowded where slopes are steep, thin and far apart where land is fairly flat. Areas which are quite flat, whether highland or lowland, remain blank. Hachuring is rarely appreciated at first sight, but familiarity develops a certain admiration of the method. The earliest Ordnance Survey maps of Britain were rather crowded with hachures but had no contours. They had spot heights, however, and many people favoured that combination. On many modern British maps hachuring in a subdued brown or purple is often combined with contours and spot heights. Relief on some European maps, notably of Switzerland, is excellently portrayed by hachures, with or without contours. Occasionally hachuring is seen which runs along the slope instead of down it. The work requires considerable skill both in the field and in the office, and is consequently expensive. There is nothing absolute about it, but features which are sometimes missed by contours, such as small gullies and knolls, are well brought out. The flatter land remains clear and so insertion of cultural detail, greatest on the flatter land, is not obscured. Hachuring has been used hardly at all in America, but here important small features are sometimes picked up by a slight deviation of contour from its correct level.

6. Hill Shading

Hill shading, which is sometimes called stippling, is executed with a stubbly brush. The aim is to bring out relief as it would be seen on a relief model lighted from above. The flat parts appear light, the slopes rather darker.

7. Shadow or Oblique Hill Shading

Occasionally a shadow effect is obtained by stippling a map to represent relief as it would appear if the area were lighted from the north-west corner. This is the direction from which light actually comes to a map which has north at the top, as seen by a person examining the map, because his body blocks the light from the south, and his right hand that from the east. The effect is not always sound, because an escarpment facing the north-west is not brought out at all, though one facing the south-east is seen by the representation of shadow.

The whole difficulty of showing relief by a uniform method which would render comparison of areas easy is that a method ideal for a region of high relief is unsuited to one of low relief. Thus, whenever a single method or combination of methods is decided upon in the production of maps in a national survey, some sort of compromise is necessary to make possible a representation of all types of topography.

CHAPTER ELEVEN

MAP PROJECTION: CYLINDRICAL

In making a plan of a small area, no difficulty is encountered due to earth curvature. When an extensive area is surveyed, however, earth curvature has to be taken into account, and it is necessary to examine at least the commonest conventional methods of dealing with the problem. The difficulty can most easily be appreciated by thinking in terms of a world survey, and having regard to the network of parallels and meridians rather than to topographical features which must perforce be drawn in their proper geographical positions within the general framework. Attempts to copy lines of latitude and longitude from a globe reveal the need to adopt some scheme or projection, and examination of atlas maps confirms the fact that various schemes are employed. As a result of some, Greenland looks as large as South America: others maintain relative areas, but there is obvious distortion of shape.

The triangulation to determine the relative positions of points is the same regardless of the projection to be used in drawing the maps, but the spacing of points so determined can be computed for any particular projection.

For purposes of study, the common projections may be divided into three groups, Cylindrical, Conical, and Azimuthal. In the cylindrical group, the graticule can be conceived as resulting from the wrapping of paper to form a cylinder about the globe and projecting lines of latitude and longitude on to it, then unrolling the cylinder to form an oblong. Lines of latitude come out as parallel straight lines across the map from east to west; meridians as vertical parallel lines their true-to-scale distance apart along the equator. An example is seen in Fig. 41. The conical group can be conceived as resulting from the projection of meridians and parallels on to a cone placed over the globe, the line of contact being a parallel. On opening, the cone forms a sector of a circle; parallels are concentric arcs and meridians are radial lines from the apex of the sector. An example is seen in Fig. 50. The azimuthal group can be regarded as resulting from the contact of a flat piece of paper with the globe. This would only be at one point, but if this were the pole, parallels would be projected on it as concentric circles, and meridians as radial lines from the pole, as in Fig. 58.

It should be noted that cylindrical, conical, and azimuthal projections need not be the result of contact respectively along the equator, an intermediate line of latitude, or the poles, since the globe could be turned to make contact in regions other than these; and also that in practice projections are constructed by geometrical methods after determination of the spacing of meridians and parallels by mathematical computation.

1. Central Cylindrical and Cylindrical Equal Area Projections

Consider first two methods of constructing cylindrical projection graticules. In Fig. 41 the meridians have been drawn as parallel straight lines spaced at their true-to-scale distance apart along the equator, the theoretical line of contact of cylinder and globe. The position of the lines of latitude has been determined by producing radii at fixed angular distances till they cut a line tangent to the equator. It will be seen that they become progressively farther apart as distance

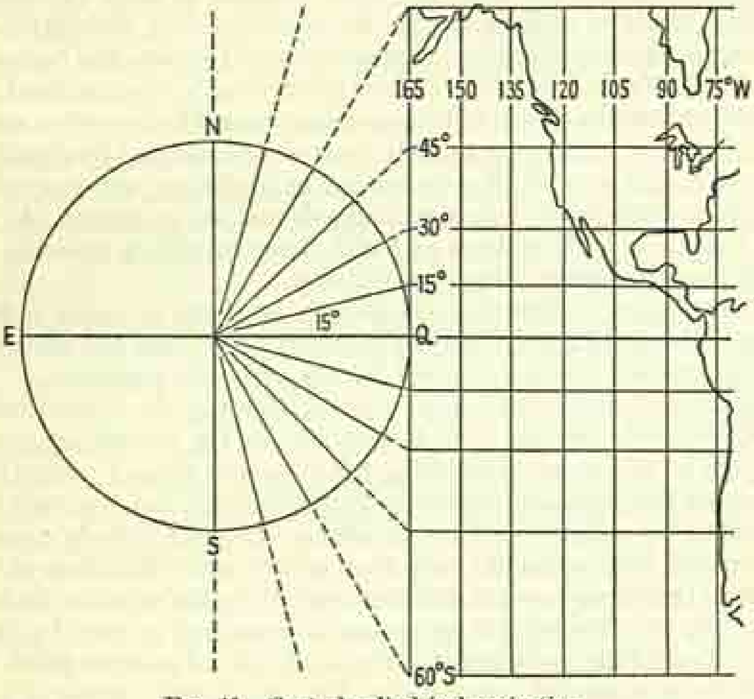


Fig. 41. Central cylindrical projection.

from equator increases, and that on this projection the poles could not be shown. Such a projection, known as the *Central Cylindrical*, has few properties to recommend it, apart from simplicity of construction.

In Fig. 42 meridians have been drawn as in Fig. 41 but the spacing of the lines of latitude has been determined by drawing lines parallel to the equator through points on the circumference at fixed angular distances from the centre. In other words, the point of projection has been moved from the centre of the sphere to infinity so that projection lines become parallel. It will be seen that polar regions can be shown on this projection, but they are very compressed in one direction and elongated in another.

It can be proved geometrically that the sphere *N A S B* has the same surface area as the rectangle $N_1 N_2 S_2 S_1$, if this rectangle is the same height as the sphere and is equal in length to the circumference of the sphere. The full length is not shown in this figure. The dimensions in terms of R, the radius of the sphere, are respectively $2R$ and $2\pi R$. The area of the rectangle and of the sphere is consequently $4\pi R^2$. All zones on the globe have the same area as corresponding strips on the rectangle. The projection is therefore described as the *Cylindrical Equal Area*. Distortion at the poles limits its usefulness, but in the equatorial regions there is very little distortion, which combined with its equal-area property render it suitable for tropical distribution maps, for example of negroes, coconuts, or rubber plantations.

2. Gall's Stereographic Projection

In *Gall's Stereographic Projection* the point of projection is neither at the centre nor at infinity as in the previous cases, but is on the circumference of the circle at E in Fig. 43. The cylinder is no longer regarded as making contact along the equator, but at 45° north and south of the equator. These parallels are made their true-to-scale length and subdivided as required. Through division points vertical parallel lines are drawn to represent meridians. An approximate graphical method of obtaining true-to-scale divisions along any parallel is described in connexion with Fig. 48.

Although the projection has often been used to show world distributions, it has few properties to recommend it. There is less distortion of polar areas than in the cylindrical equal area, but on the other hand it is no longer equal-area. Temperate regions, often of importance in distribution maps, are reasonably well shown as there is least distortion of area in those parts of the map. Unless Gall's name is invoked, the stereographic projection is taken to mean the one described in the azimuthal group. It differs considerably from Gall's.

3. Simple Cylindrical and Mercator's Projections

It is evident on the globe that all lines of latitude are the same distance apart. A series of parallel lines can therefore be drawn at their true-to-scale distance apart to represent the lines of latitude, making each one the same length as the equator. At right angles to these another series of parallel lines can be drawn to represent meridians, spaced at their true-to-scale distance apart, measured at the equator. A series of squares results, and the projection is known as the *Simple Cylindrical* or *Plate Carrée*. It has few merits except simplicity of construction, and the fact that distances measured along meridians are true to scale. Polar areas are considerably distorted by expansion along lines of latitude.

A more difficult cylindrical projection, but the one which is most used, is *Mercator's*. The examples already described, with the exception of Gall's stereographic, have one feature in common, namely that all lines of latitude are drawn the same length as the true-to-scale equator, and therefore all lines of

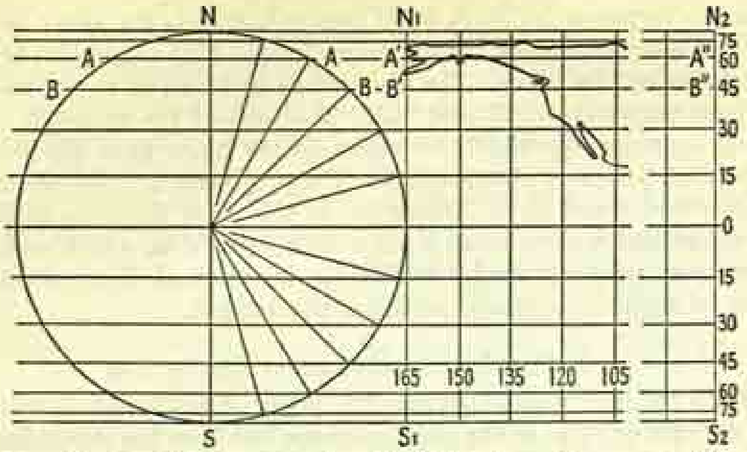


FIG. 42. Graphical construction of cylindrical equal-area projection.

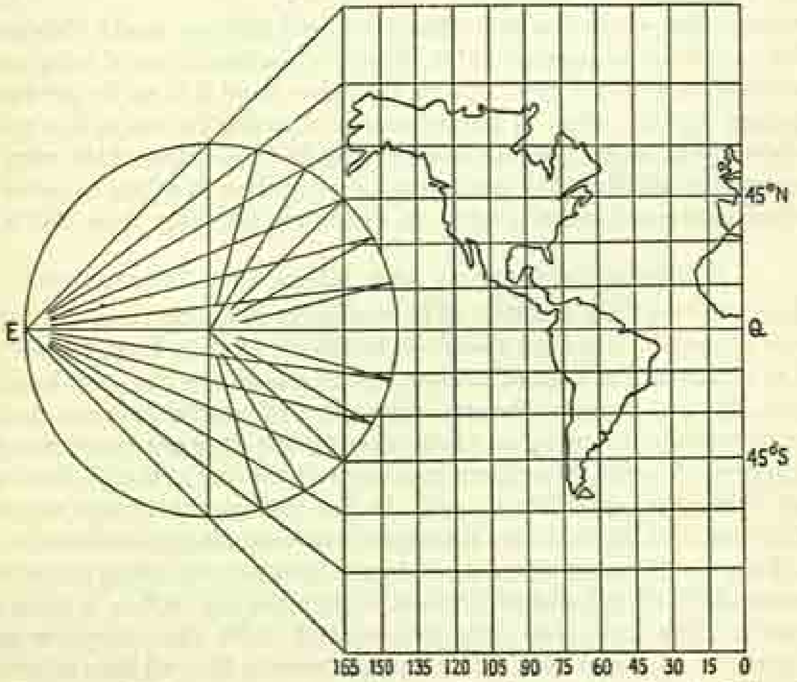


FIG. 43. Gall's stereographic projection, showing construction for 15° net.

latitude except the equator are exaggerated in length. The 60th parallel is twice as long as it should be. The 75th parallel is fifteen times as long, and the 80th parallel is thirty-three times as long as it should be. Mercator balances this exaggeration by exaggerating the distance apart of the parallels by the same amount, as seen in Fig. 44. Thus, since the 60th parallel is twice as long as it should be, the lines of latitude in this zone are placed twice as far apart as they

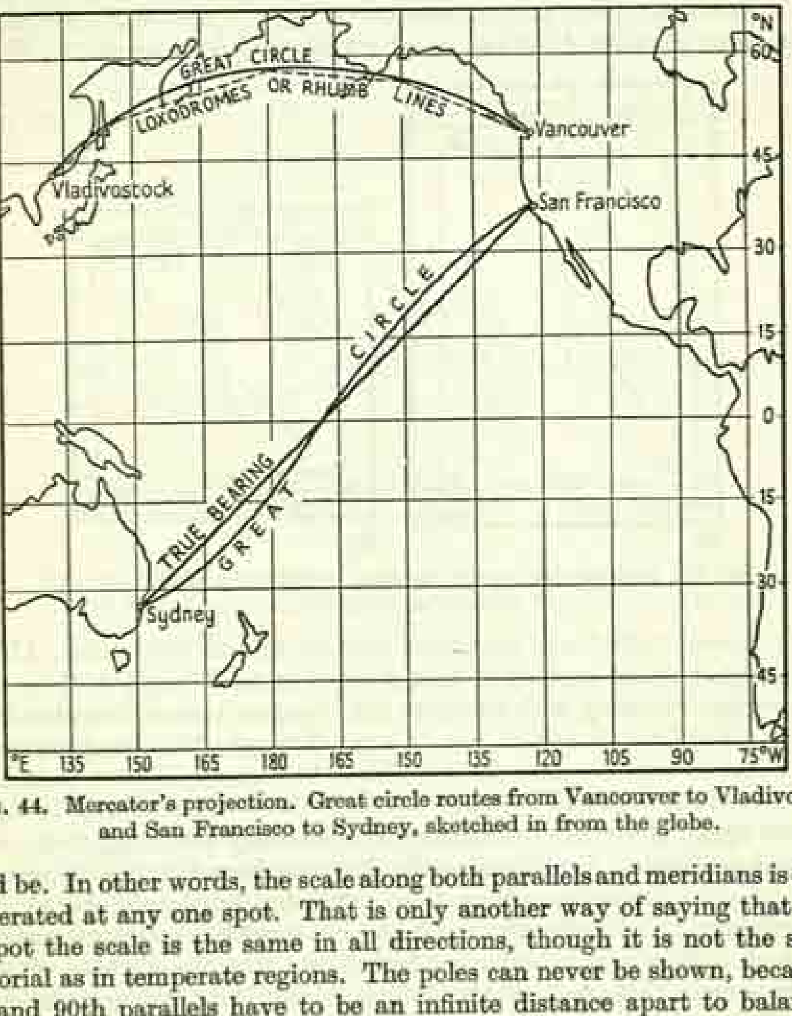


FIG. 44. Mercator's projection. Great circle routes from Vancouver to Vladivostok and San Francisco to Sydney, sketched in from the globe.

should be. In other words, the scale along both parallels and meridians is equally exaggerated at any one spot. That is only another way of saying that at any one spot the scale is the same in all directions, though it is not the same in equatorial as in temperate regions. The poles can never be shown, because the 89th and 90th parallels have to be an infinite distance apart to balance the infinite exaggeration of distance between meridians at the pole.

Mercator's projection has interesting properties. Because the lines of latitude and longitude are at right angles as on the globe, and the scale at any one point, or in practice over any small area, is the same in all directions, and not in one only, as for example on the simple cylindrical, shape is very well maintained. For this reason the projection is described as *Orthomorphic*, or true to shape, though it is only true in theory of any given point, and in practice of a limited area. Another property of Mercator's projection is its gross exaggeration of polar areas, and on this account it should never be used for world commodity or territorial distribution maps, though it has been commonly employed to show the British Empire. For reasons to be described later, it is a useful projection for maps showing direction, as of winds and ocean currents. Mercator,

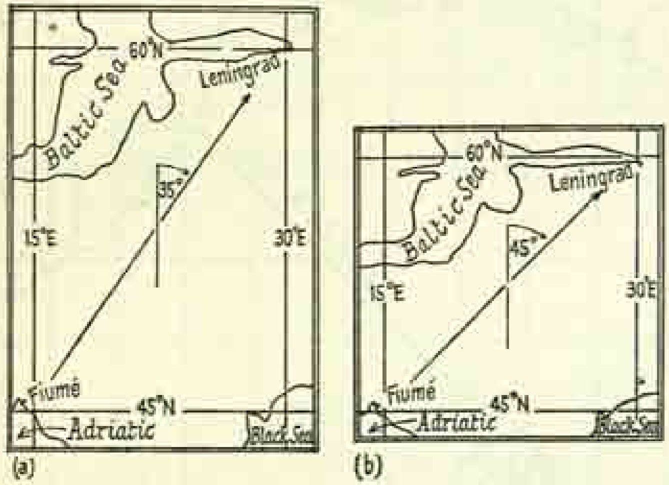


FIG. 45. Bearing seen on (*a*) Mercator's projection, and (*b*) simple cylindrical projection.

however, is most valuable in connexion with sea and air navigation. If a pilot wishes to get from his position *A* to a point *B* he need only join *A* to *B* on a Mercator map or chart, and navigate the compass course indicated by the direction of the line. A similar line on any other cylindrical projection would not be a line of true bearing. This is shown in Fig. 45, which represents the intersection of the 45th and 60th north parallels with the meridians 15° and 30° E. spaced firstly according to Mercator and secondly according to the simple cylindrical projection. On Mercator the direction from Fiume to Leningrad is seen to be approximately north-east by north, but on the simple cylindrical, due north-east. Both directions cannot be correct. Investigation of the problem on a globe will be sufficient to indicate that the direction shown on Mercator is more likely to yield the desired result. If a north-east course were followed by a pilot, he would probably end up in the Pripet marshes instead of at Leningrad.

One other point should be noted before leaving Mercator. It will be seen by stretching a piece of string round the globe that the line of shortest distance between two places, unless both are on the equator, never cuts successive meridians at a constant angle. Therefore the shortest distance between two places, which is always along the line of a great circle or globe circumference, is not the same as a line of constant bearing described above, since this cuts all meridians at a constant angle. The great circle route between places on a Mercator's projection comes out as a curved line, which means that on flat paper it is actually longer than the line of constant bearing, though the reverse is true on the globe. In practice, great circle routes are plotted on a Mercator projection and then broken into a series of *loxodromes* or *rhumb lines* as the lines of constant bearing are called. Direction is then changed at predetermined points,

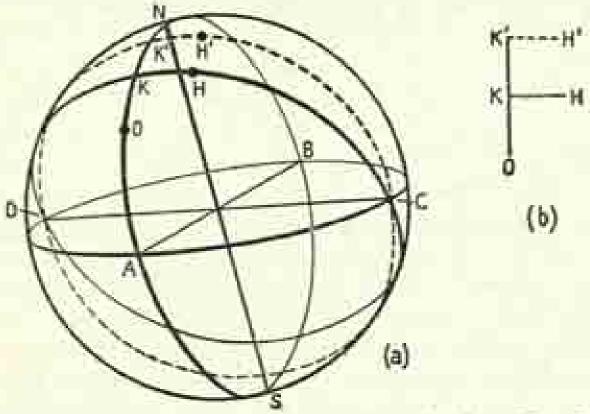


FIG. 46. Cassini's projection. (*a*) Position of points H and H' as defined in relation to O on the sphere. (*b*) Positions as set out on the projection.

say, every 500 miles. The point is quite easily appreciated if the map and globe are studied in conjunction, as in the drawing of Fig. 44, but otherwise confusion of thought is likely to arise.

4. Cassini's Projection and the Transverse Mercator

Two other projections may be considered in connexion with the cylindrical group, and though not as easy to understand as the previous, they are important for topographical maps of limited areas.

Cassini's Projection has been employed for practically all Ordnance Survey maps of England, both large and small scale. To assist in understanding it, reference should be made to Fig. 46, which represents a globe, with diameter AB and CD at right angles to each other in the plane of the equator. NS is the polar axis perpendicular to this plane. Any great circle drawn through C and D will cut the great circle drawn through $ANBS$ at right angles, but only one of

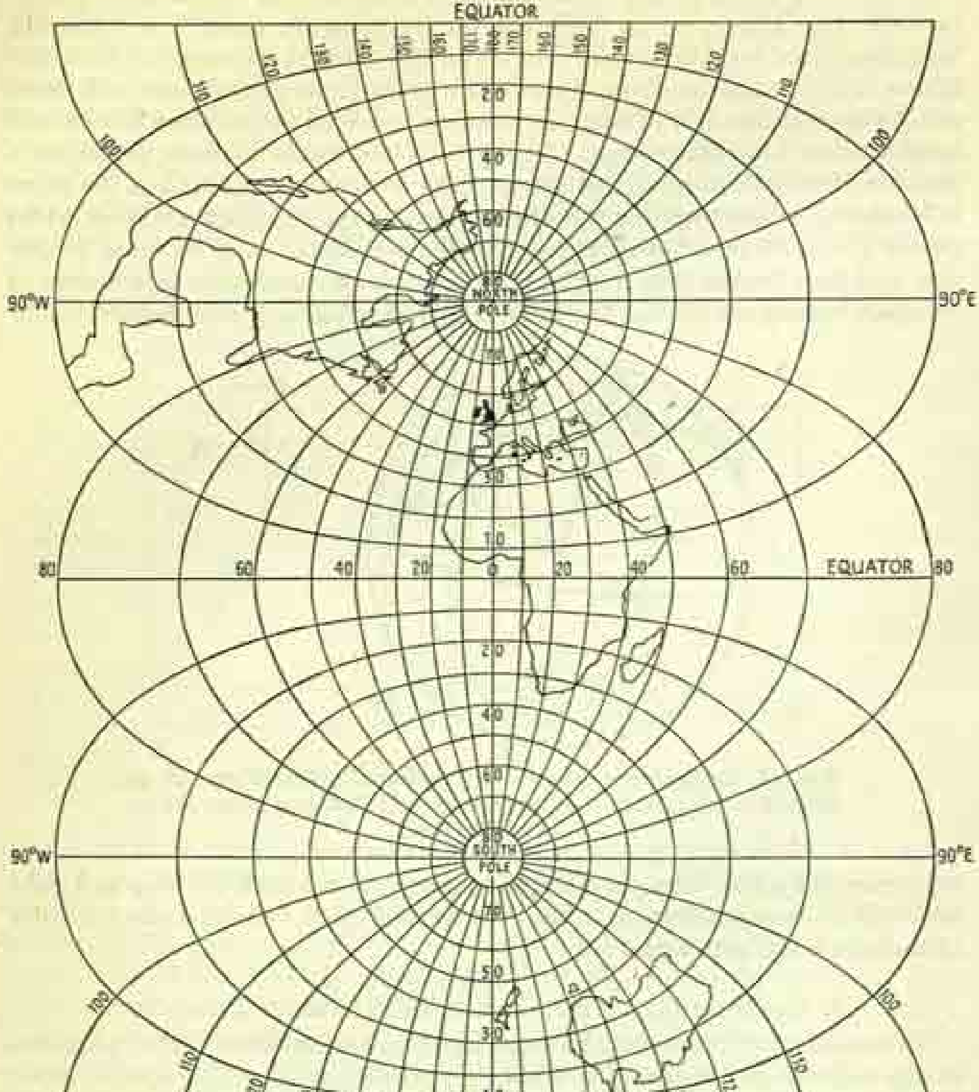


FIG. 47. The Transverse Mercator Projection.

these great circles can be drawn through a given point, such as H elsewhere on the globe. It is very necessary to appreciate the full significance of this sentence to appreciate the construction of the projection, and its successor, the Transverse Mercator. A central meridian SAN is chosen, and on it a suitable point O is taken as map centre or origin. To fix the position of a point H the great circle CHD is drawn cutting the central meridian at right angles, as at the point K. The lengths to scale of OK and KH are then calculated by spherical trigonometry and set out at right angles, as in Fig. 46 (b). The position of all essential points is similarly fixed in relation to point O, and so the net is drawn.

It will be recalled in connexion with Fig. 46 that any number of great circles could be drawn on CD as diameter, and that all would cut $ANBS$ at right angles. If C and D are regarded for a moment as the North and South poles, a series of great circles through them would resemble meridians. In constructing Cassini's projection we have in effect straightened out these great circles as in a cylindrical projection and treated the central meridian as if it were the equator of a cylindrical projection. It is obvious also that lines such as KH on Fig. 46 (a) converge towards C, but in constructing the graticule, they are made parallel to each other, because all are drawn at right angles to the central meridian, as is KH in Fig. 46 (b). Therefore on Cassini's projection distances along the central meridian are true to scale, but distances on all other meridians are too long. At an extreme distance of 175 miles from the central meridian, the exaggeration is 5 feet in a mile. On large-scale plans this would be noticeable, and hence some half-dozen different central meridians were chosen for groups of counties. Cassini's projection is therefore not suitable for topographical maps of countries of great extent from east to west, though it is suitable for countries of any extent from north to south.

Regard Fig. 46 once more as a globe with poles at C and D and a cylinder touching it along the original great circle $ANBS$, now regarded as the new equator. To construct Mercator the meridians passing through the poles C and D were drawn as parallel lines on the cylinder and greatly elongated to balance their exaggerated distance apart in polar latitudes. By means of this exaggeration the projection was made orthomorphic. In the same way, reverting to the original conception of Fig. 46, distances along all great circles could be exaggerated in constructing Cassini, till it became an orthomorphic projection. This is the *Transverse Mercator*, *Gauss Conformal*, or *Transverse Cylindrical Orthomorphic*.

It will be realized from Fig. 46 that the actual graticule will have the central meridian as a straight line down the centre of the map and that the meridians will radiate outward from the pole, as in Fig. 47, resembling nets on Bonne's projection placed pole to pole. The parallels are almost circles near the pole, but rapidly become drawn out in the direction of the cylinder's axis. The equator forms the south and north edges of the map. Thus, there is little distortion near the central meridian, but a good deal east and west of it as shown in Fig. 47.

CHAPTER TWELVE

MAP PROJECTION: CONICAL

So far, we have been concerned primarily with the spacing of parallels and meridians on a plane, that of the piece of paper on which the graticule is drawn. It is now useful to consider the actual spacing of these on the globe.

1. Spacing of Parallels and Meridians on the Globe

Suppose that Fig. 48 represents a globe to scale, and that *EQ* is the equator and *NS* the polar axis. The latitude of a point *B* is defined by the angle *BOQ* at the centre, in this case 15° N. The parallel 15° N. is a line round the globe at constant distance *BQ* from the equator. By means of such a figure the true-to-scale distances between parallels can always be found. For practice in the construction of graticules, it is sufficiently accurate to use the straight-line distance *BQ* instead of the arc distance.

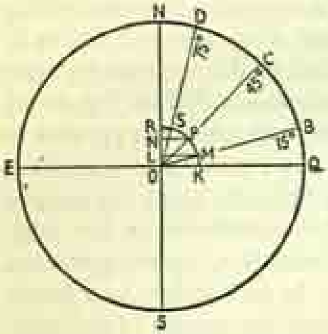


Fig. 48. Determination of approximate true-to-scale spacing of meridians.

So long as the angular interval between parallels is uniform, the distance between them on a given scale remains the same. But this is not true of meridians. They are farthest apart at the equator, and meet at the poles. The distance between meridians at any given latitude can be ascertained by trigonometry, or again there is a practical method accurate enough for drawing practice, and demonstrated in Fig. 48. At the centre of the circle a quadrant is drawn with radius *BQ*. If we require to know the distance apart of meridians at 15° intervals on a globe of radius *OQ*, radii for the required latitudes such as 15° N., 45° N., and 75° N. are drawn and lines parallel to *OQ* are constructed through the points of intersection of these radii and the quadrant. The distance apart of the meridians at these latitudes is then approximately equal to *LM*, *NP*, and *RS* respectively. Spacing of meridians at 20° intervals would be obtained by making angle *BOQ* 20°, and proceeding as before.

If the circle *ESQN* is regarded for a moment as the equator, meridians at intervals of 15° would be spaced along it at distances apart equal to *BQ*. In the method described the distance *OK* would be used, but by construction this equals *BQ* so that it is seen that approximately correct spacing is obtained along the equator. Also, without entering into any proof it is evident that the lines *LM* to *RS* diminish in length as higher latitudes are reached, just as distances between meridians decrease on the globe as the pole is approached.

2. Simple Conical with One Standard Parallel

As originally described, the conical projections can be regarded as resulting from the projection of the graticule on to a cone fitting over the globe and making contact normally along one of the parallels. A simple case is shown in Fig. 49, in which the cone PXY fits over the globe, making contact at 50° N. On opening or developing the cone, the sector form in Fig. 50 is obtained. The arc has its centre at P and radius PX or PY.

On the above principle a map net or graticule can be constructed, and Fig. 50 again used in illustration. A circle is drawn to represent the globe, a radius is drawn to a chosen latitude, say, 50° N., and from that latitude on the circumference a tangent to intersect the polar axis produced gives the required arc radius. A central line PL represents the central meridian. Z is its intersection point with the standard parallel, as the chosen one is called. The approximate true-to-scale spacing of parallels can be determined as in Fig. 48, and marked outwards north and south from Z along the central meridian. With centre P concentric arcs are then described through the marks on PL. The standard parallel is next divided true to scale by calculation or by the method shown in Fig. 48, division marks being made outwards from Z. Radial straight lines from P through these marks complete the graticule. The projection is known as the *Simple Conical with One Standard Parallel*. It is of course necessary when using practical construction methods to employ the same circle to determine the radius of the standard parallel as is used to obtain the spacing of parallels and meridians. In practice, it is sufficient to have one quadrant of the circle with a second quadrant inscribed.

The standard parallel and central meridian are chosen at will. Usually those intersecting near the centre of the area to be mapped prove suitable. The projection is most used to show areas of limited extent in temperate latitudes. By construction the scale along the meridians is correct, and along the standard parallel, but it is exaggerated along all other parallels. The projection is therefore not equal-area, nor orthomorphic, but it is simple to construct and is much used.

3. Bonne, Sanson–Flamsteed, and Mollweide

A slight modification of the graticule results in a projection having the merit of maintaining equal area. Instead of dividing only the standard parallel correctly, all parallels can be divided true to scale. The meridians are drawn by joining up corresponding division marks on the parallels, and consequently they are no longer straight, but curved. The projection is known as *Bonne's*. By construction it is an equal-area projection and is much used to map extensive areas in temperate latitudes. As in the conic with one standard parallel, the standard parallel and the central meridian can be chosen at will. The graticule shape of a limited area is shown in Fig. 51.

If in drawing a series of graticules on Bonne's projection, the parallel chosen as standard is taken progressively nearer to the equator, the parallels become less and less curved, as demonstrated in Fig. 52.

Finally, if the equator itself is regarded as the standard parallel, the radius *PX* becomes infinitely long, the standard parallel, the equator, ceases to have any curvature at all, and all parallels become equidistant straight lines. Meridians are spaced as before and the projection is still equal-area, but it is now called the *Sinusoidal* or *Sanson–Flamsteed*. Historically the credit goes to Sanson. The whole world can be shown, as in Fig. 53, though there is considerable distortion at the edges. The projection is especially useful for areas astride the equator such as South America or Africa, provided a suitable

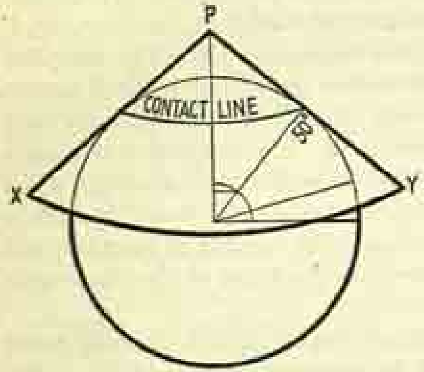


FIG. 49. Cone fitting over globe.

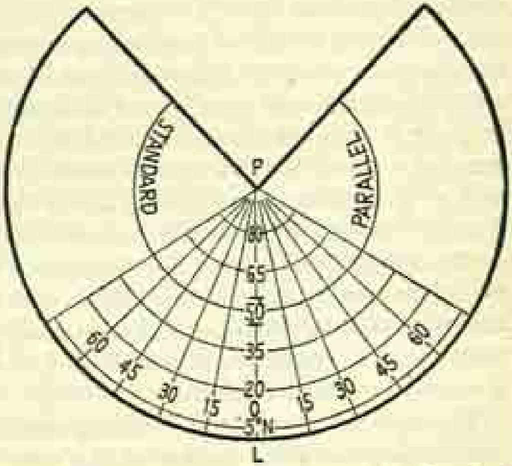


FIG. 50. Cone opened out, and graticule of conical with one standard parallel drawn upon it.

central meridian is chosen. It is not a true conical projection, but a special case of Bonne.

Another projection closely resembling the sinusoidal is *Mollweide's*. To show the whole world, an east-to-west line is first drawn to represent the equator and a line half the length is made to bisect it at right angles to represent the central meridian. An ellipse is then described about these lines as axes. If the central meridian were equally divided and lines drawn through the division marks parallel to the equator, the strips or zones would not be equal in area to corresponding strips on a globe. The strips in the tropics would be too small in area and those in polar regions too great. In order to make this an equal-area or equivalent projection, the parallels must be unequally spaced by mathematical computation. They are slightly farther apart in equatorial than in polar regions. Parallels are then divided into any required number of equal parts and corresponding division marks joined, hence the alternative name, *Elliptical Projection*. It is equal-area by construction and is useful for distri-

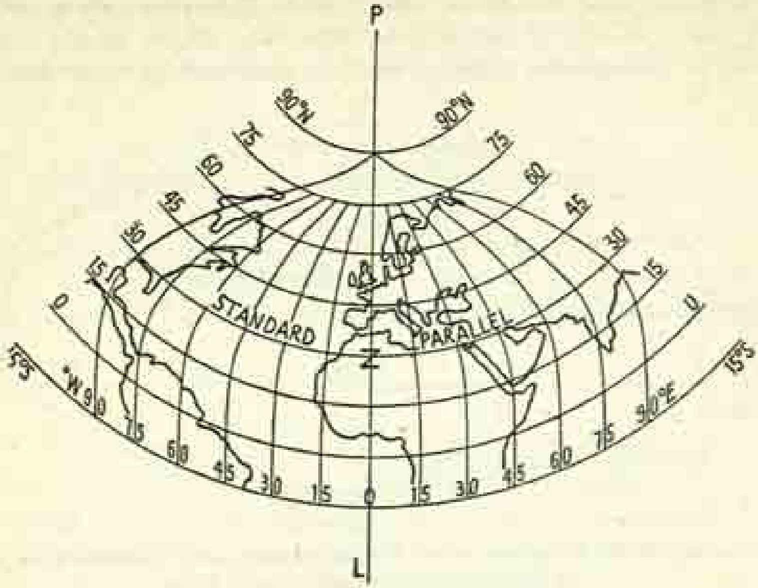


FIG. 51. Bonne graticule to show shape. Standard parallel is here 30° N.

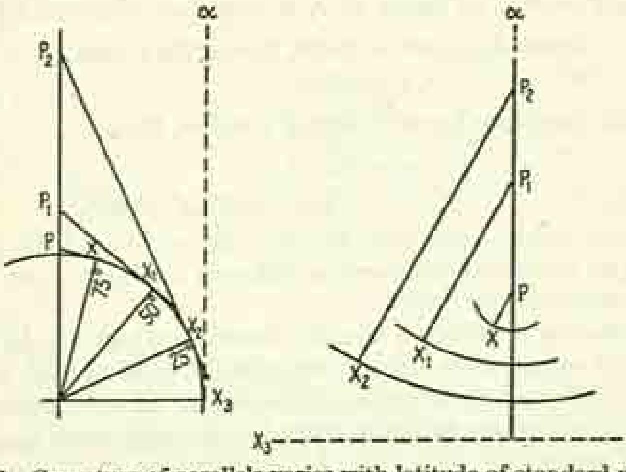


FIG. 52. Curvature of parallels varies with latitude of standard parallel.

bution maps of the whole world, the world in hemispheres, or areas astride the equator. There is less distortion at the edges than on the sinusoidal. The shape is shown in Fig. 53 in comparison with the sinusoidal. Like the sinusoidal it is not a conical projection, but it is conveniently described as a development from the conical group.

It will be seen that two of the meridians in Mollweide form a circle which contains half the area of the ellipse. Since the ellipse should contain the same area as the sphere, namely, $4\pi R^2$ as described in connexion with the

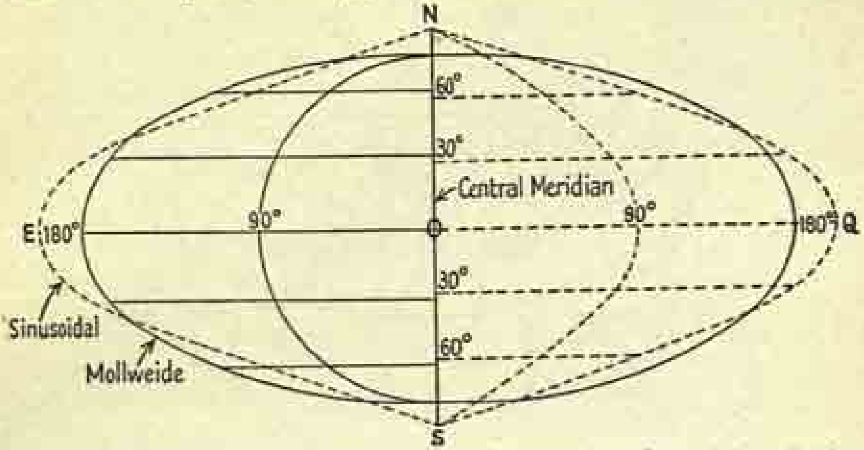


FIG. 53. Sinusoidal projection shown by dotted lines, and Mollweide's projection on the same scale shown by solid lines.

cylindrical equal-area projection, the area of the Mollweide circle should be $2\pi R^2$. Its own radius, in terms of r, is therefore obtained by the formula

$$\text{Circle Area, } \pi r^2 = 2\pi R^2, \text{ Hemisphere Area,}$$
$$\therefore r = \sqrt{2}R.$$

If, for example, the globe has a radius of 2 inches, then

$$r = \sqrt{2} \times 2$$
$$= 2{\cdot}83 \text{ in. approximately.}$$

The circle therefore has a greater radius than the globe, and this point is worth remembering as it renders necessary a different approach from that made in drawing the sinusoidal projection.

Of the equal-area projections already described which can be used to show the whole world on one sheet, namely, the cylindrical, sinusoidal, and Mollweide, the latter two suffer much distortion at the edges. In some atlases an attempt has been made to reduce this distortion by choosing more than one central meridian and proceeding to construct the projection as before, working outwards from the chosen meridians. The result is that certain areas are less distorted, appearing to occupy a central position on the graticule, and that interruptions occur in areas unimportant to the purpose of the map, commonly the oceans. An *Interrupted Mollweide* is shown in Fig. 54.

4. Polyconic and Conical with Two Standard Parallels

Before leaving the subject of conical projections, two others call for description, the polyconic and the conical with two standard parallels. The *Polyconic* is essentially the same in construction as the conic with one standard parallel. All parallels cut the central meridian at true-to-scale distances apart, but

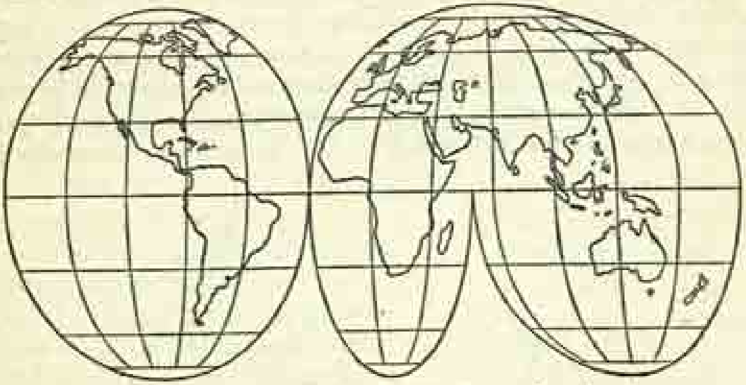


Fig. 54. Interrupted Mollweide projection to show land masses.

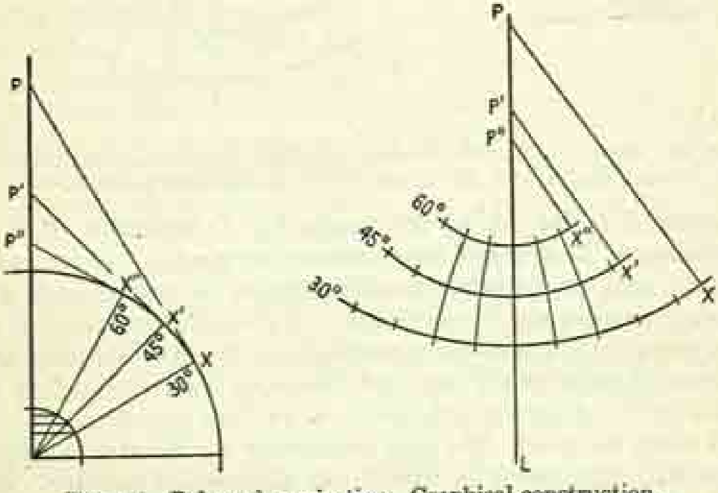


Fig. 55. Polyconic projection. Graphical construction.

instead of having a common centre P, the radius of each is determined as though it were the standard parallel, then measured back along PL from its appropriate mark, and drawn in as shown in Figure 55. Parallels are then all divided true to scale, and the division marks joined up. The projection is therefore like a whole series of cones touching the sphere at different parallels. It is not equal-area, but the scale is true along the central meridian and along all parallels. There is much distortion at the edges, but the projection is not used for a single map of large areas. It is mainly employed in a modified form for the international million map, and is referred to under projections for topographical maps.

The Conical with Two Standard Parallels, also called the *Secant Conic*, is much used for countries in temperate latitudes. A graphic approximate construction is quite simple. A straight line representing the central meridian is first drawn and divided true to scale as for previous conical projections. At those marks which represent the intersection points of the parallels chosen to be standards, XX' in Fig. 56, lines are drawn at right angles to the central meridian. Along each of these a true-to-scale distance XY, $X'Y'$ is measured outwards from the

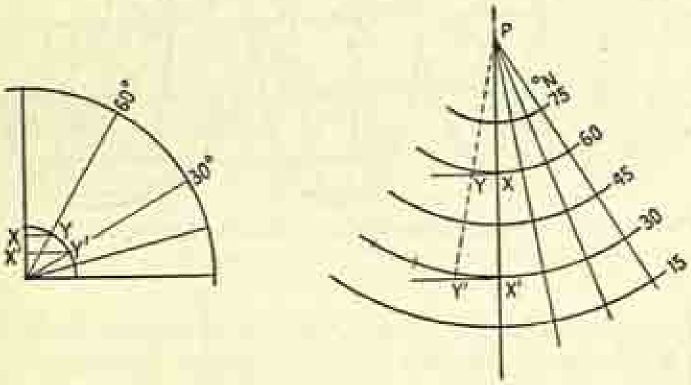


FIG. 56. Conical with two standard parallels. Graphical approximate construction with 30° N. and 60° N. as standard parallels.

central meridian. A line joining the marks YY' is produced till it cuts the central meridian at P, and this new intersection point is taken as the centre for concentric arcs representing parallels drawn at true-to-scale distances. Radial straight lines passing through true-to-scale marks on one of the standard parallels represent meridians. Since parallels are true-to-scale distances apart, scale is correct along all meridians, and also along the two standard parallels. Between the standard parallels the scale along lines of latitude is too small, and outside them too great. The map is therefore not equal-area, but errors of scale can be well distributed by wise choice of standard parallels. It is more nearly orthomorphic than Bonne's, and though not suitable for countries having a great extent of latitude, it is suitable for any extent of longitude. The continent of Europe or countries within the continent are successfully drawn upon it.

CHAPTER THIRTEEN

MAP PROJECTION: AZIMUTHAL

THE final group of projections, the azimuthals or zeniths, results from the projection of lines of latitude and longitude on to a plane surface regarded as touching the globe at a chosen point. Consider those cases where the chosen point of contact is the pole. All meridians will appear as radial straight lines. A series of concentric circles about the pole represents the parallels.

1. ZENITHAL EQUIDISTANT AND EQUAL-AREA PROJECTIONS

If the concentric circles are spaced at true-to-scale distances apart measured along the meridians, the projection is known as the *Zenithal* or *Azimuthal Equidistant*. It is easy to construct, and distances along meridians are correct, but distances along parallels are too great. At 70° N. or S. exaggeration slightly exceeds 2 per cent. and the projection is consequently not equal-area. It is obvious that to an explorer at the pole, once his map has been correctly alined for longitudinal direction, the direction of all places from his position at the centre of the map, the pole, is correct. But this property of showing true bearing, or azimuth, applies equally to all zenithal projections from the point which has been taken as the centre of the projection, though only in the polar cases are the meridians azimuths and the parallels concentric circles. It will be realized that these azimuths differ from the rhumb lines of Mercator, which cut all meridians at a constant angle.

FIG. 57. Zenithal equal-area projection, equatorial case. Not of one hemisphere.

It is clear that concentric circles of polar zenithal projections could be spaced according to some other plan, for instance to maintain equivalent area. To achieve this circles would have to be drawn closer together as distance from the pole increased. As already stated in connexion with the cylindrical equal-area projection, shown in Fig. 42, the area of a zone or cap on a sphere is equal to its vertical height multiplied by the circumference of the sphere. The radius of each circle on the projection can therefore be determined by equating this area to πr^2, the area of the desired circle, and thereby determining the value of r.

This *Zenithal Equal-area Projection* is commonly used to show polar areas. It can be used successfully to map areas in any part of the world by choosing a suitable projection centre, but the construction in all cases but the polar one is difficult. A net for one hemisphere, equatorial case, is shown in Fig. 57.

2. The Gnomonic Projection

Another way to space concentric circles in polar zenithal projections would be by projecting them on to the plane from a point at the centre of the globe, as shown in Fig. 58. In order to draw a graticule, radial lines are first drawn to represent meridians, and the radii of the concentric circles representing

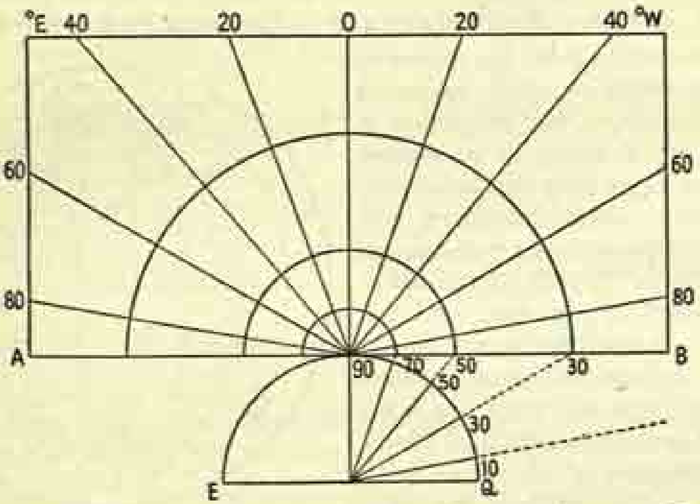


Fig. 58. Gnomonic projection, graphical construction of polar case. To complete the net the part above AB is repeated again below AB.

parallels are measured along the tangent AB. The distance apart of the parallels increases rapidly from the pole and the equator cannot be shown at all. Consequently this projection, known as the *Gnomonic*, is not much used except for charts of polar seas and large-scale charts of harbours. It has one property of special interest, however, which holds good not only in the polar case, but in every other case, namely, that any part of a great circle comes out on the map as a straight line. A little reflection will show why this is so. The plane of a great circle or globe circumference passes through the centre of the globe. Therefore, since the point of projection is the centre of the globe, the projection of the great circle upon the map is the line made between the plane of the great circle continued till it intersects the plane of the map, and two planes always intersect in a straight line. By drawing a straight line on a gnomonic projection between two given points, it should be possible to plot approximately that part of the great circle on some other projection, for example on a Mercator, by noting points through which it passes on the gnomonic.

3. Stereographic, Orthographic, and Clarke's Projection

By taking projection points other than at the centre of the globe other zenithal projections are obtained. A well-known one is the *Stereographic*, which has the centre of projection on the circumference of the globe diametrically opposite the contact point, thereby reducing the rate of increase in the diameter of parallels, as compared with the gnomonic.

The point of projection can be moved so far away from the globe that in effect the rays of projection become parallel straight lines. The projection is then known as the *Orthographic*. The construction of the polar case is easy. The parallels are projected on to the plane as a series of concentric circles, getting closer together as distance from the pole increases. They can be spaced by the construction shown in Fig. 59. The meridians come out as radial lines converging at the pole. Distances along them are greatly compressed towards the periphery. Now consider what happens if the projection is drawn on a plane tangent to the globe at the equator, as in Fig. 60. Parallels are projected at the same distance apart as in the polar case, but instead of being concentric circles, they are parallel straight lines. Each meridian on the globe is a half great circle from pole to equator. All points on a meridian will be projected directly backward on to the plane by the parallel rays of light, so that their projection will have the same form that they appear to have as seen from the source of light. That form is elliptical, because a circle seen in perspective is always elliptical in form. The only exceptions are the central meridian, which appears as a straight line, and the bounding meridians, which form a circle. The spacing of the meridians along the equator will be the same as the spacing of the parallels, and can be marked along the equator as shown by the dotted lines. The net is then completed by passing ellipses through the poles and these

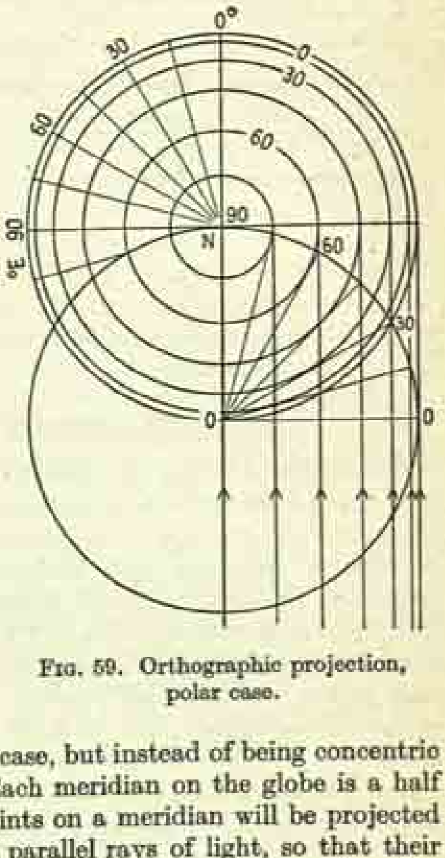


Fig. 59. Orthographic projection, polar case.

marks on the equator. Drawing may be facilitated if it is remembered that distances on the 60th parallels north and south are half those on the equator. The graticule as drawn, is, of course, for one hemisphere only.

The projection is easy to draw, but has few properties to recommend it in competition with others. It can be regarded as the view of the earth as seen by the man in the moon, and therefore his map of the earth.

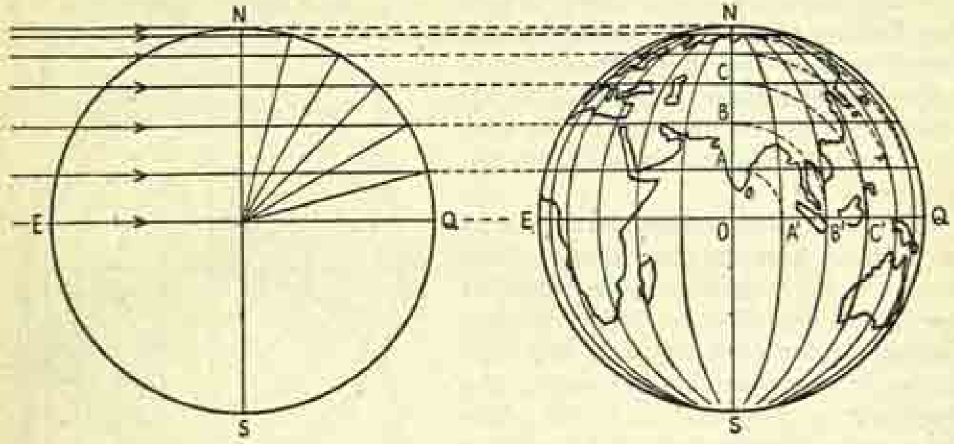


FIG. 60. Orthographic projection, equatorial case.

If stereographic and orthographic polar cases are compared, it will be seen that the former with its projection point on the circumference opposite the tangential plane results in the parallels becoming more and more widely spaced as distance from the pole increases, whereas the latter, with its point of projection at infinity, results in precisely the opposite effect. It is evident that there is something to be said for a projection point between, and various mathematicians have chosen specific points to gain desired advantages. *Clarke* took points which varied between 1·65 and 1·35 times the radius from the centre of the sphere. One of these projections was taken as the basis of the Daily Weather Map of the North Hemisphere, issued by the Meteorological Office in London. The limit of the map is from the pole to 30° N., but the most significant region is from 40° N. to about 75° N.

CHAPTER FOURTEEN

MAP PROJECTION: CHOICE AND IDENTIFICATION

ON occasion the cartographer is called upon to choose a projection for a map, or to examine critically a choice made by others. It is also desirable to be able to identify intelligently the commoner projections when the name is not given.

I. CHOICE OF PROJECTION

The choice of a projection depends broadly upon the position and extent of the area to be mapped, and particularly upon the purpose and scale of the map. Consider the drawing of atlas maps first. Regions in tropical, temperate, and polar latitudes would in general be mapped upon projections taken respectively from normal cases in the cylindrical, conical, and azimuthal groups. The whole world on one sheet could be mapped on various cylindricals, the sinusoidal, Mollweide, or Gall's stereographic. For the world in hemispheres choice would most likely lie between Mollweide, the stereographic, or an equatorial zenithal. The choice of a projection for a continent would depend largely upon whether it lay in both hemispheres, as do Africa and South America, or whether it was one largely in the intermediate latitudes like the remaining continents. There is little visible difference in the shape of maps of small countries, whatever projection is used, and consequently within limits ease of construction may dominate choice. The simple conic with one or two standard parallels is frequently employed.

Ultimate choice of projection will depend upon the purpose of the map. In general, ease of construction and a lack of obvious distortion are important. For most distribution maps, equal-area projections are desirable, and for navigation, ocean currents, and winds, Mercator is to be recommended. Every case must be considered on its merits. Thus, a sinusoidal or equatorial case of the zenithal equidistant would probably be chosen for a map showing the Cape to Cairo rail route, and a conical with two standard parallels or Bonne's to show the Trans-Siberian Railway.

Rather different considerations are likely to be taken into account in choosing projections for national topographical maps. Also different problems arise when considering a projection for topographical maps of an extensive country like the United States and a small country like Britain. In the former case it is desirable to use a series of central meridians, but for Britain or Chile one central meridian may suffice.

Topographical maps prepared for the various governments of European countries make use of more than a dozen different projections, most of which belong to the conical group, as would be expected. Bonne is an easy favourite.

It does not follow that all the maps of a single country are on the same projection. Maps of Scotland were on Bonne's projection, those of England on Cassini's. It was not till 1932 that the 1-inch series of Great Britain was put on a common projection, Cassini's, and a further change is being made, all Ordnance Survey maps of large and small scale being drawn on a Transverse Mercator.

It is almost impossible to tell from a single topographical sheet which projection has been employed, even by careful measurement, because the difference between one projection and another is not so great as the difference arising from paper shrinkage and distortion. On wet days paper swells, and on dry days it shrinks, and then not equally in all directions.

For topographical maps of the United States and India use is made of the Polyconic projection. Although on this projection every sheet can have its own central meridian, it will fit accurately sheets to north and south when the edges are lines of latitude, since the curvature is identical on adjoining north and south

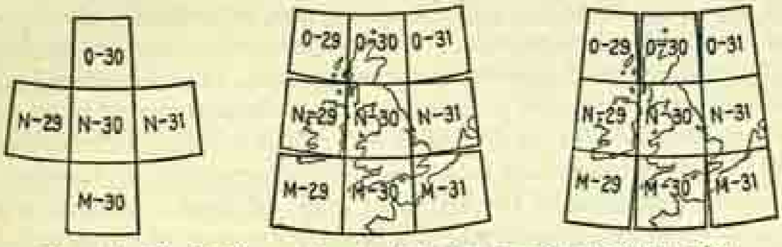


FIG. 61. Fit of adjacent sheets of the International Million Map.

sheets. East and west edges have a rolling fit with adjacent side sheets when meridians form the side edges, because there is curvature in opposite directions. On topographic sheets such curvature is hardly visible.

A modified form of the polyconic projection is used for the International Map, scale 1 : 1 million. The sheets normally cover 4° of latitude by 6° of longitude. The parallels are arcs with their own centres, but in constructing the meridians bounding parallels only are truly divided and division marks are ruled through with straight lines. Further, instead of the central meridian being true to scale, meridians 2° on each side of the central meridian are made true to scale so that the central meridian is rather shorter than normal. As a result of these modifications, any sheet will fit with its four neighbours, and a tolerably good fit is obtained with nine sheets, as shown in Fig. 61.

2. Identification and Suitability of Projections

Maps are often printed without mention of the projection employed. The following table indicates how the cases of those described may be identified, apart from Cassini and the Transverse Mercator. First examine the meridians, and decide to which group in column 1 the projection belongs. Then identify the particular member of the group from examination of parallels as set out in column 2. It is very likely, of course, that projections will be encountered which are not included in the table.

IDENTIFICATION OF MAP PROJECTIONS

1. *Meridians*	2. *Parallels*	3. *Projection*	4. *Suitability*
1. *Straight lines*, (a) Parallel	*Straight lines*, parallel		
	(a) Widest apart in Equatorial regions	Cylindrical Equal Area	World on one sheet Africa S. America Tropical regions
	(b) Equidistant	Simple Cylindrical (Plate Carrée)	Rarely employed Tropical regions least distorted
	(c) Widest apart in polar regions Difference:		
	(i) Slight	Gall's Stereographic	World on one sheet
	(ii) Marked	Central Cylindrical	Rarely employed
	(iii) Very marked	Mercator	Navigation maps and charts
(b) Radial	*Circles*, concentric		
	(a) Equidistant	*Polar cases of*: Zenithal Equidistant (Clarke's practically equidistant)	Polar areas to intermediate latitudes
	(b) Widest apart in Polar regions Difference:		
	(i) Slight	Zenithal Equal Area	Polar areas to intermediate latitudes
	(ii) Marked	Orthographic	Polar areas Other projections usually preferable
	(c) Widest apart away from Pole Difference:		
	(i) Slight	Stereographic	Polar areas
	(ii) Marked	Gnomonic	Charts of Polar Seas Straight lines are parts of Great Circles
(c) Converging	*Arcs*, concentric	Simple Conic with One or Two Standard Parallels	Countries in temperate latitudes without great latitudinal extent

1. *Meridians*	2. *Parallels*	3. *Projection*	4. *Suitability*
2. *Curved lines,* (*a*) Equally spaced along any given parallel	1. *Arcs,* (*a*) Concentric	Bonne's	Countries in temperate latitudes Europe Australia Topographic maps
	(*b*) Not concentric	Polyconic	Modified for Topographic maps
	2. *Straight lines,* parallel (*a*) Equally spaced	Sinusoidal	World on one sheet Africa S. America World on interrupted projection
	(*b*) Slightly wider apart in Equatorial direction	Mollweide's	World on one sheet or in hemispheres Africa S. America World on interrupted projection
(*b*) Closer together along any given parallel as distance from central meridian increases	*Straight lines,* equally spaced	Orthographic (Equatorial case)	World in hemispheres (others preferable) Africa S. America (others preferable)

CHAPTER FIFTEEN

THE NATIONAL PROJECTION, GRID AND REFERENCE SYSTEM OF GREAT BRITAIN

A FORM of the Transverse Mercator Projection, depicted in Fig. 47, has been adopted by the Ordnance Survey as a National Projection for general use for all new maps and plans of Britain.

1. THE NATIONAL PROJECTION

The point of origin of this projection is 49° North 2° West, but instead of the scale of the central meridian being correct, and maximum error occurring at the east and west extremities, error is redistributed by making the scale true at about 180 kilometres east and west of the central meridian. The scale is then 0·04 per cent. too small at the central meridian, and the same amount too large near the east and west coasts of Britain. These modifications have no visible effect upon the representation of topography on as large a map scale as 1/1,250, and abolish the need for different central meridians for large-scale plans of different groups of counties. Thus, after nearly a century and a half, virtually all Ordnance Survey maps and plans are to be drawn on a single projection, and this in turn has made possible the adoption of an accurate national grid and reference system. It will be realized of course that Britain only occupies a small portion of the graticule shown in Fig. 47.

2. THE NATIONAL GRID AND REFERENCE SYSTEM

A *grid* is a series of lines drawn parallel to and at right angles to the central meridian forming a series of squares covering the whole territory as in Fig. 62. The lines are here numbered in kilometres. Instead of numbering the grid lines with the true origin of the projection as 00, a false or working origin 400 kilometres farther west and 100 kilometres farther north has been adopted, a point a little to the south-west of Lands End. By this means, repetition of numbers to east and west of the central meridian is avoided, and empty space at the bottom of the grid is eliminated which, if incorporated in the numbering system, would raise grid numbers at the north of Scotland above 1,000 kilometres.

The lines forming squares appear in the same relation to the detail on any map regardless of scale, though the number of grid lines drawn on the map, and their spacing, is naturally related to scale. On the 10-mile and the ¼-inch they are at intervals of 10 kilometres; on the 1-inch and 6-inch at intervals of 1 kilometre; and on the large-scale plans at intervals of 100 metres. Each kilometre square on the 1-inch and 6-inch maps is covered by one square plan on the 1/2,500 scale, and each of these is in turn covered by four square plans on the 1/1,250 scale, in so far as they are published. As explained later, each plan is numbered in relation to its grid position.

The metric system is used because in it units of measurement step up in tens like our number system, and in any case the grid is not used to find how far a place is from the point of origin, but to enable its position on the map to be located or described.

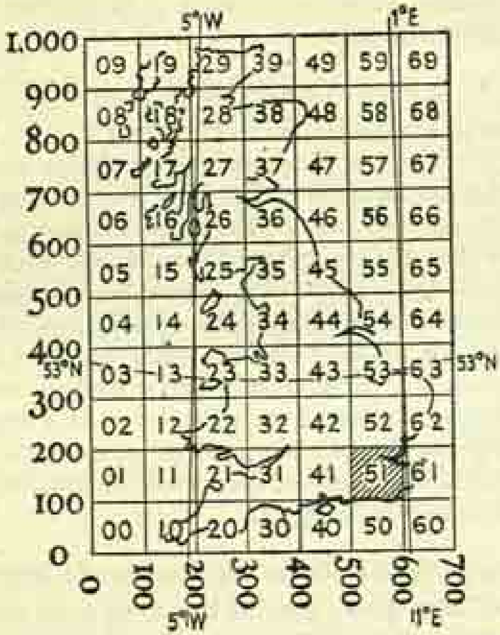


FIG. 62. Parallel grid lines and converging meridians.

Thus the location of the point in North London shown in Fig. 63 may be described by saying it is 538,932 metres east of the point of origin, and 177,061 metres north of the point of origin. This is a cumbersome description, but it is possible to adopt abbreviated versions. For instance, as Eastings are always written before Northings, the reference may be written 538932 177061. On 10-mile and ¼-inch maps, reference to the nearest kilometre may be sufficient, namely, 538 177. Again, since the general location of a point is usually known to within 100 kilometres, the first or 100-kilometre number in each ordinate may be dropped, and the reference written simply as 38 77. This is known as the *Normal Kilometre Reference* or *Four-figure Reference*. On 6-inch and 1-inch maps reference may be desirable to the nearest tenth of a kilometre, so the corresponding references are 5389 1770, or in its shorter form 389 770. This latter is called the *Normal National Grid Reference*.

It will be realized that by dropping the last two or three figures of the full ordinate numbers, there is loss of precision in defining location, but this is not appreciable on maps of medium and small scale. But when the first figure, the 100-kilometre figure, is dropped, an ambiguity of general position is introduced, because the same Normal Kilometre Reference and Normal National Grid Reference occur in every 100-kilometre square shown in Fig. 62. Instead of avoiding ambiguity by retaining the 100-kilometre figures in what may be regarded as their normal reference positions, it is found more convenient in practice to place both figures together and separate them from the remaining figures of the reference by a stroke, thus, 51/38 77 or 51/389 770. These forms are known respectively as the *Full Kilometre Reference* or *Full Four Figure*, and the *Full National Grid Reference.*

FIG. 63. A position to define.

Summarizing these names and references for small- and medium-scale maps we have the following table for the point whose full co-ordinates are E538932 m. N177061 m.

Map scale	*Precision*	*Name of reference*	*Grid reference*
10-mile and ¼-inch	1 km.	Normal kilometre or four figure	38 77
Do.	1 km.	Full kilometre or full four figure	51/38 77
1-inch, 6-inch, and 1/25,000	100 metres	Normal National Grid	389 770
Do.	100 metres	Full National Grid	51/389 770

It is not only necessary to be able to abbreviate a detailed reference correctly but also to be able to obtain it correctly from the map. And just as there are appropriate methods of abbreviating, there are appropriate systems of numbering the grids which are drawn on the maps. The system of numbering the 100-kilometre squares drawn on the map of all Britain in Fig. 62 is self-evident. On 10-mile and ¼-inch maps a 100-km. grid would be of little value, so grid lines are placed at intervals of 10 kilometres. Single figures are shown in the margins against each grid line, as in Fig. 64. The estimated position of point P is 3·8

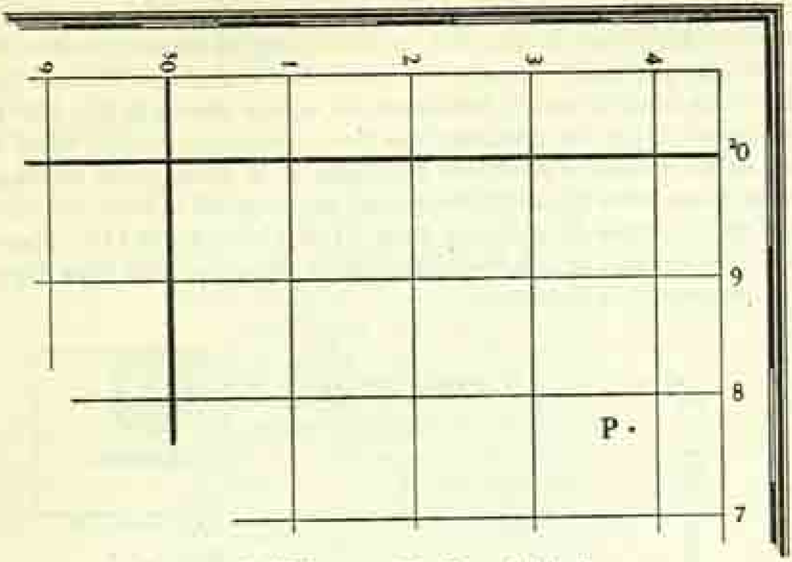


FIG. 64. Grid lines on 10-mile and ¼-inch maps.

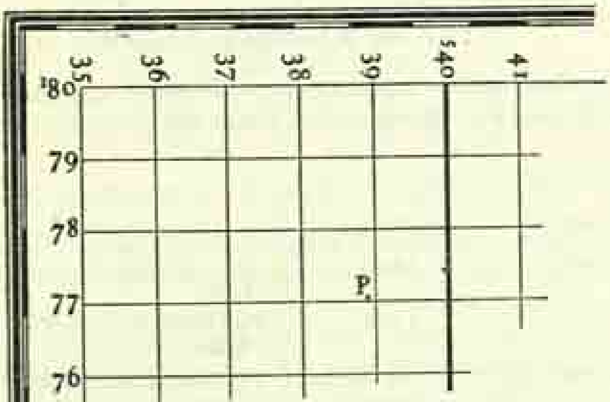


FIG. 65. Grid lines on 1-inch and 6-inch maps.

units east, 7·7 units north, that is, 38 km. east, 77 km. north, which gives the Normal Kilometre or Four-figure Reference of 38 77.

On 1-inch and 6-inch maps, and those on the scale of 1/25,000 which lies between, grid lines are spaced at intervals of 1 kilometre. Pairs of figures in the margins as in Fig. 65 indicate the number of kilometres in the ordinate of that grid line, and position to the nearest tenth of a kilometre is done by estimation as before. Thus the Normal National Grid reference of P in Fig. 65 reads 389 770. The Full Kilometre or Full National Grid Reference is obtained by picking up from the margin the small-type figures representing the hundreds of kilometres in each ordinate, and putting them together in front of the other figures as explained before. In both Fig. 64 and Fig. 65 it will be seen that the required figures are 51. In case of difficulty in seeing this point, imagine the appropriate small-type figure to be printed against all large-type figures. The required 100-kilometre number also appears in a margin or cover diagram on small- and medium-scale maps.

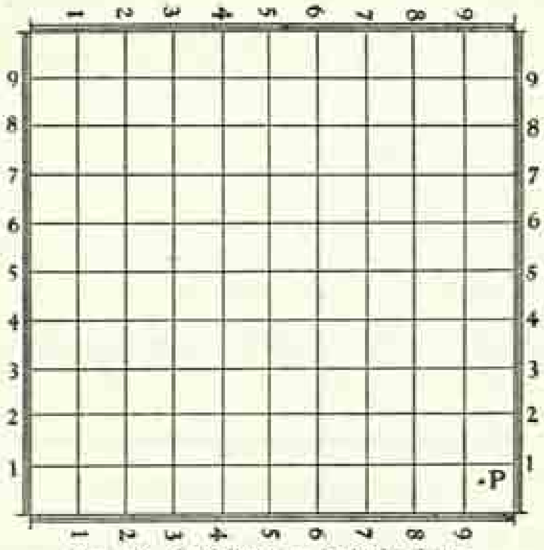


FIG. 66. Grid lines on 25-inch plans.

On the so-called 25-inch to the mile plan, more accurately the 1/2,500 plan, the reference system varies slightly from the above. Each sheet in the new series is one kilometre square and covers one grid square from the system shown in Fig. 65. Each of these squares already has its reference number. Thus the kilometre reference for the square containing P is 38 77, and the Full Kilometre reference is 51/38 77. Consequently any detailed reference on this particular plan can be prefaced by this reference number, rendering it unique throughout the country.

Pin-pointing is done as before. The kilometre-square sheet is divided into squares of 100 metres a side, as in Fig. 66. The most general reference to the point P is that it lies in square 90. This is appropriately called the 100-metre reference. By estimation, the position is more accurately described to the nearest 10 metres as 93 06. By using a scale reading in metres, a one-metre reference is obtainable, namely, 932 061. In order to avoid ambiguity with similar references on other sheets in the series, the plan number must preface the detailed reference, thus 51/3877/90 for the *Full Hundred-metre Reference*, and so on for the *Full Ten* and *Full Metre Reference*.

The largest scale plans, the 1/1,250, approximately 50 inches to the mile, take four sheets to cover the same ground as one sheet on the 1/2,500 scale. Each quarter has the plan reference number suffixed by NW., NE., SW., or SE. The point *P* lies in the SE. quarter of Fig. 66, therefore the largest scale plan showing

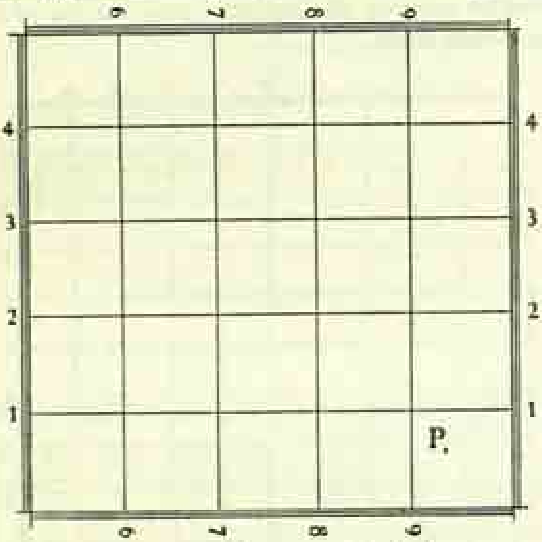


FIG. 67. Grid lines on 50-inch plans.

the point *P* is Plan 51/3877 SE. Each sheet is divided into squares of 100 metres a side, like the parent plan, and identically numbered. Thus there are fewer squares but they are larger in size, as shown in Fig. 67, and this enables the position of *P* to be stated to the nearest metre with rather more certainty than on the 1/2,500 scale, but the method of procedure is the same.

Grid references on the large-scale plans, of a point whose full co-ordinates are E 538932 m. N 177061 m., may therefore be summarized as follows:

Plan scale	*Precision*	*Name of reference*	*Grid reference*
1/2,500 and 1/1,250	100 metres	Hundred Metre	9 0
	10 metres	Ten Metre	93 06
	1 metre	One Metre	932 061
	100 metres	Full Hundred Metre	51/3877/9 0
	10 metres	Full Ten Metre	51/3877/93 06
	1 metre	Full One Metre	51/3877/932 061

3. Grid and Graticule

A grid has been described as a series of lines drawn parallel to and at right angles to the central meridian forming a series of squares. By contrast, a graticule is a series of lines of latitude and longitude. Only in one projection previously described, namely, the simple cylindrical or *plate carrée*, do lines of latitude and longitude also form a series of squares. It follows therefore that since this projection is not in use for topographical maps, a Grid and Graticule never coincide.

On the Ordnance Survey National Projection the central meridian is 2° West, and all north-south grid lines are parallel to it. The meridians converge towards the north as shown in Fig. 62, but the grid lines by definition do not converge. A place therefore has true north indicated by its meridian and grid north indicated by the grid. Grid north and true north coincide only at 2° West, and magnetic north coincides with these only at long intervals of time when the local magnetic variation is 0.

Every place on the map has a reference in terms of latitude and longitude, which is fixed and which can be stated in varying degrees of precision commensurate with the scale of the map. But estimation must nearly always enter into definition of location, and this is infinitely easier and more certain when using a series of squares than when working on indefinable shapes bounded by curved lines to north and south and slightly converging lines to east and west.

It is to be hoped that some day each sheet will bear an alphabetical index of the names to be found upon it, with grid references. This would be of assistance to map-users who search for a name that is not there, or which is there but refuses to give itself up. It would be a natural development of the system, like the bench-mark lists and the numbering of fields on the 1/2,500 plans, achieved by quoting the four-figure reference of the field centre.

Diagrams in this chapter have been reproduced from the O.S. pamphlet on the National Grid with the sanction of the Controller of H.M. Stationery Office.

CHAPTER SIXTEEN

MAP TITLE AND SCALE

THE remaining chapters in this first part of the book deal essentially with outstanding aspects of maps, a knowledge of which is necessary for sound map-reading, and with the broad geographical interpretation of landscape as depicted on topographical maps.

Two items which might well receive early attention since they come first in the study of a map are the title and the scale.

1. MAP TITLE

Map sheets are nearly always given names to facilitate reference and location. The name may take after an important town, district, or natural feature. Thus sheets are published bearing the names Lincoln, Napoli, Zara; Lake District, Yosemite; Cairngorms, and Crater Lake.

Many topographical sheets are normally necessary to show the whole of a country, and consequently it is essential to decide where sheet edges or sheet lines shall fall. The sheet lines of the International Million Map and of many national surveys follow lines of latitude and longitude, but sheet lines of the Ordnance maps of Britain divide the country into a series of rectangles. Whatever system is adopted, the sheets are usually numbered in rows or by grid reference, and consequently each bears a number as well as a name.

Arrangements are commonly made to cover exactly the same area on a scale *a* as is covered by four maps on a scale *b*. Thus four maps in the Ordnance Survey 25-inch ungridded series cover the same area as one quarter-sheet in the 6-inch series. The same applies to the United States maps on scales 1 : 62,500 and 1 : 31,680, and to maps in the India Survey series.

Sometimes sheet lines fall awkwardly, cutting through the heart of a town or district which possesses essential unity. A special sheet made up of parts of relevant sheets may then be issued as a Special or District sheet.

Unless a region is well known, it is sound practice to locate it on an atlas map, and to relate relief and drainage to the country at large, and towns and villages to surrounding settlements. This provides a background against which detail may be studied. Thus the Lake District sheet is seen in relation to the whole of north or north-west England, or the Zara sheet in relation to the Dalmatian coast. This practice also gives realism in the use of the atlas, because the mind becomes trained to see the detail behind the generalized atlas maps.

2. Map Scale

After noting the name of the map in order to establish location, one should instinctively look for the scale. This is usually shown in a number of ways, notably

(a) in words;
(b) by scale lines; and
(c) as a representative fraction.

Let us consider each of these in turn, adding
(d) other indications of scale.

(a) *Words.* Words can convey scale very simply and conveniently in such a phrase as one inch to the mile, because it is easy to think in terms of inches on the map, and of miles on the ground. Quite naturally maps often become known by convenient scale names, such as the Eighty-thousand, the 1-inch, and the 10-mile. It might be noted that United States sheets on a scale of 1 : 62,500 are sometimes wrongly spoken of as 1-inch maps, just as the British maps on a scale of 1 : 2,500 are miscalled 25-inch maps.

(b) *Scale Lines.* A scale line several inches long usually appears on all topographical sheets, and subdivisions represent units of national measurement. Thus units will represent miles, furlongs, and chains, or kilometres and tenths of a kilometre. By using dividers, the distance apart of places is read from the scale line. More than one scale line may be given, often one in terms of miles, one in kilometres, and one in thousands of yards. Distances can then be read in any of the units without arithmetical conversion.

The major units in a scale line are termed primaries, and the subdivisions secondaries. If the whole scale line is divided into primaries and secondaries, it is said to be *fully divided.* More often, the scale line is not fully divided, but a primary unit is placed in front of the zero mark at the left-hand end, and this alone is divided into secondaries, numbered from the zero mark towards the left. This gives an *open divided scale,* and once the reason for the arrangement is grasped, as it is likely to be immediately a length is scaled off with dividers, a fully divided scale is seen to be unnecessary. Both methods are seen in Fig. 68. It is of course preferable to read distances direct from a scale line rather than to measure them in inches with a ruler and then make mental conversions.

On some maps a time-scale line is given, based on about $4\frac{3}{4}$ kilometres per hour. In hilly country, people accustomed to walking keep an extraordinarily steady pace, and in these circumstances the time scale is useful. It might be noted that a signpost at the foot of a mountain showing the time normally taken to reach the summit is more useful than one showing distance. A modern application on air-maps would be a series of lines marked off in terms of time at various speeds possibly from 150 to 500 miles per hour.

Distances are often taken from a map with dividers, and measured on a *diagonal scale*, although this is seldom drawn on maps. The principle of the diagonal scale which is designed to give a high degree of accuracy is illustrated in Fig. 68 (*c*). The primary divisions need no explanation. The secondaries on the top and bottom are tenths of primaries. By joining points obliquely as from *O* to *R*, lines become progresssively farther from the vertical *OQ*. Thus the point *X* is half a tenth from *OQ*; while in terms of primaries *Y* is 0·73 from *OQ*. A diagonal scale for a 1-inch map could have a primary of 1 inch divided into

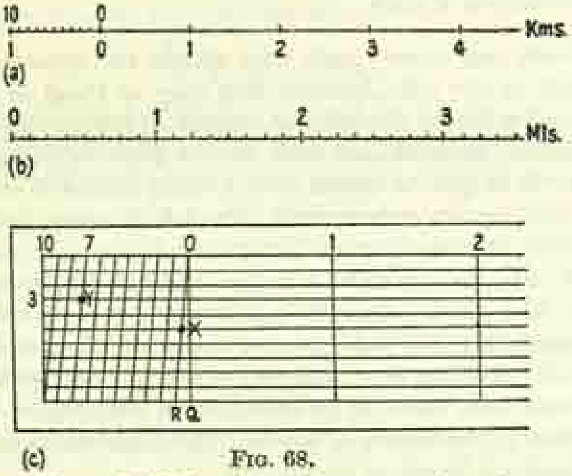


FIG. 68.

(*a*) Open divided scale in kilometres and tenths
(*b*) Fully divided scale in miles and furlongs
(*c*) Diagonal scale to read in tenths and hundredths

eight secondaries to show furlongs. Ten horizontal lines would then enable distances to be read in miles, furlongs, and tenths of a furlong, that is, in miles, furlongs, and chains.

(*c*) *Representative Fractions.* On a 1-inch map, 1 inch on the paper represents 1 mile or 63,360 inches on the ground. The representative fraction is therefore said to be 1 to 63,360, and is shown on the map as 1 : 63,360, or as $\frac{1}{63,360}$. This not only means that 1 inch on the map represents 63,360 inches on the ground, but equally that 1 foot, yard, or centimetre represents 63,360 feet, yards, or centimetres. The representative fraction, often abbreviated to the letters R.F., of the 6-inch map is similarly 6 : 63,360 written in the form 1 : 10,560.

It should be observed at the outset that the representative fraction denotes the relationship between linear measurements on the map and on the ground, and not the relationship between areas. Thus when the R.F. is 1:63,360, 1 linear inch represents 63,360 linear inches, but 1 square inch represents 1 square mile, or 63,360 × 63,360 square inches.

Plans and topographical maps of any country are generally drawn in scale series. One French series runs 1:50,000, 1:100,000, and 1:200,000. The scale of 1 : 1 million gives rise to a 1 : 250,000, 1 : 125,000, and 1 : 62,500, and these scales are almost identical with the British series of a quarter-inch, half-inch, and one inch to the mile.

When the representative fraction is stated, it is easy to draw a scale line using any system of units. Suppose for example the R.F. of a map is 1 : 63,360, and it is desired to draw a scale line in kilometres. The following proportion sum holds true:

	63,360 cm.	on the	ground	are	shown by	1 cm.	on the	map.
$\therefore$	1 cm.	,,	,,	is	,,	$\frac{1}{63,360}$ cm.	on the	map.
$\therefore$	100,000 cm.	,,	,,	are	,,	$\frac{100,000}{63,360}$ cm.	,,	,,
i.e.	1 km.	,,	,,	is	,,	1·578 cm.	,,	,,

A line is then drawn and marked off into lengths each 1·578 cm., either with a ruler or by geometrical methods.

It is always possible to calculate quite simply from the representative fraction, the accuracy with which measurements can be taken from a map, provided of course that there has been no material distortion of the paper. It is not difficult to measure distances on the map to the nearest hundredth of an inch. Then since, for example, 1 : 50,000 means that 1 inch on the map shows 50,000 inches on the ground, $\frac{1}{100}$ inch on the paper shows 50,000 hundredths on the ground, that is, 500 inches, or 14 yards approximately. In the same way, ground measurements can be taken from a 1-inch map within about 17½ yards, from a 6-inch plan within about 3 yards, and from a 50-inch plan within about a foot. This helps one to understand that on the 50-inch plans buildings and roads are shown true to scale without difficulty.

People often wonder what size churches, hospitals, and houses look to a pilot from this height or that. The representative fraction of the map could tell them. A 6-inch plan, R.F. 1 : 10,560, held one foot from the eye, represents detail the same size as it would look from a height of 10,560 feet. The 25-inch plan, R.F. 1 : 2,500 held 1 foot from the eye, shows detail the same size as it would appear from a height of 2,500 feet. The same principle is applicable to other scales, provided detail is true to scale, in which connexion it must be remembered that on medium- and small-scale topographical maps many features such as roads, canals, railways, and rivers are not drawn true to scale.

The table opposite Fig. 7, page 12, shows the representative fractions adopted by various countries for their official maps. The table below shows the equivalents in inches to the mile and miles to the inch of a selection of representative fractions.

(i) *Representative fraction*	(ii) *Inches to the mile*	(iii) *Miles to the inch*
1/1,250	50·69	0·02
1/2,500	25·34	0·04
1/10,000	6·34	0·16
1/10,560	6·00	0·17
1/31,680	2·00	0·50
1/50,000	1·27	0·79
1/62,500	1·01	0·99
1/63,360	1·00	1·00
1/80,000	0·79	1·26
1/100,000	0·63	1·58
1/125,000	0·51	1·97
1/126,720	0·50	2·00
1/253,440	0·25	4·00
1/500,000	0·13	7·89
1/633,600	0·10	10·00
1/1,000,000	0·06	15·78

The method of establishing the relationship shown in columns (i), (ii), and (iii) may be shown in the following example:

If the R.F. of a map is 1 : 80,000, find

(i) what length in miles is shown by 1 inch,

(ii) what length in inches shows 1 mile.

(i) 1 inch on the map shows 80,000 inches on the ground,
i.e. 1 inch ,, ,, 1·26 miles ,, ,,

(ii) 80,000 inches on the ground are shown by 1 inch on the map.
∴ 1 inch ,, ,, is ,, $\frac{1}{80,000}$ inch on the map.
∴ 63,360 inches ,, ,, are ,, $\frac{63,360}{80,000}$ inches on the map.
i.e. 1 mile ,, ,, is ,, 0·79 inches on the map.

(*d*) *Other Indications of Scale.* There are often other indications of scale, chiefly in the form of (i) minutes of latitude marked along the side edges of the map, or (ii) a grid made up of squares of stated dimensions, or (iii) distances along roads stated in miles.

(i) As the circumference of the earth is approximately 25,000 miles, a degree of latitude is very nearly 70 miles, and a minute of latitude 1·1 miles. If minutes of latitude are marked along the side edges of the map, and the length of one of these is measured in inches and equated to 1·1 miles, a sound idea of the scale of the map is obtained. Thus if the length of a minute on the map is approximately 1·1 inches, it is reasonable to surmise that the map scale is either 1 inch to the mile or the nearest other common scale, 1 : 62,500. The length of minutes of longitude varies with the latitude, because meridians converge as they approach the poles, and consequently their length is not equally helpful in determining scale.

It might be noted that the latitudinal method of determining approximate distances is often very helpful when using an atlas map, or when approximate latitudes are known from memory. Thus one could give a fairly satisfactory answer if asked the distance from Hudson Bay to Magellan's Strait or from the Cape to Cairo, pairs of places which lie roughly on the same meridians. On some foreign maps, such as Japanese, the only immediately decipherable information about scale may come from the degrees of latitude and longitude marked in the margins.

(ii) On gridded maps scale can be deduced if the spacing of grid lines is stated in ground distance.

(iii) On some maps road distances are marked between towns, and on others, miles are numbered along main roads outward from large towns. In either case it is a simple matter to calculate the map scale from the information given. The reverse process was used to determine the length of the English mile used on the Gough Map.

CHAPTER SEVENTEEN

SECTION DRAWING AND CONTOUR PATTERNS

FAMILIARITY with the map-key or legend is a prerequisite to effective map-reading. But no amount of familiarity with conventional signs and symbols can give or replace the ability to visualize topography from the map, and this ability is one of the most important assets in the interpretation of landscape as depicted on maps. No apology is therefore made for the considerable space which is devoted to ways and means of developing this ability. The simple exercise of section drawing forms a suitable introduction, and this will be followed by an examination of contour patterns.

1. SECTION DRAWING

The Roman custom in road-building was apparently to make roads straight from place to place, regardless of hills and vales. The rise and fall or long-

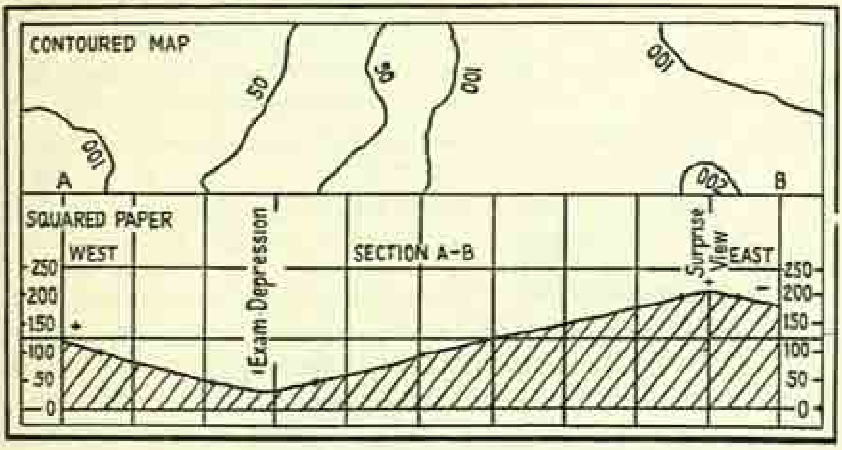


FIG. 69. Section across contoured 6-inch map.

profile of the road is a section across country along the line of the road. It is comparatively easy to draw cross-sections along any line on a contoured map, but it is best to begin with simple exercises where contours are widely spaced and clearly marked. The following example in reference to Fig. 69 shows the method.

The line of section *A–B* is first examined to ascertain the difference in altitude between the highest and lowest points, here from somewhat below 50 feet to over 200 feet. A convenient vertical scale has then to be chosen, remembering that over- or under-emphasis of relief alike produce an absurd effect. In general a section should not exceed about an inch in height. Hence in this example 1 inch in height could represent a range of altitude from 0 to 250 feet. One horizontal line on a piece of $\frac{1}{10}$-inch squared paper is then numbered 0, and the horizontal line an inch above it, 250 feet. A rise or fall of 50 feet is shown by 2/10ths of an inch, so alternate intermediate lines are numbered 50, 100, 150, and 200 feet.

The top edge of the squared paper is laid along the line of section, as in the figure. The small squares have been omitted for clarity. Working from left to right, the first contour crossed is the 100 feet. At that point on the section line the land is therefore 100 feet above sea-level. A dot is made in the appropriate place on the section paper by following down the vertical line of the paper which meets the section line at the 100-foot contour, until this vertical line crosses the horizontal line numbered 100. The second contour is numbered 50, so a dot is placed in its appropriate position to the right of the first, but on the horizontal line numbered 50. The process is continued until all cutting-points of section line and contours are represented by dots. These are then joined by a flowing freehand line, and not by a series of straight lines which would give artificially abrupt changes of slope.

One problem which arises is the height of the section at the left edge before the 100-foot contour is reached. Inspection will show that as the land slopes downwards from the 100-foot to the 50-foot contour line, it will also slope downwards to the initial 100-foot contour. Therefore the left end of the section line must commence somewhat above the 100-foot line. This fact could be indicated by a small plus sign when marking section dots.

A second problem is that two dots are both at 50 feet. The land between is likely to rise or fall. Since the land on both sides slopes downwards towards the two 50s, it can safely be presumed that between them the land is below 50 feet. Therefore, when inserting the two dots, a small minus sign may be placed between them to remind one to dip the line in this part. Similar problems occur between the two dots at 200 feet, and at the right-hand edge of the section. It will also be noted that there is a change of contour interval from 50 feet to 100 feet, but this should occasion no special difficulty in drawing the section. The change of interval, however, does show the difficulty of visualizing relief simply by the distance apart of contours, and the need to note in the initial scrutiny of the map whether or not contour interval is constant.

Sometimes it is difficult to decide whether land is rising or falling, but help is often available from spot heights between contours, or from streams which necessarily occupy valleys. It is often of help to notice also the lie of the land just above the section line, or just below it, the latter information being obtained by raising part of the paper with one hand while holding the remainder in position with the other. With experience it will be realized that a profile never changes its direction of slope, from down to up or up to down, except between contours of identical height. The same principle is seen later to have a general application to all isoline maps.

On many maps around the scale of an inch to the mile contours are so crowded as to make the above method of section-drawing seem impracticable. In such cases it is sufficient to ignore all but contours at conveniently chosen vertical intervals. If some contours are thickened, these can be used to simplify the work, and on layer-coloured maps changes of colour may be used in the same way.

Sections along roads, rivers, and railways present difficulties because the straight edge of the paper will not lie along a sinuous line of section. If the section line approximates to a series of straight lines, the paper can be twisted this way and that to fall along each straight length, and a composite section is drawn as a series of sections end to end. If this is impossible, horizontal distances between contours must be measured by some other means, as with dividers. The contours themselves show the amount of vertical rise and fall.

It is not necessary always to represent sea-level on a section, although this is frequently done. Such would be of little value on a section to show profile of a proposed road or railway. It is good practice, however, to name outstanding hills and valleys, and even town positions on a section. The names are most conveniently printed vertically, though this does not simplify reading. Appearance is often improved if the section is filled in solid. A title and statement of section direction, such as NNE–SSW., should be given.

Intervisibility of Points, that is, whether or not one point is visible from another, is probably most quickly revealed to a beginner by drawing a section from one to the other. The section method will also show the extent of dead ground, or ground which cannot be seen when looking from a point in any given direction. Intervisibility of points cannot be assumed, as many people would affirm who recall occasions when they thought themselves almost at the summit of a mountain only to find on surmounting a shoulder that the summit appeared as remote as ever.

Exaggeration of Vertical Scale is a last problem which often gives trouble in connexion with sections. It should be realized at the outset that sections have two scales, the one horizontal and the other vertical. The horizontal scale is that of the map, unless deliberately altered. The vertical scale is chosen at will, and is often arranged so that the section is about an inch high. In nearly all cases the two scales are different, the vertical scale being greater than the horizontal. Any vertical exaggeration can be determined by dividing the horizontal scale into the vertical. To do this, both scales must be expressed in *the same terms*. Either of the following methods is satisfactory:

(*a*) By completing the following statement:

(i) Vertical scale: No. of inches that show 1 mile or 5,280 feet =

(ii) Horizontal scale: No. of inches that show 1 mile or 5,280 feet =

(iii) Exaggeration of vertical scale is (i) $\div$ (ii) =

As a concrete example take the section drawn in Fig. 69. On the original drawing the vertical scale is 1 inch to 250 feet, 21·12 inches to 5,280 feet. The horizontal scale is 6 inches to the mile, the same as the scale of the map. Therefore line (iii) above reads $21{\cdot}12 \div 6 = 3{\cdot}52$.

(*b*) By comparing the scales expressed as representative fractions. Using the same example:

(i) Vertical scale is 1 *inch* to 250 *feet* or 1/3,000

(ii) Horizontal scale is 6 *inches* to 1 *mile* or 1/10,560

(iii) Exaggeration of vertical scale is (i) ÷ (ii), i.e. $\frac{1}{3{,}000} \times \frac{10{,}560}{1} = 3{\cdot}52$.

If it is desirable, as it often is in geological work, that the section should be *true to scale*, or in other words that both horizontal and vertical scales should be the same, the horizontal lines would have to be numbered, in this example, so that 6 inches above the zero line read 5,280 feet. This would give 88 feet per 10th of an inch, an awkward quantity when contours read upwards in 50s and 100s.

Summarizing the do's and don'ts of section drawing:

(*a*) Don't use scrap-paper to transfer contour spaces to section paper.

(*b*) Don't as a rule make sections more than 1 inch high.

(*c*) Don't use more dots than necessary if contours are crowded.

(*d*) Don't reverse direction of slope except between contours of the same altitude.

(*e*) Name outstanding features along the line of section, indicate direction, state vertical and horizontal scales, and any exaggeration of one scale in terms of the other.

2. Contour Patterns

A further aid to the visualization of relief as shown by contours is the ability to recognize contour forms or patterns and to connect them with the topographical forms which they represent. The chief of these, which are illustrated in Fig. 70, may be described briefly as follows, assuming the contour interval to be constant:

(*a*) *No contours*, land virtually flat or without rise and fall greater than the vertical interval of contours: flood-plains, marshlands, deltas, plateaux.

(*b*) *Contours uniformly spaced*, land sloping uniformly: escarpments, valley sides.

(*c*) *Contours getting closer together* from low land to high, a concave slope, steepening towards the top: the lower slopes of valleys in regions of mature water erosion, sides of cirques or corries.

(*d*) *Contours getting farther apart* from low to high land, the reverse of (*c*): upper slopes of valleys and spurs, often a continuation upward of (*c*), the change taking place at the point of inflection, and giving with the previous slope a complete profile sometimes spoken of as the Hogarthian line of beauty.

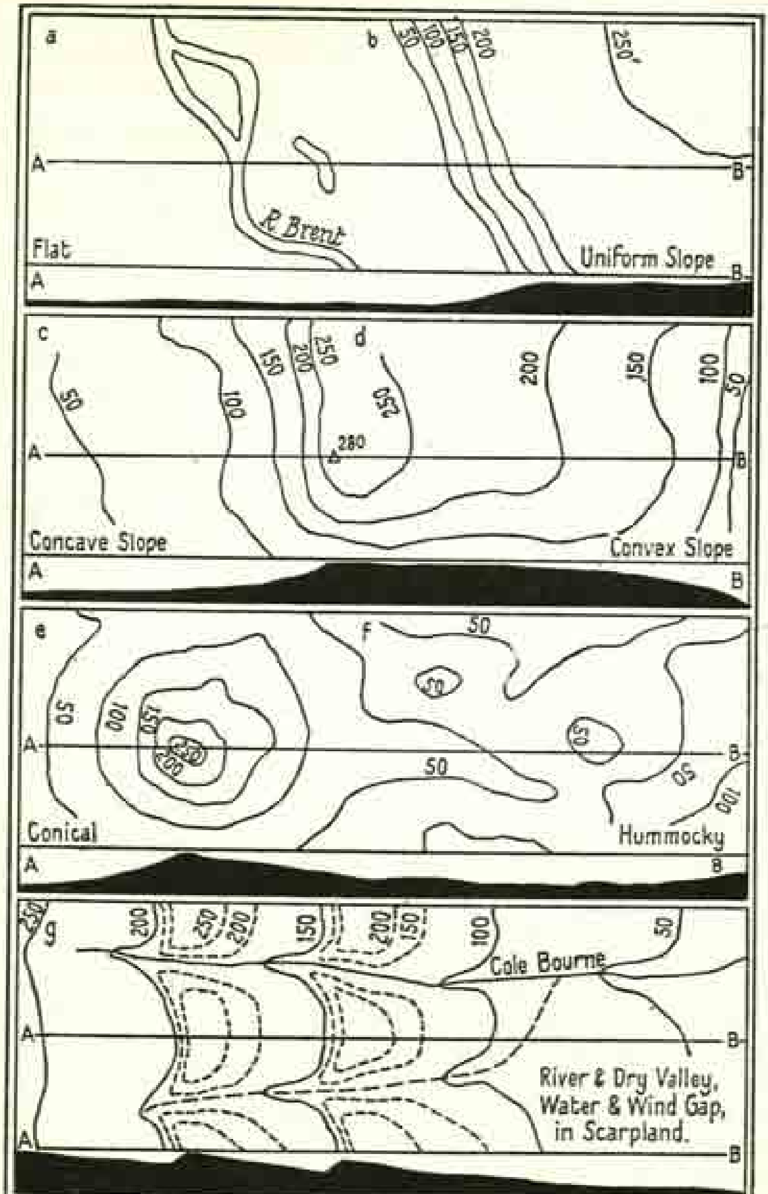


FIG. 70. Contour patterns and land forms.

(*e*) *Contours circular* or approximately so, a conical hill, or in reverse, a basin: volcanoes, puys, domes, granitic uplands, tors, residual hills, craters, basins of inland drainage.

(*f*) *Contours showing no distinctive pattern*, land hummocky and without well-defined land forms: peneplains, ground moraines.

(*g*) *Contours V-shaped* as shown by the solid lines in (*g*), valleys or spurs. The slope of the valley-sides may be uniform, concave, or convex, or a combination of these.

Once patterns are mastered, it is not difficult to draw contour sketches to represent given land forms. As an example, suppose that it is necessary to represent on one sketch a river valley, a dry valley, a wind and a water gap in a region with two parallel scarps, proceed in stages to produce a sketch like that shown in Fig. 70 (*g*).

1. Draw a river and a tributary valley, here shown by a dotted line.

2. Draw fairly evenly spaced contours as shown in solid lines, and number these to show a general slope from river sources towards the mouth, cutting back V-shapes in the contours to mark the valleys.

3. Between these contours and the rivers draw a series of closed contours, here dotted, close together on the one side to represent the steep scarp slopes, farther apart on the other side to show the gentler dip slopes. Number these, taking a cue from the numbers of the contours drawn first. If the dotted valley-line is then rubbed out, its former position marks a dry valley; wind gaps occur where this valley cuts the escarpments, and water gaps occur where the river cuts the escarpments.

This example makes use only of contour patterns (*b*) and (*g*). In representing a glaciated upland, use could be made of (*a*) for flat glaciated valley-floors, (*b*) for steep valley-sides, and possibly (*f*) for the uplands. A more pronounced upland relief would make use of rather elongated forms of (*e*). A dissected plateau in a dry region might show a series of steep-sided ravines and canyons more or less at right angles, all revealing pattern (*b*), and with pattern (*f*) showing only slight relief on the plateau, or combined with (*e*) for residual hills.

In *Map Reduction*, as when reducing a map on a scale of 1 inch to the mile to a scale of ½ inch to the mile, it is obviously necessary to omit much topographical detail, such as small tributary streams and certain of the contours. A whole sheet is too much to tackle as a unit, but the work is simplified by drawing over the original map a grid of 2-inch squares, and copying one feature at a time, square by square, on to a 1-inch grid. Comparison of a topographical map and a corresponding atlas map offers a guide as to how far detail is commonly omitted and salient features generalized. The finished sketch should, however, preserve the salient characteristics of the original map, and an eye to contour pattern is a valuable aid to this end.

CHAPTER EIGHTEEN

MAP MODELLING

ONE of the most effective and interesting methods of learning to read relief is to make a model from a contoured map. Three different approaches are described below. A small area taken from a large-scale map with well-spaced contours should be chosen for practice.

1. THE PEG METHOD

Suppose it is desired to produce a model of Fig. 70 (*c–d*). Contours are shown for 50, 100, 150, 200, and 250 feet. Sets of pegs are prepared to represent these heights above sea-level. If one-quarter of an inch is allowed for each 50 feet, the sets will measure respectively in inches $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, and $1\frac{1}{4}$. Appropriate pegs are then set up perpendicularly along the contours. A peg $1\frac{3}{8}$ inches long represents the spot marked 280 feet. The space between the pegs is then packed with a suitable medium so that the surface passes smoothly from the tops of one row of pegs to the next. The result is a model of the figure.

The contours can be traced on cardboard or plywood, and the pegs cut from matchsticks. They can be stuck in position by dipping the ends in glue. Alternatively wire nails of appropriate length can be hammered into the base. Where relief is intricate many pegs are necessary, but where gradient is uniform few pegs are required. If a piece of glass is used as base, it is only necessary to place it over the map and stick pegs in position on the glass.

Plasticine, moulder's sand, or clay are suitable filling-materials. Clay cracks on drying, but a cast of the model can be taken before cracking commences. Moulder's sand consists of fine quartz sand with about 4 per cent. of clay, and is usually available at foundries. It is used when moist and then dried slowly. Any cracks are filled with more sand, and the surface finally hardened with a fixative, such as dilute gum arabic, after which it will take oil colours.

2. THE LAYER METHOD

In the Layer Method contours are each traced on separate sheets of cardboard and contour forms are cut out. The model is then built up by fixing the lowest contour form to a suitable base, and successive forms in altitude order from base upward in the same relative places as corresponding contours occupy on the map. The work is very tedious where contours are numerous and complicated, but the results are worth while, and the method is that employed by various professional model-makers. Steps are taken out with plasticine or clay.

It is often practicable to cut original maps glued to thin cardboard, and so at little expense to avoid tedious tracing. In any case, each layer should have marked upon it the next higher contour, to ensure accurate placing. Cutting is best performed by fret-saw, unless the cardboard is so thin that scissors or a knife prove adequate. As an alternative to glue, tacks can be employed.

Materials other than paper and cardboard are suitable for building up the layers. Clay or plasticine may be rolled into sheets of uniform thickness by placing strips of wood on each side of the board for the roller to run on. The material is less inclined to stick to the board and roller if these are sprinkled with chalk dust for clay, or sponged with water if plasticine is being used. Contours are transferred to the medium by tracing them on paper, preferably in reverse, with hectograph ink, and then placing the paper face downwards on the clay. Cutting is accomplished with a pin or knife. Steps are smoothed out without the addition of new material, but constant reference to the original map is necessary.

Experiments can also be made with such materials as Keene's cement. Layers of uniform thickness are made by pouring the liquid cement onto a level oiled glass plate, edged with wooden strips. Layers are cut before the cement becomes brittle. Ordinary gelatine soaked in cold water, then removed and heated till melted, can also be poured onto oiled glass and later cut to shape and placed in position. Steps in this material are taken out with a hot palette knife.

A variant of the above method is to start with a number of sheets of cardboard the same size as the base. On the first sheet is traced the highest contour. The contour form is cut out and put aside, while the remaining cardboard is turned face downwards and stuck to the base. The next highest contour form is cut away from the second sheet, which is likewise turned over and stuck down. In this way a negative form or mould of the relief is built up. The steps are taken out as before, and a positive is cast in plaster. Theoretically, at least, no tracing of contours is necessary, since cutting is done with the same map placed over successive sheets. Position of successive layers is determined by the fit round the edges of the model.

3. The Section Method

The section method was employed with success to make a relief model now exhibited in the National Museum, Cardiff, of the whole of Wales on a scale of 1 inch to the mile. Sixty-seven different blocks were made, the normal size being 18 by 12 inches. Parallel vertical sections across the map were drawn on thin cardboard at intervals of $\frac{3}{10}$ths of an inch. The profiles were then cut out and the cardboard made up to a thickness of $\frac{3}{10}$ths of an inch with plasticine. When these thickened sections were arranged in order, they gave a generally accurate representation of relief. It was necessary to trim off or fill in the steps, smooth the surface, mark streams with a needle, and check surface features.

Moulds and positives were made with Keene's cement. The production of a single positive from start to finish involved about 112 hours' work, but a high standard of accuracy was aimed at, and nearly half the time was spent working over the plasticine surface.

A slight variant of the above method consists in transferring sections from the map to both faces of each plasticine or clay slab, then moulding the edge to pass evenly from one profile to the other. When the slabs are placed on edge in juxtaposition there should be no steps, as the profiles along adjacent faces should be identical.

Sections may also be cut out in strong paper or thin cardboard, and gummed into vertical position, and the spaces filled as in the peg method. There is probably little difference in the layer and section methods so far as time is concerned, but a region which proves laborious to model by the layer method may prove easier by the section method.

4. Casting Moulds and Models

A permanent model is best obtained by making a mould from the original, and in the mould casting a fresh positive in plaster or cement. A mould can be made quite simply in plaster of Paris, by placing the original, which should be entirely free from undercuts, on a smooth surface, building walls around it, and running liquid plaster of Paris over the model to a depth of ½ to 1 inch. The walls may consist of strips of plasticine or clay, pieces of wood or glass.

The recognized way to mix plaster is to let it run through the fingers, palm upwards, into a basin of water until enough is added to stand above the surface. Three pints of water will probably take 4 lb. of plaster. The hand is then immersed in the basin and the plaster thoroughly mixed. The creamy liquid is poured over the model and blown into all crevices to eliminate air-pockets. More plaster can be mixed and added until the desired thickness is reached.

If the mould is ultimately to be chipped away from the cast, as would be necessary if undercuts were present, the first basin of plaster should be coloured so that proximity to the cast is appreciated. Usually, however, undercuts are avoided and several positives are required, and then there is little point in using colour.

The plaster will set firmly in an hour, and the original can be stripped out, often most easily by immersing the whole block in water to eliminate suction. All that remains is to cleanse the mould with water and render it non-porous with two or three coats of enamel, shellac, or soft soap worked on the surface for twenty minutes in a lather, followed by a film of oil or grease each time the mould is used.

Casts can be made in any suitable plastic material, such as cement, plaster, paper-pulp, or papier mâché. Walls are again built against the sides of the mould and the plastic run in. Separation under water may again be necessary.

A plaster model is greatly strengthened by immersing pieces of cotton or wire-netting in the plaster when liquid. A wire loop can also be inserted for hanging purposes. The relief of comparatively featureless areas is brought out when drainage is marked on the model.

There is a great deal to be said in favour of using builders' cement for the mould. It takes longer to dry and improves or cures if allowed to lie for some days. It is rather heavy, but very strong, less porous, and less liable to get damaged than a plaster mould. Cement can also be used for positives. The surface when cured takes paint, can be written upon in Indian ink, and can be varnished.

A plaster cast is best treated with weak size, then coloured with poster or oil paints. Paint is also used for rivers and names, as it does not flake off as readily as Indian ink. The surface is finally treated with a solution made by dissolving one part of white wax in ten of warm turpentine. If the original surface is pitted, holes should be filled with killed plaster before painting. Some people prefer Keene's cement, which is handled like plaster of Paris, but hardens less quickly.

Relief models are sometimes coloured to show geology. Then the strata are shown in section on the vertical faces. Land utilization could equally well be shown and correlation revealed between utilization, topography, and altitude.

Paper pulp, which can be used in the mould like any other plastic material, is prepared by soaking torn newspaper, blotting, or tissue paper in water for some days, and beating it till a pulp is formed. The process is hastened by boiling and adding small quantities of caustic potash, but if this is done the pulp should be thoroughly washed before use. Once a pulp has been produced, excess water should be squeezed out and the pulp mixed with an adhesive such as flour paste, cold-water paste, gum arabic, glue, or plaster of Paris.

To produce a model in papier mâché, five to eight layers of paper are pasted in the greased mould. On drying, the model shrinks and leaves the mould. The papier mâché is prepared by tearing any rough-surfaced, unglazed paper, such as newspaper, sugar paper, or experimental paper, into 2-inch squares and allowing these to soak in water for an hour, after which they are removed and pressed flat between sheets of blotting-paper. Flour paste, with a teaspoonful of powdered alum to each cup of flour, forms a suitable adhesive. If desired, a layer of butter muslin or plain paper can be used as the first in the mould. In order to tell when the whole surface has received a complete layer of paper, it is advisable to alternate the direction of the print, or use different coloured papers for different layers. A long period of drying is desirable. The surface can be rubbed down with glass-paper and painted. Models made this way are rather liable to warp, but are extremely light and durable, and suffer no harm even if dropped.

If the original model is built in low relief with layers of cardboard or plywood and the steps have not been taken out, a sheet of plasticine pressed over the top takes an adequate impression, and when stripped off serves as a mould. Cement or plaster is mixed and poured in. The plasticine may allow some distortion to occur because of its flexibility, but no difficulty is encountered with slight undercuts which almost inevitably remain when the steps of a layer relief model have not been smoothed out.

5. Vertical Scale

It is not always practicable, or even desirable, to make the vertical scale of a relief model the same as the horizontal scale. Even on a 1-inch model of England, which would measure about 10 yards from north to south, the highest mountain without vertical exaggeration would be only $\frac{7}{8}$ inch high. A rise of 50 feet, though significant to the average individual, is only $\frac{1}{100}$th inch rise on a true to scale model, just the thickness of a sheet of writing-paper. Consequently, in all but very hilly country vertical exaggeration is desirable on 1-inch maps, both to bring out significant relief features and to produce what the eye interprets as a reasonable representation of relief. Models with a horizontal scale of less than 1 inch to the mile normally require considerable vertical exaggeration, but this should never be such as to caricature relief. Models made from 6-inch maps can have identical horizontal and vertical scales.

Probably the best general rule about vertical scale is to aim at a model whose range of altitude lies between 1 inch and $\frac{1}{4}$ inch. This approach caters for mountainous and flat land, large and small scales. The vertical and horizontal scales should be stated on the model, and also any vertical exaggeration.

6. Model Illusion

An illusion of a landscape model may be produced very quickly and with so little trouble that it is worth trying by all who are interested in maps. The only apparatus required is a contoured map, about half a dozen sheets of glass, a square foot each, some thin oil paint, and a brush. Cloche glass is convenient and cheap and may usefully do a turn in the laboratory during its off-season.

A sheet of glass is placed over that part of the map which it is desired to see in relief, and the lowest contour is traced on the glass with a water-colour brush dipped in very thin oil paint. Provided that the contour is easy to follow, the time taken should be no longer than with pencil on paper. Indiarubbers or small squares of cardboard are then placed or glued at the corners of the glass and a second sheet is laid on top. The next highest contour is then traced, and the process repeated till the work is finished. The result is a remarkable illusion of a transparent solid model within the glass sheets, an effect which is even heightened by boxing in the edges.

There is little need to go into detail. Oil paint is easily thinned with turpentine, and a thimbleful is more than enough to complete the job. House-paint or artists' oil colour is suitable. The contour interval should be uniform, and such that the range of relief in the area treated is covered by the number of glass sheets available. Speed and certainty in following the contours is increased if these are first traced on paper so that unnecessary detail does not confuse. It is desirable to number the glass sheets, and unless these are identical in size, to put guide-marks at the corners to ensure correct placing on subsequent occasions. Incidentally relief of the region may be shown in reverse by reversing the order of the glass sheets, or a mirror view obtained by maintaining correct number order and turning each sheet face downwards.

The appearance of the model is naturally affected by the thickness of the corner-stops. Experiment is desirable to establish an optimum thickness, but it seems that when these are about double the thickness of the glass, a satisfactory result is obtained, so that half a dozen sheets give a model about 2 inches high. Appearance is improved if a white sheet of paper is placed under the model, and stops are placed on this to raise the first sheet of glass also. Intricate contour patterns are possible, but details of drainage cannot be inserted. There is also difficulty in showing summit heights, but names are as easily painted on the glass as the contours themselves. The glass is cleaned quite quickly with turpentine, and may be used again for other districts or land forms. Sheets of transparent plastics may prove more convenient to handle than sheets of glass.

CHAPTER NINETEEN

BLOCK DIAGRAMS

Another method of learning to read relief, and the last which will be described, is by drawing block diagrams. These may be regarded as sketches of relief models, and they have the advantage not possessed by models in that they can be used in book illustration. They can be drawn from the map without first producing a model, and some interesting problems arise during the process. Time, patience, imagination, and artistic ability are all desirable. Various approaches may be described under the same headings that were employed in the first part of the previous chapter, though it is more convenient to change the order.

A small area with distinctive relief features should first be attempted and a direction of view chosen that is likely to yield good results. If the topography can be visualized from the contours, a view of the landscape which would yield a good photograph is likely to prove suitable for experiment.

1. The Layer Method

There are four distinct steps in the production of the block diagram, and these are described in order.

(*a*) *A Plan View* is first traced from the map, as in Fig. 71 (*a*), showing contours and drainage. The basis of this example is an area 3 miles square taken from a 1-inch map. Only the 1,500-, 2,000-, and 2,500-feet contours are drawn as they are sufficient to reveal land form. They are numbered 1, 2, 3. A 1-inch grid is superimposed for reference.

(*b*) *A Perspective View*, as in Fig. 71 (*b*), is then drawn on tracing-paper. The amount of foreshortening and the spacing of the horizontal grid lines is best judged by eye. The grid lines provide a guide for copying the contour lines as they would appear in perspective. An extension of the near edge provides a marker for use in the next stage.

(*c*) *A Raised Contour View*, as in Fig. 71 (*c*), is produced from the perspective view first by redrawing the perspective base shape minus the contours, but with the marker line as before. Vertical lines are drawn at the ends of this marker line, and scaled upward in tenths of an inch, starting at 0. Trial may be necessary to establish the best scale unit for any particular model, but it will generally be found that divisions should not exceed 1/10th of an inch each in length. Or, put differently, the range in altitude on the block diagram might conveniently lie between $\frac{1}{2}$ and $\frac{2}{3}$ of an inch, just as it might for the solid model. Vertical lines are erected at each corner of the base shape, to represent the vertical edges of the block. The tracing is then placed over the perspective base shape, with its marker line on the marks numbered 3. The contour numbered 3 is then traced. Next, the tracing is drawn down the page till the marker line is on the marks numbered 2. The contour numbered 2 is then traced. If this second contour cuts the one drawn first, the intruding part is rubbed out, as in a model it would be out of sight behind the first. The process

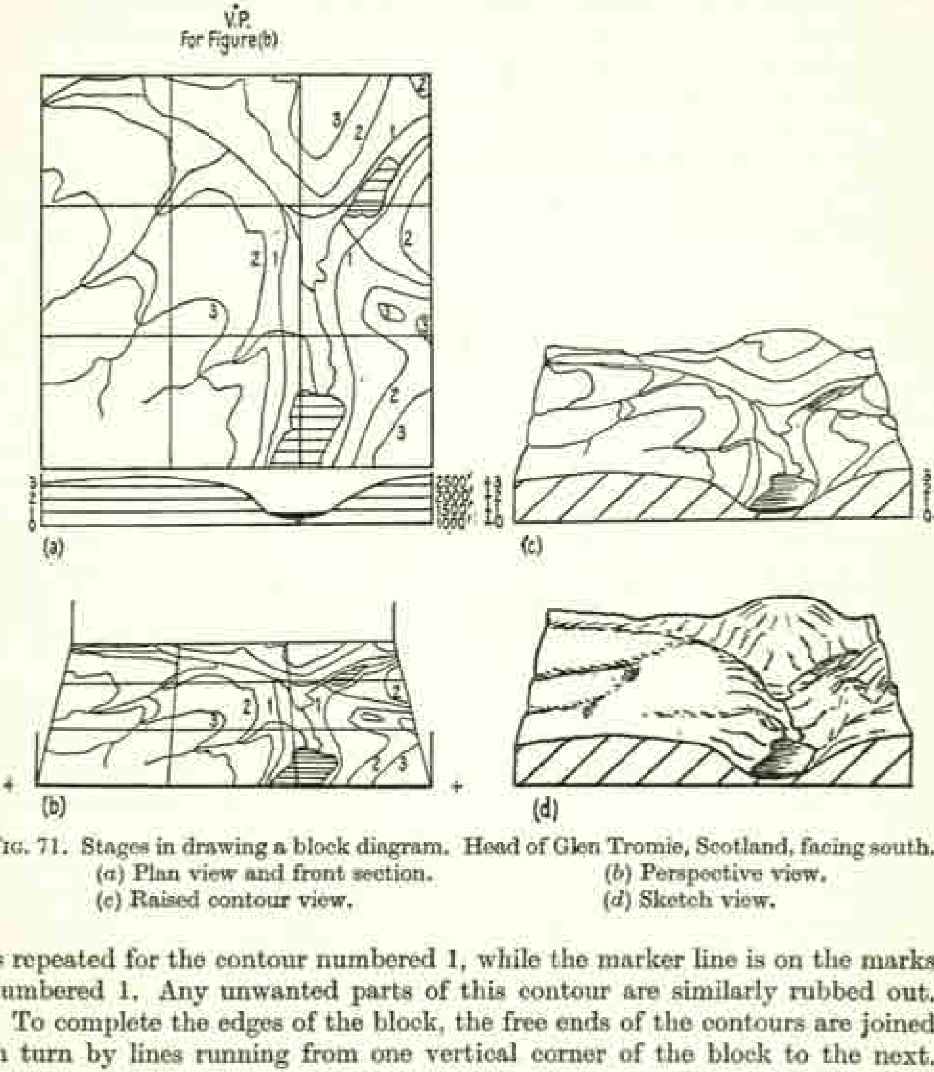


FIG. 71. Stages in drawing a block diagram. Head of Glen Tromie, Scotland, facing south.
(*a*) Plan view and front section. (*b*) Perspective view.
(*c*) Raised contour view. (*d*) Sketch view.

is repeated for the contour numbered 1, while the marker line is on the marks numbered 1. Any unwanted parts of this contour are similarly rubbed out.

To complete the edges of the block, the free ends of the contours are joined in turn by lines running from one vertical corner of the block to the next. This operation presents no difficulty on the front edge because the result is a straight forward vertical section along the near edge of the plan or perspective view, as seen in Fig. 71 (*a*), but imagination is necessary in drawing the greatly foreshortened side edges, for in places parts of the vertical sections may pass out of sight behind high land, indicated by the horizontal contour lines. Depth may be added to the front face to make the block look thicker, and the rivers should be marked.

(*d*) *A Sketch View* or block diagram, as in Fig. 71 (*d*), is then completed by placing a clean piece of tracing-paper over the raised contour view and drawing a minimum number of lines down slopes and elsewhere as deemed essential to bring out the land forms seen through the tracing-paper. In some places rivers will be adjudged as out of sight and hence not drawn as continuous lines. All edges of the block are traced, as they are most significant in aiding the eye to visualize slopes. The best results are often obtained by shading with a soft pencil, but pen is usual if printed copies are required. Much can be gained by studying the technique of the masters.

2. The Section Method

Steps taken to produce a block diagram by the section method are similar to those described for the layer method, thus:

(*a*) *A Plan View*, with grid, is traced from the map.

(*b*) *A Perspective View* is drawn from the plan view.

(*c*) *A Multiple-section View* is then obtained by redrawing the base shape and grid of the perspective view, and drawing upon it in correct position a series of parallel vertical sections taken across the perspective view. The result should look like a sketch of a model in production by the section method. Or with reference to a particular figure, a view of Fig. 70 (*a*, *b*) in this stage would show a series of sections like that drawn along the line *A–B*, but getting shorter from front to back with the escarpment edge moving to the left in successive sections.

(*d*) *A Sketch View* is completed by placing tracing-paper over the multiple-section view, and with economy of line, indicating land forms and drainage as before. The front section provides a face for the block, but depth can be added if desired. The side edges are drawn by joining the free ends of sections, while the back section itself forms the back edge.

If accurate perspective is aimed at, the vertical scale of the sections must be reduced from the front section to the back one. This is not a difficult matter, as reference to Fig. 72 shows. Simply extend the side edges of the perspective base shape till they meet at a point referred to as the vanishing-point. At the corners of the front edge erect vertical lines, and on these mark off a scale ready for the front section. Then through each mark on the scale draw a line back to the vanishing-point. Then wherever a section is drawn across the block, these converging lines give the appropriate vertical scale.

There is no similar easy means of introducing true perspective into the layer method. The same means can be employed to get a true perspective section, but this would not accurately join the free ends of contours, which are raised the same amount regardless of their distance from the observer.

3. The Peg Method

As before, the object is primarily to produce by logical methods a drawing of the model as it would appear in production, and from this to make a sketch to represent the landscape.

(*a*) *A Plan View*, and

(*b*) *A Perspective View* with grid are once again drawn.

(*c*) *A Peg View* is then obtained by drawing vertical lines to scale to represent pegs on the perspective view, not so much along the contours, which need not be drawn in this method, but to represent heights of mountains and escarpments, and of rivers at significant places along their courses. The base position of any peg can be determined by transferring its plan position to the perspective drawing. The height or length of the peg as seen in perspective is determined as in the section method shown in Fig. 72. When the heights of sufficient spots have been shown by pegs, vertical sections are next drawn along the front and rear edges of the block, either by a method already described or simply by drawing vertical pegs of appropriate height at significant points along the edges, and then joining peg tops. Drainage should be inserted at this stage.

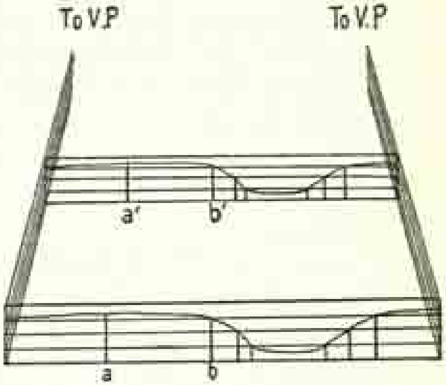


Fig. 72. Identical vertical sections drawn in perspective along the front and back edges of a block. Pairs of pegs lettered *a a'*, *b b'* are of identical height, but are shown in perspective height. The appropriate heights of sections or pegs in intermediate positions may be determined from the scale grid along the side edges. Compare the front edge of the block shown in Fig. 71 (*a*).

(*d*) *A Sketch View* is finally obtained by placing tracing-paper over the peg view, and drawing responsive lines to indicate topography. Drainage is marked and depth added to the block if necessary.

4. Uses of Block Diagrams

Block diagrams serve several useful purposes. Above all they can be used to show the relation between topography, geology, and structure. The latter features are drawn from geology maps upon the vertical face of the block. The evolution of a land surface can be shown by a series of blocks. They require very little skill in their interpretaton, they render long verbal description unnecessary, and are fairly easy to remember and reproduce. They illustrate land forms better than photographs do, and when applied to fairly extensive areas, they illustrate topography in a way which maps alone fail to do. Thus a block diagram of a region exhibiting river capture is often a better illustration than a carefully contoured map on which the vertical interval is rarely less than 50 feet. So far they have been employed mainly by geologists and physical geographers, but possibilities seem to exist for using block diagrams in conjunction with land utilization. Such diagrams would bring out land utilization in relation to topography and altitude.

In the description above, all illustrations have been based on one-point perspective, so that only one face of the block is shown. By two-point perspective, one corner of the block is made to appear near to the observer, revealing a face to left and right of the near corner. This involves some complication of perspective in the section and peg methods, but intelligent application of the principles of perspective already discussed should solve the new problems that arise.

5. Block Diagrams and Small-scale Maps

The methods described in the production of block diagrams necessitate the use of topographical maps to bring out detail of relief, and some artistic ability in the final stage to represent the surface pictorially. Much of their value is lost if recourse is had merely to atlas maps, but the pictorial method of representing topography as used on block diagrams can be applied to small-scale maps with considerable success. No perspective view of the outline is attempted but different types of landscape are treated pictorially on a regional basis. Elevation above sea-level is not shown by this physiographic method, but topography is often a more important factor than elevation, so on balance there may be a gain. Skill is required in the preparation of the maps, but they are easily interpreted by people unskilled in reading conventional physical maps. A scheme has been developed classifying topography into forty different forms, each of which has fairly distinctive pictorial representation. The work shows up well in black and white and has possibilities both in geographical literature and especially for maps in the daily press.

CHAPTER TWENTY

INTERPRETATION OF LANDSCAPE FROM MAPS

In studying a map, outlook is conditioned by the purpose in mind. The motorist is normally interested in roads, the airman in navigation, and the yachtsman in coasts and harbours. The broadest of map studies, which is the purpose of the present chapter, may be described as geographical. To pursue such a study successfully, facility in map-reading and training to interpret landscape as revealed by the map are necessary. Both physical and human geography are involved.

1. Physical Interpretation

The physical geography of the region shown on a map can be studied under two main headings: (*a*) Relief and (*b*) Drainage.

(*a*) *Relief*. A glance at the map should reveal the general height of the region above sea-level. If high, it should be noted whether the surface could be described as mountainous and, if so, whether the mountains have a common summit level, probably indicating that they have been eroded from a former uplifted plain or peneplain. Any characteristic mountain pattern should be observed. The country may show a grain in one direction indicating folding, faulting, or parallel lines of erosion as caused by the movement of an icesheet. Mountains may be grouped, irregularly distributed, or isolated, as in the case of some types of volcanic phenomena. Well-defined mountain forms may be apparent, such as the peaks of sierras, the rounded uplands and tors of ancient igneous laccoliths, or the flat-topped table-mountains and mesas of dry lands and regions of horizontal strata. The walker will inevitably look for the spurs and shoulders which lead to the crests or ridges and will in imagination avoid the valleys or re-entrants that bite back into the mountains only to end in precipitous slopes which seem to guard the summits.

Some high regions show less variety in relief, and are better described as plateaux. The plateau may be of uniform height or show a slope in one direction. Detail may take the form of ravines, gorges, and canyons, or of flat-topped hills like the kopjes of the veld. Lower plateaux often descend to the lowland in a single escarpment or scarp. The steepness, regularity of slope, and degree of dissection might be observed.

Other regions may be described as merely hilly. Such a term is often used when the rise and fall above the general level of the land does not exceed a thousand feet. A surface dotted with hillocks or knolls may be described as hummocky, while a rolling surface typical of grass-covered chalk areas is often termed downland.

If the region is not high above sea-level, it may take the form of a rolling plain or lowland, or an almost featureless plain. If it is an area over which a river apparently wanders in the course of time with consequent deposition, it may be termed a flood plain, or if worn almost flat by erosion from highlands, a peneplain.

Most studies are simplified if the area lends itself to ready subdivision. Thus the hill district of the north-west might be differentiated at the outset from the south-east lowland, and the detail of each region studied in turn. Suitably chosen names give a sense of intimacy to the study. A sketch-map to show subdivision should be bounded by lines to give a figure similar in shape to that of the sheet itself, and single lines should be drawn *between* regions, not round them, or patches of no-man's-land will appear. The number of regions is best limited, with subsequent subdivisions of main types if this is necessary.

(*b*) *Drainage.* At the outset the direction of the main rivers and the extent of their basins should be noted. The basin of a river is the whole area drained by the river *and its tributaries.* Adjacent river basins can be demarcated by carefully plotting the water-partings or watersheds which separate them. These divides usually coincide with the crests and cols, and again, they are represented by single lines between adjacent basins, and not independent lines round each.

In highland regions streams are often fairly straight and river pattern simple. Gradients are considerable, flow is rapid, and waterfalls frequent. There is much vertical erosion, and valleys are characteristically V-shaped, narrow, and deep. Streams eat back into the high land, and those which find a line of weakness, such as a fault or softer beds, cut deeply and by excavation of their valleys undermine and capture streams from other valleys. Recent and imminent cases of river capture are apparent when drainage is studied.

In flatter regions streams have less gradient, are less swift, and often swing from side to side. The valley form is more open, though the river pattern may be more complicated. There is less vertical erosion, but more lateral erosion. In some cases subsequent uplift and rejuvenation may cause renewed vertical erosion and the formation of incised meanders, or simply river terraces and platforms. River capture may still occur, and leave dry gaps or wind gaps which were cut by streams through ridges before the streams fell a prey to more vigorous neighbours. Small misfit streams may meander along the floors of the valleys of once-important rivers.

On the flattest land, whether high or low, rivers may be seen to meander aimlessly. The rivers toil with their load of silt, building beds above the surrounding landscape. Tributaries find difficulty in entering the main stream through lack of slope towards the river, or even through reversal of slope. Old meanders may become isolated and appear as lakes, variously called oxbow lakes, mortlakes, cut-offs, or billabongs. The hand of man may be revealed by a network of canals, dikes, and cuts constructed to drain the area.

In dry regions valleys may still be present, but few may be occupied by rivers. Streams may descend from the high land, drop their loads of rock waste as alluvial fans, and then disappear. Rivers that are supplied with a large volume of water usually show much vertical erosion but little lateral erosion in crossing a dry region, with resultant canyons and ravines. Dikes and canals may again appear, but as irrigation instead of as drainage channels.

In very cold regions the surface may be largely covered with ice and snow, while in others the valleys may contain glaciers. The effect of ice erosion may be seen to perfection in some regions now free of ice. The main valleys are U-shaped, with small lateral valleys joining in a precipitous plunge at the junction. These are the hanging valleys so characteristic of glaciated regions. Small lakes may still occupy the floors of corries or cirques and dot extensive eroded landscapes, while larger lakes occupy moraine-dammed glacial valleys.

Drainage features not only afford information about climate and physical history, but inferences can be drawn about the nature of the rocks. Thus if in a region of considerable precipitation streams disappear at a certain level, it can be assumed that a very porous stratum, as of limestone, has been reached. The reappearance of streams would indicate the existence, at that level, of impervious beds. Extensive areas of pure limestone may show practically no surface drainage, but features characteristic of karst or causses. With experience it is not difficult to distinguish such an area from a semi-arid region of inland drainage with its salt lakes, wadis, and bolsons.

Coasts reflect both relief and drainage, and notice should be taken at least of outstanding features. Characteristic forms include low sandy shore-lines with or without dunes; high cliffs; fiords often with skerry bands; and rias.

2. Human Interpretation

After the physical geography of the map region has been studied, the human geography of the area should receive critical attention. It must be appreciated that there has been much skilful compression of information, and hence careful and detailed study of the map will reveal infinitely more than a superficial examination. The fact that something fresh can nearly always be discovered on maps probably explains why they fascinate so many people. Constant reference to the key is necessary both to interpret symbols and to understand abbreviations.

One point which should receive early attention, though often obvious, is interrelationship of physical features and communications. In mountainous regions advantage is taken of valleys and cols. Roads often avoid the valley bottoms, and railways employ cuttings and tunnels to avoid climbing. Canals, if present at all, must of necessity follow contours between locks. In regions of poor drainage roads and railways often seek the higher, less floodable land even where this means by-passing villages built on isolated patches of gravel. Resort is also had to embankments and viaducts.

Subdivisions which are used for description of relief frequently serve for analysis of distribution of settlements. In mountainous districts villages are often situated on the only flat land on the valley floor, where they have the advantages of easy communications, fertile soil, arable land, and protection from severe winds, and also where advantage can be taken of water-power from lateral tributaries and of hill-slope pastures. In some mountainous districts settlements are strung out high above river-level along the sunny side of the valleys.

On low-lying, floodable land settlements are prone to seek knolls of gravel which raise them above flood-level. Since these patches of gravel are often the result of river deposition, they tend to occur in lines, and so do the settlements.

In rolling, well-drained, rich agricultural areas villages are frequently evenly distributed. The village in the most accessible position tends to develop as a market centre and outgrows others.

Settlements may also reveal a relation to water-supply and drainage. One type of water-shunning settlement has already been described. Many villages, though near the sea, seem to turn their backs upon it and depend for their existence upon agriculture.

Where water is scarce, whether on account of the nature of the rocks, as in karst country, or on account of climate, settlements seek water. In such regions, wherever a spring occurs, or watertable is high, human habitation finds at least one favourable factor. Springs often occur in lines at the foot of an escarpment or where an impervious rock outcrops beneath a porous one. Hence wet-point or spring-line villages tend to occur in lines like dry-point villages. Sea-side and lake-side holiday and health resorts and fishing villages might also be regarded as water-seeking settlements.

Some regions are remarkable for the density and size of their settlements. In these will generally be observed abundant evidence of mineral wealth, industrial activity, and a network of roads, railways, and canals. Relief may impose a peculiar distribution in such an area, as in the South Wales coalfield where houses, mines, and mills are strung out along congested valleys.

The situation, form, and function of major concentrations of population may call for comment: the route town, fort, bridge town, port, market, or industrial centre. The map may provide evidence of factors determining the general situation of settlements and also of their precise location. Many ancient towns owed their importance to converging routes, but their life they owed to sound natural defences of a particular site.

Prehistoric tumuli, ancient earthworks, and indications of primitive land-routes may provide evidence that peoples lived and moved about within the area thousands of years ago, just as place-names with such endings as *thorpe*, *thwaite*, and *ton* provide a clue to the origin of later settlers, in these cases Danish, Norwegian, and Anglo-Saxon respectively.

The occupations of a people are always an important aspect of the human geography of an area. The map usually affords much direct evidence of occupations by marking such things as mines, quarries, quays, farms, and mills. Much also can be inferred, as forestry in a forested district, catering in a town at the sea-side where there are good sands, sheep-rearing on moorland, and so on, though it is well to state clearly the basis of any assumptions. Thus upon the physical basis is built a picture of the life of the region, and an appreciation developed of the intimate relationship between physical background and human development.

CHAPTER TWENTY-ONE

INTERPRETATION OF AIR PHOTOGRAPHS

THERE is no doubt that the air photograph has come to stay as a commonplace means of illustration, and it may come as a supplement to maps for official and semi-official purposes. It seems certain that the uninitiated gather far more from one oblique aerial photograph than from several maps.

1. ORIENTING A PHOTOGRAPH FOR INSPECTION

An oblique photograph is naturally viewed in the camera direction, and though rectangular in shape, a plan of the area is approximately V-shaped, the arms opening out usually between 40° and 60°. The map convention that north should be at the top does not follow, and if location and orientation are being determined in conjunction with a map, churches, bridges, and stretches of road and railway are of assistance.

A vertical photograph should always be placed with the *shadows falling towards the observer* as in Plate VIII, for reasons mentioned in the section on hill shading. The shadows are not very pronounced in this photograph, but the effect, especially on the railway embankment, of turning it the other way round should be tried. But for the river, it might then be interpreted as a cutting. As with obliques, north is not necessarily at the top.

Objects on large-scale photographs are fairly easy to recognize, but experience is necessary for even superficial interpretation of small-scale photographs. If taken when the sun is fairly low but bright, shadows are very long, while the foreshortening of objects gives them an unfamiliar appearance. Because of the contrast in tone, shadows are often more prominent than the objects themselves. Shadows sometimes give information about objects seen in plan. It seems tolerably certain, for example, that the church in Plate VIII has a spire and not a tower.

If possible, stereoscopic pairs should be examined in the stereoscope, for much that is otherwise vague and uncertain is then revealed.

2. PHYSICAL AND HUMAN INTERPRETATION

There is no need to repeat in a slightly different form what has already been said in Chapter XX on map interpretation. Since it was written first, however, and without thought of the present chapter, it is of interest to re-read it with air-photos in mind in place of maps. It will be seen that practically the whole applies equally well to photo interpretation.

There are differences, however. A vertical photograph nearly always covers far less ground than a topographical map, so it is likely to include less topographical and human variety. But there is far more detail on the photograph than on the map. The photograph will vary with the season, and show temporary features such as hayricks. Names, which aid interpretation, are missing from the photograph.

The surface of the photograph, even when not viewed stereoscopically, has a more plastic appearance than is obtained by contouring, and different types of land are more readily distinguished, such as badlands, boulder clays, bedded limestones, or rolling chalklands. The topographical map shows a selection of the features of the visible landscape, and employs much symbolism. The photograph records all features, but the small scale and unusual view render them difficult of identification.

3. Economic Interpretation

Economic interpretation of aerial photographs is to a great extent the work of specialists, but it is worth while at the outset to take heart and realize that specialists are not possessed of supernatural optical powers, but are aided by a background of knowledge and experience. They are greatly assisted by an examination of photographs in deciding such matters as road and railway routes, laying out of power schemes and water-supply, land drainage, irrigation and soil conservation, economic possibilities of existing forests, agricultural potentialities of undeveloped areas, and the places most likely to give positive results in mining and prospecting, or archaeological research. One case is recorded where a million and a half pounds' worth of work on a railway in a tropical country was scrapped and another route chosen after an aerial photo survey.

4. Detail Interpretation

As already indicated, it is in the mass of detail that the photograph is unique as a topographical record.

Artificial objects such as houses and gasometers, because bounded by straight lines or by regular curves, are easy to identify. Hayricks and barns may be mistaken for cottages, unless one finds supporting evidence for the latter assumption, such as a surrounding garden plot. Railways are easily picked out by long straight stretches, regular curves, cuttings, and embankments. Roads are less regular, are usually without cuttings and embankments, and often show ribbon development. Some natural objects, such as rivers, streams, and woods, are also easily picked out.

Tone is due to the amount of light which is reflected to the camera, and this in turn depends primarily upon the nature and texture of the surface. Water and standing corn may appear almost white till rippled by a breeze. Field 41 in the accompanying figures is a good illustration of reflection. On the other hand, smooth water may lie in a part of the camera field from which it reflects

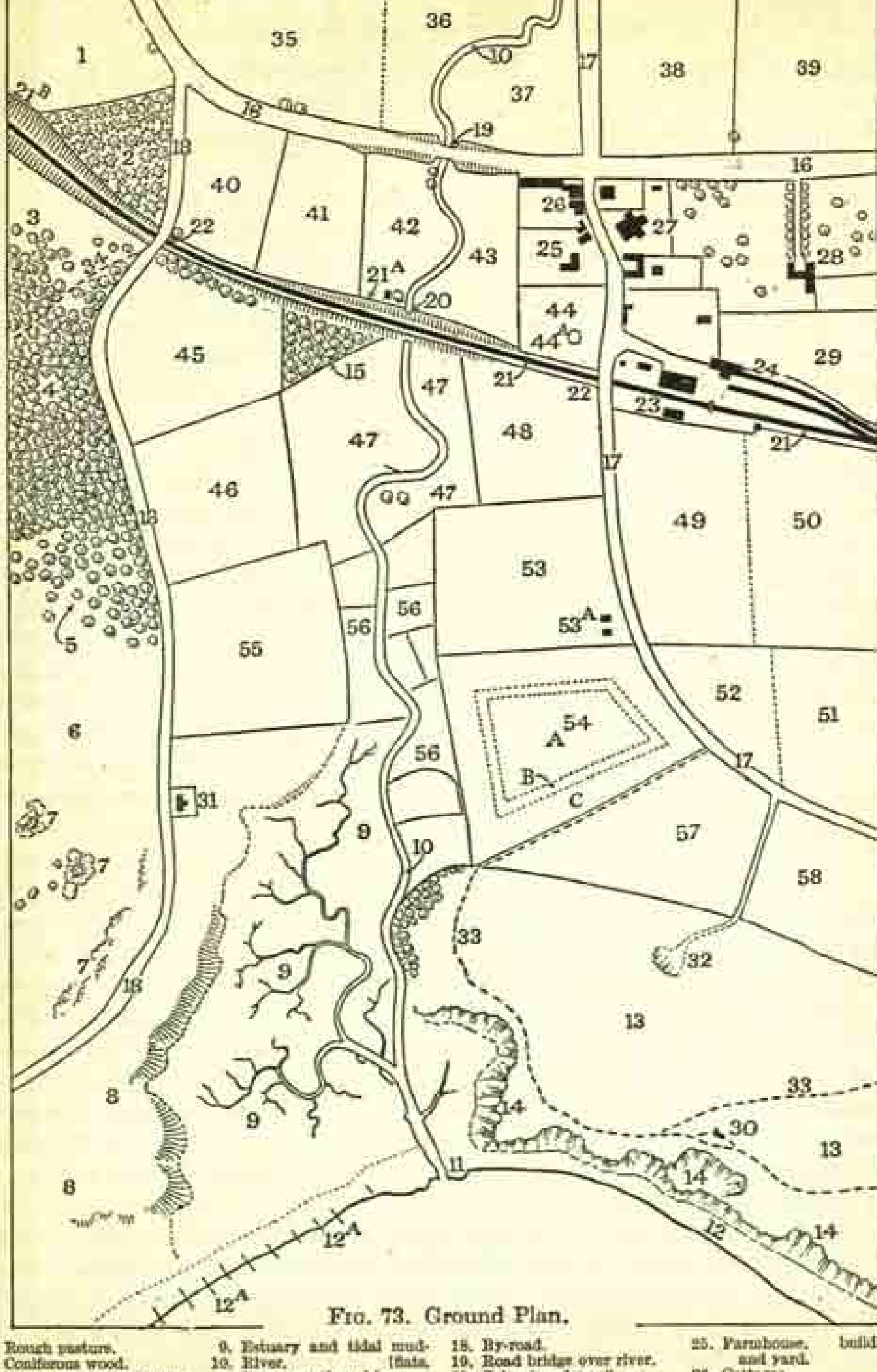
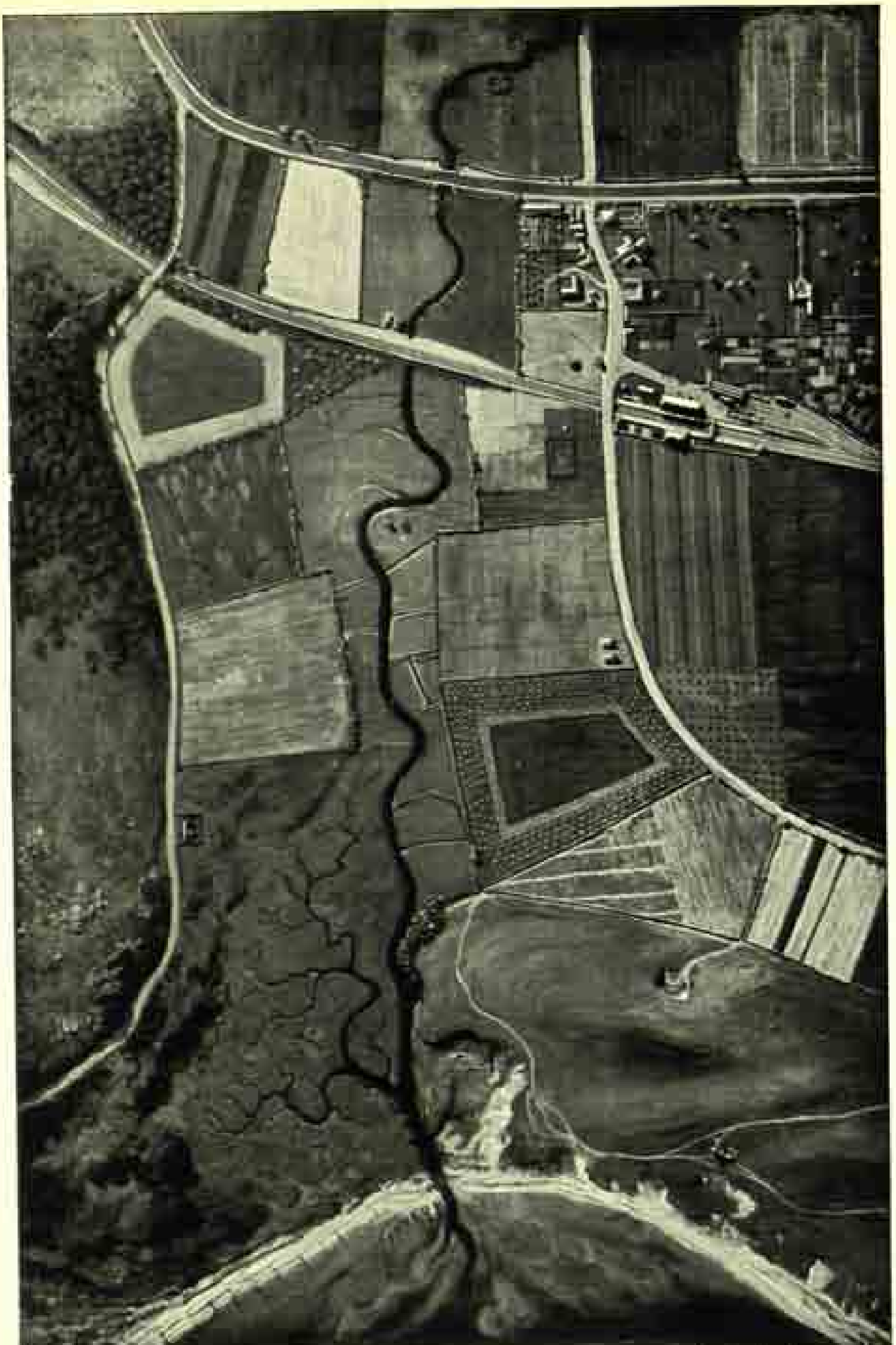


FIG. 73. Ground Plan.

1. Rough pasture.
2. Coniferous wood.
3. Rough heathy pasture with scattered trees.
4. Deciduous wood on hill-side.
5. Scattered deciduous trees.
6. Heath and gorse on rising ground.
7. Rocky tors.
8. Broken cliffs.
9. Estuary and tidal mud-flats.
10. River.
11. River mouth and bar.
12. Sea beach.
12A. Groins.
13. Chalk downs.
14. Chalk cliffs.
15. Willow copse.
16. Main road, tarred.
17. Secondary road, macadamized.
18. By-road.
19. Road bridge over river.
20. Culvert under railway.
21. Railway. (21A on embankment, 21B in cutting.)
22. Road bridges over railway.
23. Railway station.
24. Goods sheds and railway sidings with trucks.
25. Farmhouse, buildings, and yard.
26. Cottages.
27. Church.
28. House and gardens in park.
29. Allotments.
30. Coastguard station.
31. Barn.
32. Chalk pit with cart-track.
33. Foot-paths on chalk.



University Press, Oxford

VIII. Air Photo.

Plan and photo reproduced with the sanction of the Controller of H.M. Stationery Office.

34. Track through wood.
35. Clover.
36. Old pasture eaten off and sun-dried.
37. Old pasture from which hay has been carried.
38. Potatoes.
39. Freshly cultivated and sown land.
40. Plough (dark strips show fresh ploughing).
41. Mangolds (light appearance due to reflection from the very smooth leaves).
42. Sown grass.
43. Permanent pasture.
44. Permanent pasture much trodden.
44A. Pond.
45. Field of grass partly cut.
46. Corn nearly ripe and much beaten down.
47. Water meadows.
48. Sheep in turnips (the light parts show where the roots have been eaten off).
49. Growing roots (the young plants do not conceal the ridge and furrow).
50. Growing wheat (green).
51. Roots.
52. Beans cut and shocked.
53. Stubble (53A Corn stacks.)
54. Wheat, A standing, B cut and lying in sheaves, C in shocks.
55. Standing barley.
56. Saltings.
57. Clover cut and partly raked.
58. Ploughing on chalk (the dark strips may indicate fresh ploughing).

no light, and it then appears almost black. Tracks show up so clearly because a reflecting surface has been formed through pressure. Often the towpath along a canal appears as a light line. Roads, though dark in colour, reflect sufficient light to appear a lightish grey.

There is obviously opportunity for nice weighing of evidence, as to orientation, time of day and season, and purpose of things seen. A lake may be observed to have a dam at one end, evidently then a reservoir. If for drinking-water, shores are likely to be cleared and trees farther back to be coniferous rather than deciduous. A gate-house may be seen near the dam. If for power, factors to ensure purity of water will be less in evidence. If for pleasure, there is likely to be a boathouse, boats, a pavilion, diving-stands, and a bathing-beach. The detail which can be seen inevitably depends to a great extent upon the scale of the photograph, and its interpretation upon experience.

Without further ado, these ideas might be applied to Plate VIII and an attempt made to identify and compile a full solution to the numbers in Fig. 73. The photograph shows an interesting range of tones and textures. *Afterwards*, reference might be made to the official version recorded beneath the figures.

PART II
STATISTICAL MAPS

CHAPTER TWENTY-TWO
DOT MAPS

THE representation of the earth's surface in map form by no means exhausts the possibilities of mapping. Maps are in continual demand to show the distribution of rainfall, temperature, crops, population, minerals, and a hundred other things of social and scientific interest. These are distinguished from topographical maps under the general title of *Statistical Maps.* Sometimes they are termed *Distribution Maps*, but strictly speaking this term is applicable to all maps. Well-known types are distinguished according to the method of representation employed. Thus there are *Dot Maps, Density Maps, Isoline Maps,* and *Diagram Maps.*

For the successful compilation of statistical maps it is desirable, firstly, to have specialized knowledge of the map-subject; secondly, a general knowledge of methods available to represent statistical information in cartographical form; and thirdly, an appreciation of map projection, since the projection determines the properties of the space background upon which the distribution is shown.

Since such maps are more often the work of geographers, economists, and students of social problems than of professional surveyors and draughtsmen, the first point can be dismissed. The second point forms the subject of study in subsequent chapters, while that of map projection has already received considerable space. Suffice to say, therefore, that in general all quantitative distributions and most qualitative ones are most appropriately shown on Equal-area Projections, unless direction is a vital consideration, in which case use may be made of Mercator's, the Gnomonic, or Zenithal projection.

Although probably not a century old, the *Dot Map* has established itself as an exceedingly popular form of statistical map. Description of the construction of a dot map will make the method plain.

1. CONSTRUCTION OF A DOT MAP

Suppose that it is desired to map the distribution of woodlands in Britain. Statistics are available showing the acreage of woodland in each county. The following extract is for southern England only, but the method is equally applicable to the whole:

1. *County*	2. *Area in woodland*	3. *Per cent. land area in woodland*
	Acres, 1924	
Berkshire . . .	39,864	8·7
Cornwall . . .	27,985	3·2
Devon . . .	80,610	4·8
Dorset . . .	39,202	6·3
Hampshire . . .	122,038	11·6
Kent . . .	108,255	11·1
Middlesex . . .	1,897	0·9
Somerset . . .	45,500	4·4
Surrey . . .	56,459	12·3
Sussex . . .	130,118	14·0
Wiltshire . . .	51,063	5·9
BRITAIN . . .	2,958,672	5·3

(*Census of Woodlands*, H.M.S.O., 1928.)

In addition to the statistics it is necessary to obtain an outline map of Britain showing county boundaries, such as is normally available in any atlas on a convenient scale, say, of 1:2,500,000 or 40 miles to 1 inch. The outline is traced in ink, and the county boundaries are inserted in pencil. The counties are referred to as statistical units. If figures had been published for parishes, as they are for population, an outline showing subdivisions of counties into parishes might have been employed, and the statistical unit would then have been the parish.

A preliminary examination of the statistics suggests that a dot could be inserted in the appropriate county for each 1,000 acres of woodland. Thus Berkshire's woodland would be represented by 40 dots, Cornwall's by 28, Devon's by 81, and so on.

It is necessary to take into consideration not only a suitable dot value which determines the number of dots required for each statistical unit, but also a suitable dot size. Column 3 of the table of statistics shows the percentage of woodland area in each county, and this reveals in which counties dots will be dense and in which they will be sparse. It is advisable to make trial of dense and sparse areas to ascertain the most suitable dot size. Different methods of making dots uniform in shape, size, and density, and with a minimum of effort, are described later.

When preliminaries indicate that the effort is likely to meet with success, the appropriate numbers of dots are inserted county by county. The boundaries are then rubbed out, and an impression of the distribution of woodland remains, as shown in Fig. 74. This map reveals that when dotting was in progress county boundaries were perhaps unconsciously avoided, with the

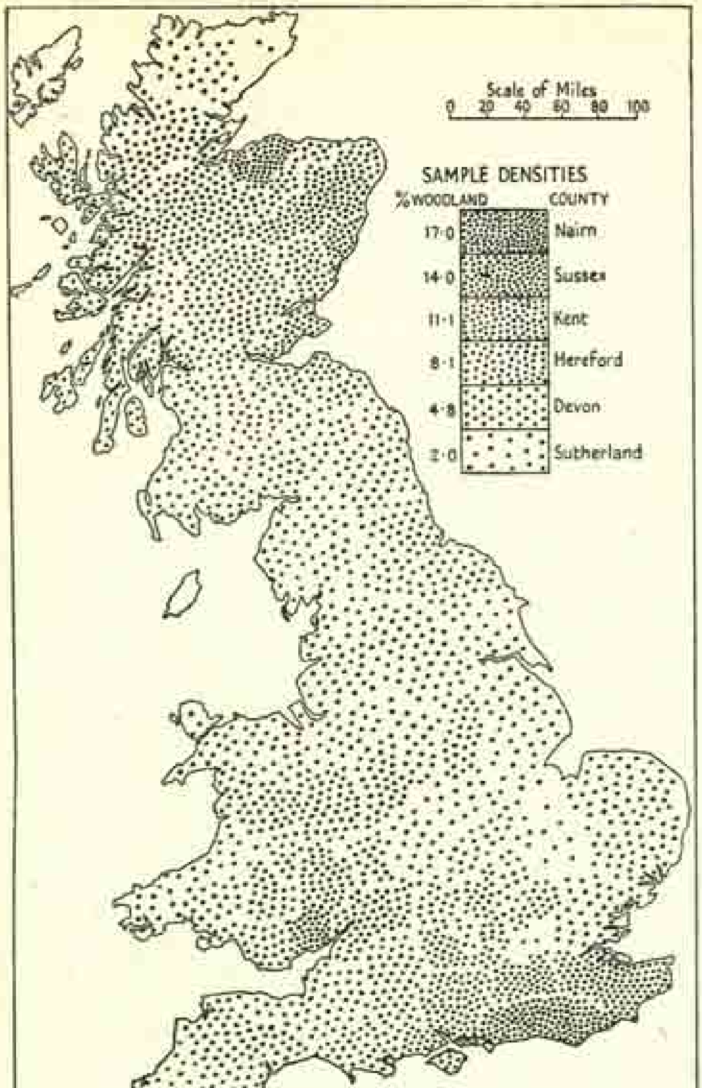


FIG. 74. Dot map to show distribution of woodlands in Britain. Note undesirable appearance of county boundaries through imperfect dot distribution. Dots made with Uno-type pen.

undesirable result that they now appear as broad white bands running between dot clusters, though the actual distribution of woodland in the field has no regard to county boundaries.

2. Advantages of the Dot Method

When dealing with distributions by area it is occasionally possible to maintain a true-to-scale dot, and so show absolute density over a region. But neither distribution nor relative density is affected if the dot covers a larger area than it actually represents, which is usually the case. On the Woodlands Map dots cover about 20 per cent. of the paper, but woods cover only about 5 per cent. of the country. On very small-scale maps dots are sometimes one or two hundred times larger than the areas to scale which they represent.

The dot method is not limited to distribution involving areas, but can be employed to show distribution by value, volume, weight, and number. The size of the dot then has no particular significance, and is simply a matter of convenience. Much of the graphic effect, however, depends on balance between space background and the area covered by dots, no less than upon careful draughtsmanship.

Because dots are discontinuous in form, they lend themselves particularly well to show the distribution of things which occur in discontinuous units, such as people, stock, and crops. The sporadic distributions in which these are found can be imitated by a similar sporadic distribution of dots.

Further, the distribution of more than one commodity can be shown on a single map, and though as a rule this is not good practice, it may be of value to have on one map related commodities, such as sugar-beet and sugar-cane, or rice and wheat. If distribution nowhere overlaps, they may be distinguished by a dividing-line or by colour-washes on the base map. Otherwise dots of different shapes or colours may be employed. By such means distributions at different periods can be shown upon a single map.

The dot method is sometimes referred to as the *absolute method*, because of the absolute ratio between quantities represented and the numbers of dots employed. Every statistical unit has placed within it the appropriate number of dots, and in this respect is independent of all other units. The same is not generally true of shading and colouring, in which each statistical unit is assigned to one of a number of predetermined grades or colours. If on such a map the differences in density from region to region are only slight, the inevitable changes of colour or shading are likely to give the impression that changes of density are material. The dot map in these circumstances gives the truer mental picture, revealing that density changes are only slight.

At times it is claimed as an advantage of the dot method that dots can be counted over a given area and reconverted into statistics, but the practice is open to objection because of difficulty and liability to error. It is preferable to place by the map a small statistical table containing the essential material from which a map has been constructed. Such material might be shown in the form of a bar chart or pie-graph to supplement the map. Use might also be made of a dot key showing a range of representative densities to match against different parts of the map. A key of this type has been drawn for Fig. 74.

3. Disadvantages and Difficulties of the Dot Method

So far important advantages of the dot method have been considered, but there are difficulties and disadvantages. It is soon discovered that without experience dots uniform in shape and size are not easy to make. When dot value is low there is a merging towards the solid in dense regions, and refinement of position is impossible. If dot value is high, some areas are as a consequence left blank. If on a map to show the distribution of pigs the most suitable dot value for dense areas is one dot per hundred pigs, one dot can only occupy one point on the map, and therefore it cannot be placed with precision towards the limit of pig-rearing where one hundred pigs are probably spread over a very large area. Similarly, if on an atlas map of world population a suitable dot value is half a million, where should the cartographer place the three dots which represent New Zealand's population?

Inset maps with adjusted scale and dot value are sometimes used to bring out detail, or alternatively dots of a different order are introduced, distinguished by shape, size, or colour, and having a different value not necessarily commensurate with change in appearance. This approach breaks down the whole convention and the system can no longer be described as absolute. A defect has been introduced to overcome a difficulty.

Dot value and map scale therefore need harmonizing to produce good results. On a small-scale commodity map, say, of less than one to a million, dot value may of necessity be high, whereas on a large-scale map of the same commodity value will be lower. As a guiding principle dot value should be kept as low as possible, while the base map should be as large as can be handled conveniently, or as large as statistics merit.

Sometimes detailed distribution of dots is limited by the form of the published statistics. In Britain agricultural statistics are published only on a county basis, whereas population figures are published on a parish basis. The smaller the statistical unit in relation to the map as a whole, the more accurate will be the distribution of dots.

Often it is exceedingly difficult to get a base map which marks the boundaries of small statistical units, particularly of countries outside one's own. This creates a problem by no means peculiar to the dot method. It should be made a national and international crime to publish any census without an outline map marking the statistical units employed. The cost of such a map would be negligible, and people engaged on useful research would be saved countless hours of unnecessary labour.

The system adopted in placing dots within the statistical units is of considerable importance, for dots may be spaced evenly or grouped to accord with some information about distribution within the units. It is rare for any commodity to be distributed evenly over a single statistical unit. Hops in Worcestershire grow mainly along the western side of the county. The population of New England and Australia is mainly near the coast and centred in a few large cities. There may be nothing in the published statistics to indicate these facts, and therefore no statistical authority to warrant anything but an even distribution of dots over the whole area.

Maps which do reveal an even distribution of dots within statistical units are not necessarily misleading. The experienced map-reader knows and understands that a degree of misrepresentation is inherent in the method, and makes allowance for the fact. The degree of misrepresentation is by no means constant, however, as it involves the number of units into which the base map has been divided. For example, while such a method using states as statistical units would give but a poor idea of the distribution of population in New England, it would be by no means so ineffective if applied to the mapping of population for the whole United States.

On some maps dots are distributed unevenly within statistical units to accord as nearly as possible with actual distribution. Information of this may be gained from field work, from intelligent correlation with other maps, or from a knowledge of factors limiting distribution. Thus detailed topographical maps reveal much about distribution of population, while crop distribution is closely related to soils, altitude, and climate. The dots on the Woodland Map could have been placed to agree more nearly with actual distribution of woodland if a larger base-map had been employed, and use made of information available in map and book form. This reasoned distribution method gives a greater degree of accuracy to the finished map, provided that the bases of differentiation are reasonably accurate. But errors of judgement are not readily recognized, not easily checked, and largely compel acceptance. It would be well for a statement of method to accompany each dot map, particularly to indicate the principles upon which any modification of distribution within statistical units had been effected.

Even when a map is produced with dots uniform in shape, size, and value, and accurately distributed, it does not of necessity give a correct visual impression. A given number of dots in a central area looks less dense when surrounded by areas with many dots than when surrounded by areas with few dots. In other words, dot density appears to vary inversely with that of surrounding areas. Fig. 75 illustrates the point.

It also seems true that if the number of dots in a given area is increased, the visual impression of density is not increased to the same extent. The higher densities tend to be under-estimated. Increasing the number of dots would solve this problem only if there were general agreement on the increase necessary to make density look right.

Even the arrangement of dots in straight lines or otherwise affects visual impression, as may be seen in Fig. 75. Satisfaction with the method may therefore be more mental than visual, though visual effect matters most. There is obviously room for research in testing the intensity of sensation produced upon the eye by different dot densities and arrangements.

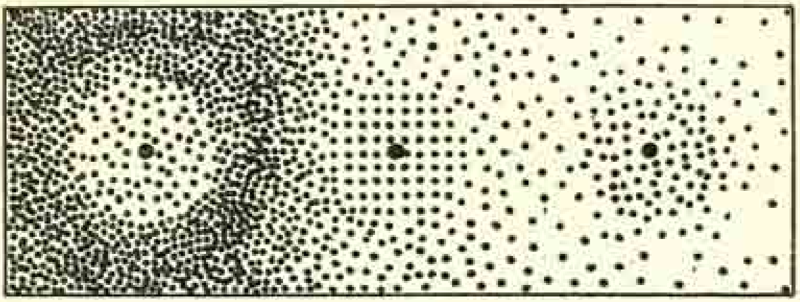


FIG. 75. Dot densities and arrangement. Identical numbers of dots were inserted with Uno-type pen in the preparation of this figure, in each of three circles of 1 inch diameter centred on the larger dots. Appearance of the three areas is influenced by dot pattern and density of dots in surrounding areas.

A final disadvantage of the dot map is the difficulty involved in copying it. Often the only accurate way is by photography. By contrast, most other types of distribution maps can be copied without undue difficulty or loss of accuracy.

4. Dotting the Dot Map

Dotting a dot map may prove no problem to a trained draughtsman, who probably regards the job as small beer. But because factors other than draughtsmanship are involved, the lot usually falls to the geographer or economist who may lack technical knowledge and a high standard of cartographical skill. It is axiomatic that unit quantities should be shown by dots of the same shape, size, and colour value, since graphic representation is unsound if some dots are outstanding in appearance and unduly attract the eye. Therein lies the problem, to make hundreds and even thousands of dots uniform in shape, size, and density.

Useful methods may be summarized in connexion with the instruments chiefly employed, namely: (*a*) pens, (*b*) dies, (*c*) punches, and (*d*) compasses. Choice of method is likely to depend upon the size and number of dots required, and upon patience and personal preference.

(*a*) *Pens.* The immediate reaction to the problem is to use pen and ink. But it is soon apparent that dots made with the ordinary school nib vary in shape and size. Other nibs are available, such as the litho or crowquill, and these can be touched up on sand-paper or blunted to make larger dots. Then there are reservoir nibs with round flattened tips 2 millimetres or more in diameter. These are very useful, for twenty-five to fifty uniform dots may be made with each dip of ink at the rate of a dot a second.

Undoubtedly the most successful dotting pen is one constructed on the stylo principal, and sold under such trade names as Leroy and Uno. The reservoir is conical in shape and a dot is made each time the pointed end of the cone touches the paper. Sets of pens are available producing dots which range upwards in diameter from $\frac{3}{10}$ths of a millimetre. An improvised version is made by drawing out glass tube pipette fashion.

Different kinds of ink can be used, but in general varieties yielding black non-reflecting dots are most suitable. Possibilities include bottled Indian ink, china stick, and process black. The first-named is waterproof and needs no preparation, but tends to clog in action. The unproofed ink is available in bottles and is easier to handle. Process black possesses least gloss.

Almost any type of paper from thin tracing to Bristol board gives good results. The greasiness of tracing-paper can be removed by sponging lightly with bull's gall. If it is desired to aline dots, this is achieved quite simply by placing graph-paper beneath the map before dotting commences. The co-ordinate lines will even show through Bristol board if a powerful enough light is placed beneath the work in a tracing-box.

(*b*) *Dies.* Another method of dotting the map is with a stamp or die, but certain difficulties immediately present themselves. The thin inks used with nibs are unsuitable, as they do not give a dense impression and the edges of the dots are not well defined. Printers' ink is the most suitable, provided that an exceptionally rapid drying variety is obtained. Two methods of applying the ink to the die are practicable. One is to spread a layer of ink on a felt pad in a small tin lid and over it draw tightly a piece of silk. A thin film of ink squeezes through this, and the inked felt acts as a reservoir which replenishes the surface each time the die is pressed on the silk. The other method, which is preferable, is to roll a small quantity of ink on glass with a squeegee or printers' roller. After the ink is worked well up, the die is inked by touching it on the roller before each dot is made. This closely imitates the principle of mechanical machine printing. Speed depends on many factors, but thirty-five perfect dots per minute are ordinarily possible for dots 2 millimetres in diameter, with reduction to about ten dots per minute when diameter reaches 12 millimetres. Should the ink become too thick, it can be thinned with a little pure turpentine, and is washed from roller and glass with paraffin.

The actual die with which the impression is made is not of great moment. Experiments show that box-wood sticks about 3 inches long are suitable. These are sold specially for stick printing. There immediately emerges an advantage over the pen nib. Different shapes are available, sticks circular, square, or triangular in section being obtainable in a range of sizes. The sticks may be tipped with linoleum if it is desired to have the ends very smooth and so minimize the possibility of uneven density. These linoleum tips can be cut with a leather punch, a common pattern of which has six separate punches fixed in a rotating wheel. Three sticks, each with different sized tips at both ends, comprise a useful set. Shapes other than circles may be cut with a pen-knife.

Probably the best dies are those selected from printers' type. This is sold by weight, and less than a pound will include a whole range of dots, squares, triangles, and stars. The type is not quite as convenient to handle as a dotting-stick, as it is only about 2½ centimetres high. But one side of each die is grooved, and this enables it to be bound securely to a stick which acts as a handle. Cartridge paper proves the easiest upon which to work, as it has a matte surface which takes ink very well and promotes rapid drying.

(c) *Punches.* Another simple but effective method of dot making is to punch holes out of paper. Provided the holes are not crowded, the results are excellent. The chief difficulty may be to obtain a suitable punch. An ordinary paper clipper punch will not work far in from the edge of the paper, but the individual punches of the common leather punch already described may be extracted and used. A clean-cut hole is obtained by placing the map on a piece of stout leather and tapping the punch with a mallet. More than thirty holes per minute can be made, size having little influence upon speed. The map is completed by mounting on black paper. This, however, is not necessary when the map is for reproduction, as a black sheet placed in the copying frame has the same effect. The best results are obtained when the work is executed on a thin white hard paper.

There is obviously a complementary method, namely, to punch dots from black paper and stick them on a white background. This adhesive dot method makes a strong appeal. True, it is not to be compared with certain other methods for speed, but there is a perfection of appearance difficult to obtain by any other equally simple means. Dots are placed in position with the utmost ease and accuracy, they can be removed at will, and there is no fear of smudging or of imperfect dots. There is practically no initial trouble as with the printing method and, perhaps equally important, there is no clearing up afterwards. Experience has led to the following procedure. A strip of adhesive paper, such as is used in the wrapping of parcels, is glued along its edges to a piece of thin cardboard. The paper is then painted with Indian ink and allowed to dry. Holes are then punched through paper and cardboard together, the punched-out portion or dot emerging at the top of the punch. The cardboard prevents a number of black dots sticking together as a result of pressure. The dots are picked up individually on the point of a darning-needle, touched on water or diluted mucilage, and pressed on to the map with a blunt needle held ready in the other hand. The dots naturally adhere to any kind of paper. The actual cutting of the dots is a quick process, but it takes about a minute to fix ten dots in position.

The same method has been applied in the preparation of distribution maps which involve the use of spheres of various sizes, either to replace or to accompany dots as in Fig. 84. It is very difficult to draw a large number of spheres, but once a range of sizes has been completed, any number of copies can be printed, and from the printed sheets the particular sizes required are cut out and stuck in position on the base map, almost as simply as sticking stamps on letters.

Short pins with spherical glass heads form an interesting type of adhesive dot specially suitable for use in offices. Maps are mounted on a base of cork-mat, linoleum, or three thicknesses of corrugated strawboard, and pins to show the location of agencies, salesmen, customers, and so on are stuck in preferably till the pin-heads touch the surface of the map. If the pin-heads are red, orange, or black, the map may be reproduced by photographic methods, though the negative may require touching up to take out high lights.

(d) *Compasses.* A final method of dot making which may be described is with compasses. Rotating, pump-bow, or spotting compasses have a central fixed point shaft, and the ink-pen is made to rotate round this by turning a milled nut. With the commoner spring-bow compasses an experienced draughtsman can produce dots of less than one-tenth of an inch in diameter and fill them with Indian ink rather faster than adhesive dots can be placed in position, but inexpert handling of compasses results in considerable variation in the shape and size of small dots. Large circles are comparatively easy to draw and fill in. One limitation in the use of compasses, as of the punch-hole and generally of the adhesive dot, is that the dot shape is limited, a factor which does not apply to die printing.

Most of the above methods of dot making are applicable when dots of different colours are wanted on the same map. If the map is to be reproduced in colour, however, separate dot maps are required for each colour, though black only should be used on each original. The printer is then able to obtain clear photographic plates of each and overprint them in any desired colours. Base-map detail is shown on one of the maps only, other dots being placed on superimposed tracing-paper, or, better, on blue prints pulled from the original map. The blue outline does not show on the photographic plates. All the media of black already mentioned can be obliterated from any paper for photographic purposes by process white, rendering correction possible.

5. Uses of Dot Maps

Dot maps have become very popular because of the ease of construction, the confidence that is felt in the method, and the fact that the result is often visually impressive and informative. They are frequently useful in suggesting a line of inquiry, for problems tend to become apparent after statistics have been mapped which were not apparent before. The dot map lends itself admirably for examination in conjunction with other distribution maps, particularly those in the isoline group. Thus a dot distribution map of some crop may have superimposed upon it in turn isoline maps showing relief, rainfall, temperature, and frost-free periods, and correlative deduction is at once possible. Or again, the distribution of deaths from a particular disease may be mapped by the dot method, and the result compared with maps of suspected causes such as elevation, humidity, or drainage. It does not follow that conclusions are free from error, but the method has much initial value and may point the way to discoveries of profound practical importance.

It is frequently possible to insert much useful information on dot maps, apart from the dots. Thus market and refrigerator centres may appear on cattle maps, and grain elevators on wheat maps. Care and skill are necessary to ensure that such information does not interfere with, or spoil the effect of, dot distribution. Very successful examples are to be seen with base-map information in grey, and dots in black or prominent colour.

Three atlases call for special mention because of the large collection of dot maps which they offer for inspection. They are *Geography of the World's Agriculture*, by Finch and Baker, 1917; *An Agricultural Atlas of England and Wales*, published by the Ordnance Survey in 1932; and *Chambers of Commerce Atlas*, published by G. Philip & Son, London, 1925. Both agricultural atlases make use of black dots throughout, and all dots on any single map are uniform in shape, size, and value. The maps in the *Atlas of England and Wales* were drawn on a parish basis and afterwards reduced to a scale of 1:1¼ millions. They are printed on tracing-paper, and folder maps of relief, rainfall, geology, and markets allow correlations to be made. The *Chambers of Commerce Atlas* employs the dot method to show distributions of commercial interest throughout the world. On some maps dots are printed in several colours and variations in shape and size are introduced to vary dot value, while there is much base-map information. All three publications deserve critical and comparative study.

6. Location Dot Maps

Some maps make use of dots to show location only, but these are in a rather different category, since location is not quantitatively measurable. Such maps might show location of state forests regardless of area, as in Fig. 76, water-power sites without indication of horse-power, districts in which foot and mouth disease have occurred, insurance offices, sites of prehistoric remains, and so on. Like the dot maps already described, they may be used in conjunction with other maps in the elucidation of problems, and sometimes in series to show development, discovery, or movement.

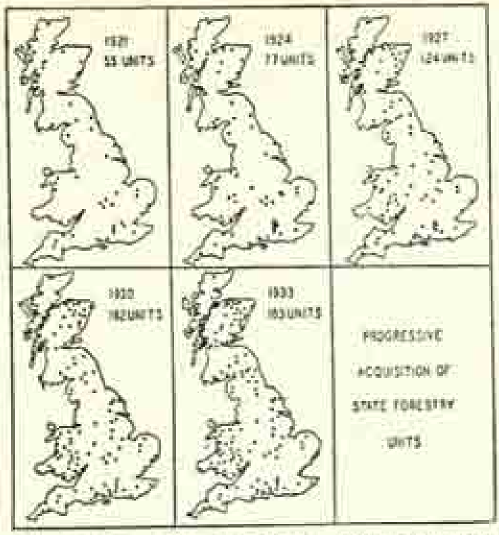


Fig. 76. Location Dot Map. Dots show the location of state forestry units, regardless of acreage. Adhesive dots were used in preparing the original maps, which were then much reduced in scale.

The number of dots on a location map is usually fewer than on a dot map which shows quantitative distribution, and consequently the pin method of preparation is often convenient. Pins are obtainable with flat heads having numbers or letters in white on a black background. Maps so prepared take little time, trouble, or expense, they look effective and photograph well for reproduction.

CHAPTER TWENTY-THREE

DENSITY MAPS

An important aspect of distribution is often quantity in relation to area, summed up in the word *density*. Dot maps themselves show density when the dots are of uniform value and are placed on a space background or base map having equal-area properties. But since the dots are used as quantitative symbols, a density map is not produced if the base map does not possess equal-area properties.

To show density, the quantitative symbol is replaced by an areal symbol, seen in the familiar grades of shading or colours employed to distinguish different density grades. The unit areas so distinguished are normally administrative units such as the township, county, or state.

Maps of this type can be drawn to show almost anything for which a percentage, ratio, or average figure is obtainable for component units. To quote a few illustrations, it is possible to map yields per acre, average *capita* bank balance, *per capita* consumption of commodities by weight, volume, or value, percentage variation, ratios such as acreage of wheat to acreage of tillable land, or value of one crop compared with the value of all other crops.

There is no accepted generic name for all these maps. The word *choropleth* has been suggested, expressing quantity-in-area, in contrast to the name *isopleth* which is explained in the next chapter. The term *Ratio* or *Density Map* is simpler, however, though a wide interpretation of the word density is necessary to include the variety of maps already suggested.

1. Drawing a Density Map

Suppose that it is desirable to map the density of population in Italy. There are sixteen departments with population in 1931 as shown in the Table opposite.

An outline map of Italy must first be procured, and the departments marked. An examination of column 3 suggests that a key for shading could be employed to differentiate densities on the basis of hundreds per square mile. Six grades are then necessary. This number lends itself quite well to density mapping, for too few grades yield a map of very little value, while too many confuse.

A suitable six-grade scheme of shading must be worked out, and each department appropriately shaded. The result is a density map, as seen in Fig. 77. An eight-grade key has been drawn to render it applicable to the inset map. It may be noted that procedure differs from that employed in dot mapping in that statistical unit boundaries are not erased.

2. Choosing a Scale of Densities

The present example offers little difficulty in choosing a scale of densities. The six density grades follow quite simply in arithmetical progression. But one weakness is apparent. Six out of sixteen departments fall into a single grade, though their densities range from 309 to 377 per square mile.

1. *Department*	2. *Population ('000)*	3. *Population per square mile*
Piedmont	3,498	309
Liguria	1,437	685
Lombardy	5,545	603
Veneto	4,123	420
Venezia Tridentina	660	123
Venezia Guilia	959	289
Emilia	3,218	377
Tuscany	2,892	327
Marches	1,218	326
Umbria	694	212
Latium	2,385	360
Abruzzi e Molise	1,499	252
Campania	3,495	670
Apulia	2,487	334
Lucania	508	132
Calabria	1,669	287

When densities vary widely from place to place, a density key having changes in geometrical progression may be preferable. This allows more differentiation over extensive areas of low density than is possible when an arithmetical progression is employed, and at the same time makes practicable some differentiation in congested areas where densities increase rapidly in a limited space.

Many population maps show a simple geometrical progression in densities as follows: 1–64, 64–128, 128–256, and 256–512 persons per square mile. It seems that these numbers are employed partly for the reason already given, namely, that such a sequence yields better results than an arithmetical progression, and also because these particular grades of density are readily determined when areas are quoted in acres, the normal practice when dealing with small administrative units such as parishes. The following example should make the point clear. Suppose that it is necessary to know into which grade of the above key a parish falls whose area is 1,708 acres and whose population is 302 persons. It follows that:

(*a*) Area of parish in acres	1,708
(*b*) Population of parish	302
(*c*) Population per square mile	$\frac{302}{1,708} \times 640$
(*d*) No. of sixty-fours per square mile	$\frac{302}{1,708} \times \frac{640}{64}$

Line (*c*) involves a certain effort in arithmetic, and a similar calculation is involved for every parish, though finally many will be grouped together in a single grade. By contrast, line (*d*) can be solved at sight to the nearest whole

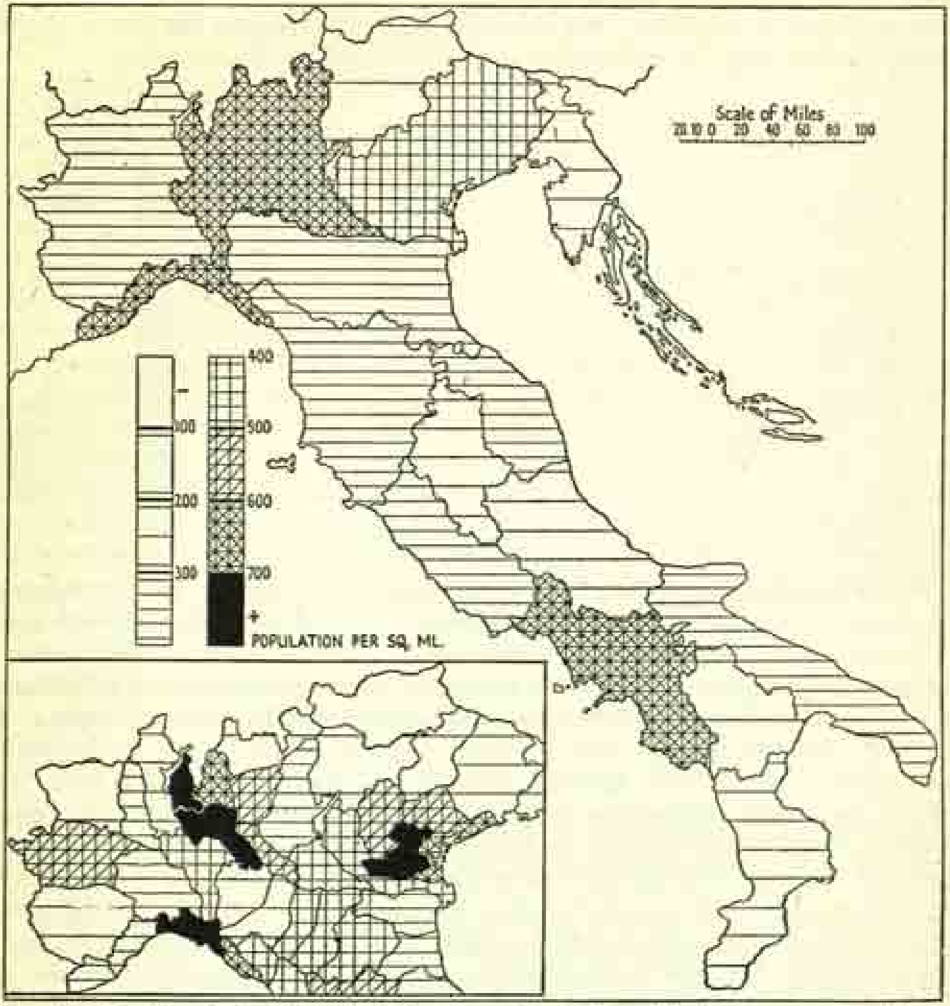


FIG. 77. Density of Population in Italy shown by shading. The inset map of northern Italy shows detail brought out by using smaller statistical units.

number, and so the position of the parish in the density scale, which is comprised of multiples of 64, is ascertained by inspection.

Some maps show irregular steps in the key for no apparent purpose. On the other hand, careful study may reveal an advantage in irregularity of change, as to separate a number of regions which would otherwise be grouped together and which for the purpose of the investigation are best differentiated. To illustrate again from population maps, choice of densities may enable distinction to be made between business and residential areas, and, also on the same map, between urban and rural areas. One scheme of densities proposed as applicable to population maps of any part of the world differentiated numbers of persons per square mile as follows:

0–8	hunting and fishing
8–39	grazing
26–65	first agriculture
65–130	extensive farming
130–194	intensive farming
194–259	first manufactures
259–389	mixed farms and manufactures
389–518	manufactures predominating.

Changes in the key may therefore be made in arithmetical or geometrical progression, or may be made at irregular intervals to improve territorial distribution of shadings or to reveal points of significance in an investigation. The changes to be aimed at are those which have significance on the ground itself.

It is obviously sound practice to make density of shading increase as density of population or commodity increases. When this is done the resultant map is graphic, and there is little need to refer to the key. The perfect map would probably need no key. Yet not uncommonly scales of shading are seen where different densities are shown merely by changes in the direction of shading, line spacing remaining unaltered. Hybrid systems, such as lines associated with rows of crosses and circles, are especially to be deprecated.

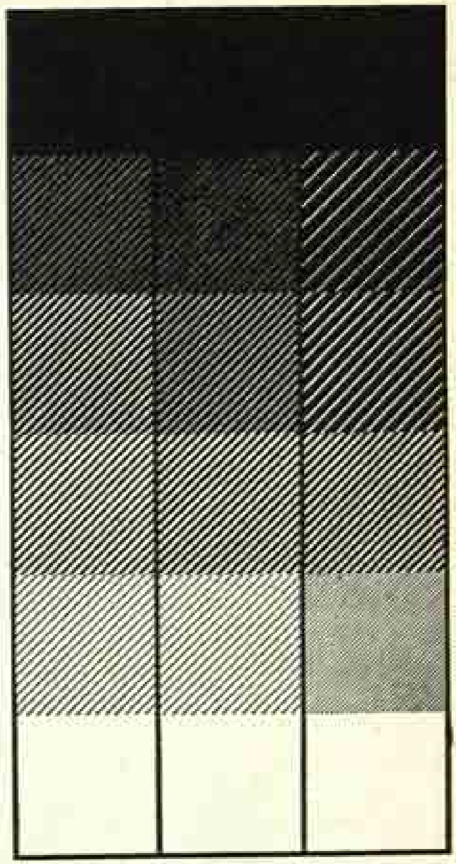


FIG. 78. A series of experimental shadings designed to pass by uniform steps from white to black. In the right-hand series the ratio of black to white in each square forms a simple arithmetical progression 0:5, 1:5, 2:5, 3:5, 4:5, 5:5. The two other series are attempts to get uniform sensory changes between white and black.

The scale of shading need not start at blank and finish with solid black. There are objections to such a scheme. In the first place the area left blank does not look merely of low density, but appears altogether void, which may not be true. Secondly, it is impossible to overprint anything on areas of solid black. Finally, even the most carefully graded scales passing from white to black, as seen in Fig. 78, may give a wrong impression of actual density changes.

FIG. 79. The same statistics are used for this map as for Fig. 77, but proportional shading is employed.

3. Proportional or Relative Density Shading

One way to meet density scale objections is to maintain a ratio between the densities it is desired to represent and the density of shading within the statistical units. This may be termed *Proportional* or *Relative Density Shading*.

It is surprisingly little employed. For the sake of comparison with the previous method, this method has been employed to re-map the density of population in Italy, and the result is seen in Fig. 79. Parallel lines are drawn at so many to the inch, in this example one per inch for every fifty people per square mile. This is done by drawing a north–south line in pencil through each department, and marking along it the required number of divisions. Through each mark an east–west line is drawn in ink, and the pencil work is rubbed out.

Limitations of the method are met when there is great variation in density, as application becomes impossible. It is well to experiment with dense and sparse areas first. An administrative area is sometimes so small that there is room for one cross line only, and its density cannot therefore be established by comparison with a key. There is difficulty in drawing a key at all, for only a representative series of densities can be shown, comparable to that on the Woodlands Map, Fig. 74, and the eye must decide the approximate position in the series of any particular area whose density is required.

In some respects the proportional shading method approaches the absolute. Maps so drawn are often not as striking as when an ordinary series of shading grades is used, but the impression accords more nearly with the facts of density distribution. The commoner method seems of particular value to impart elementary concepts, and the proportional method for more advanced work involving finer appreciation.

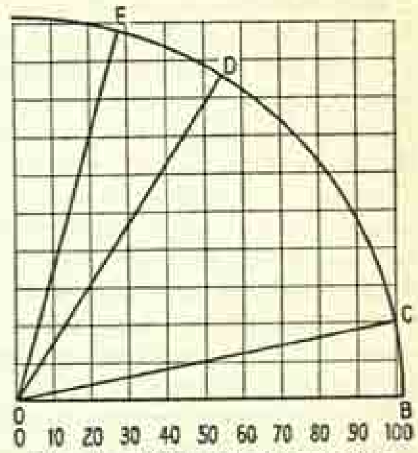


FIG. 80. Dividing a line into any number of equal parts.

It may be awkward at first to divide the vertical line into unusual fractions of an inch in order to get correct spacing, but a little excursion into the realm of practical geometry offers a solution, illustrated in Fig. 80. Instead of working in terms of lines per inch, a unit length 4 inches was chosen, as this offered the possibility of subdivision into any number of equal parts from 2 to 102, by drawing a single arc on millimetre graph-paper. The method employed is as follows with reference to Fig. 80, on which representation of millimetre squares has had to be omitted.

With centre *O*, and radius 4 inches, an arc *BCDE* is drawn on millimetre graph paper. Vertical parallel lines cutting *OB* are numbered, beginning at *O*. All lines, *OE*, *OD*, *OC*, *OB* are of equal length because all are radii. *C* marks the point where the arc is cut by the hundredth vertical line. But since all these vertical lines are parallel and equidistant, *OC* is cut by them into

100 equal parts. Similarly OD is cut into 55 equal parts. If it is required to divide the unit length into 28 parts, the twenty-eighth vertical line is followed till it cuts the arc, as at E. OE is then joined and is cut into the required number of equal parts by the verticals. Appropriate divisions are conveniently taken off along a straight edge of paper or with dividers.

An alternative method is to work out each case by simple arithmetic, in terms of millimetres, the smallest convenient unit of measurement. Thus taking an inch as equivalent to 25·5 millimetres, 17 cross lines to the inch would be spaced at 25·5 millimetres $\div$ 17, which is $1\frac{1}{2}$ millimetres apart. Spacing-marks are conveniently made with dividers.

Map correction is usually possible by scratching out, painting over, or patching. The latter is effected most neatly if a new piece of paper is placed under the map and cutting is performed through map and paper with a razor blade held vertically. The one operation then cuts away the unwanted portion and provides a patch identical in shape. A piece of adhesive paper at the back of the map enables the patch to be inserted with a flush finish.

Instead of changing the number of lines to the inch, different density grades can be shown by changing the thickness of the lines. For example, a six-grade key results if the lowest grade is left blank, the second has 20 parallel cross lines to the inch each $\frac{1}{100}$th of an inch thick, the third 20 cross lines per inch each $\frac{2}{100}$th of an inch thick, and so on till the sixth grade has 20 lines each $\frac{5}{100}$th of an inch thick, resulting in solid black. This is after the style of the right-hand column in Fig. 78.

The above key increases in simple arithmetical progression from white to black, the black occupying in successive grades, 0, 1, 2, 3, 4, and finally 5 fifths of the space. It should be possible to introduce a refinement offering an alternative form of proportional shading. This would simply require that the number of cross lines per inch remain constant, and that their thickness be made to vary directly with the densities to be mapped. The draughtsman's pen is useful to produce lines of various thicknesses, adjustment being made by means of the milled nut which controls the setting of the blades. Experiment is necessary to find the position of the milled nut to produce a line of any required thickness, and to determine for each map the most suitable number of cross lines per inch.

An approximate method to determine the thickness of any line is illustrated in Fig. 81, where (b) is a magnification of (a). It is apparent from (b) that when two lines AB, CD cross, a lozenge shape is formed, here lettered $KLMN$. Suppose that through K a line XY is erected perpendicular to CD, and through R a second perpendicular is erected to meet AB at A. Then from similar triangles ARM, XYM, $AR:RM = XY:YM$. Even on the unmagnified figure lengths corresponding to AR, RM and KM can be measured. Now if KM is regarded as approximately the same length as YM, then the length XY can be calculated by substitution in the above equation, and XY is approximately twice as long as the thickness of the lines AB or CD.

One difficulty in practice is that when drawing-pen blades are far apart the flow of ink becomes very rapid. In these circumstances the pen must be used dry to make parallel marks on the paper which are afterwards filled with ink by means of an ordinary nib.

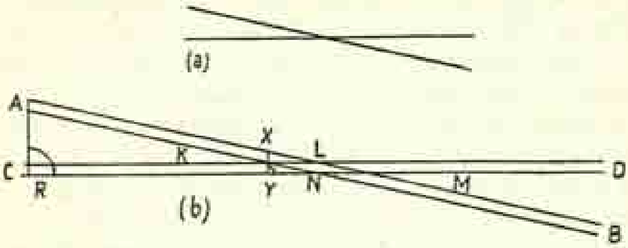


FIG. 81. Method of finding the approximate thickness of a line.

4. USE OF COLOUR

A great deal of use is made of colour in modern cartography and some very beautiful maps result. When density is shown by means of colour, optical effects have to be considered, quite apart from the fact that many people are colour blind, and still more are uncertain on colour. Red stands out more than yellow and should be employed for regions of greater and not of lesser density. Any colour series should be so chosen that density order automatically suggests itself. There is only a limited number of such series, the commonest passing from white to purple through various shades of yellow, brown, and red. This convention is usually employed on population maps.

Colours are sometimes used in spectrum order, but this does not necessarily give an optically graded series. The yellows usually appear unduly bright. An alternative is the use of monochrome, where depth of tone suggests density. A well-executed map has much to recommend it, and many pitfalls are avoided, though the method is seldom employed. On hand-painted maps, and in particular on those verging towards monochrome, it is well to insert numbers to check against similar numbers on the colour key. This system was adopted on old hand-coloured geological maps, and has been retained on modern geological maps although perfected colour printing has rendered numbers less necessary.

The use of colour to show density has one big advantage over shading, in that much base-map information can be inserted without upsetting visual effect. All that is normally printed in black, such as railways, rivers, and names, can remain. These are often a great aid in the use and interpretation of density distribution. When statistical units are large enough, it is even possible to overprint the density of each in figures, giving more detail than is obtainable from the key alone.

5. Other Aspects of Density Mapping

Much of the success in density mapping depends upon balancing such variables as the system of shading, the number of densities distinguished, the numerical values assigned to each grade, and draughtsmanship.

The possibility of wide application of the method ranks as one of its advantages, though rather ridiculous results can follow. If, for instance, the percentage of cultivated land devoted to one particular crop were mapped for a desert region, a single acre of that crop, occupying the only cultivated acre within the administrative unit, would cause the whole to be shown as 100 per cent., and administrative units in arid lands are often extensive. The mapping of the Tucuman sugar crop and the cotton and sugar crops of the Peru Coast Desert might yield instructive misapplications of the method.

A disadvantage of the density map, though by no means peculiar to it, is the confusion of thought to which it can give rise. Density is an abstract idea and is unrelated to actual distribution or arrangement. There is always the possibility that uniform shading, though showing the average density concept correctly, will be taken to imply uniformity of distribution over the whole statistical area. Misconception of this kind is greatest when distribution varies widely within the unit, as is likely when units are very extensive. On the map of Italy, as seen in Figs. 77 and 79, about 100,000 square miles have been treated in sixteen departments. Each department is therefore very large, is of varied topography, and distribution of population within each is by no means uniform. One means of getting a truer picture of density distribution is to subdivide departments into provinces. This has been done for north Italy, and the results are shown on the inset maps of Figs. 77 and 79. It seems obvious that these inset maps are more successful because statistical units are smaller in relation to the size of the map, and are fairly uniform in size.

It is more than probable that density changes rarely coincide with administrative boundaries, though it is inherent in the method that they appear to do so. Many parishes in England are long in proportion to width, and include a share of water-meadow, arable land, and hill grazing. If no adjustment is made and average density of any single commodity is mapped on a parish basis, it will almost inevitably give a false impression of density distribution. The commodity will appear fairly sparsely spread all over the parishes, though it probably ought to appear densely distributed in a single belt across them.

A more accurate map is sometimes made by redrawing boundaries on a density basis to accord with experience or information, observing recognized principles such as those described in connexion with dot maps. The method has been termed controlled guess-work, but at its best and as described below in connexion with the Ordnance Survey 1:1 Million Population Map, it is more than that. Care must be taken that the several densities assigned to different parts of an administrative unit are consistent with the known average density of the whole. For example, if in terms of unit squares the average density of the whole is 100, and the estimated density of $\frac{1}{3}$ is 10, the average density of the remaining $\frac{2}{3}$ is 145, as shown in the following equation, where x stands for the unknown density:

$$\begin{aligned}(\tfrac{1}{3}\times 10)+(\tfrac{2}{3}\times x) &= 100\\ \therefore\ \frac{10}{3}+\frac{2x}{3} &= 100\\ \therefore\ 10+2x &= 300\\ \therefore\qquad x &= 145\end{aligned}$$

6. Ordnance Survey Population Maps

The colour boundaries on the 1:1 Million Population Map of Britain, produced by the Ordnance Survey, are redrawn density boundaries and not administrative boundaries, although in some places, especially in agricultural districts having scattered farms and hamlets without aggregations of population, the two coincide. The change from parish to density boundaries was made by examination of maps which showed that in most cases almost the whole of the population of a parish could be localized within a restricted area to become a separate density area. The remaining scattered dwellings in the parish were counted and the population calculated on the known general average per dwelling-house. The acreage of the separate areas was computed and the respective densities calculated. In the case of urban areas, the smaller ward unit was dealt with in the same way. The separate densities were then classified in accordance with the adopted scale of numbering, and like classes grouped within the new density boundaries.

Twelve density grades are distinguished by colour tints ranging from white to black through browns and olive-green. In the key each has a descriptive title such as Sparse, Normal Rural, Urban, and so on.

A Population Map of Greater London was published by the Ordnance Survey in 1935, on a scale of $\frac{1}{2}$ inch to the mile. The same principle was applied in compiling the density areas for this map as for the 1:1 million map.

The colour scheme on the $\frac{1}{2}$-inch map is graded from white to dark brown in twelve tints, and approaches monochrome in treatment. The only other colour used, apart from blue for water-features and black for writing, is green for open public spaces. As these are treated as void of houses, there is no colour overlap. The total effect is pleasing and brings out the compact nature of the dense area of metropolitan population, extending from 10 to 12 miles in all directions from London Bridge. Points of maximum density are indicated by a dot in a circle, and those of minimum density by an open circle. The approximate population at each point is given in persons per acre.

On a separate sheet, five sections are drawn on a ½-inch scale to show relief with population density superimposed. Fig. 82 has been based on one of these sections (which are at a much larger scale on the O.S. map).

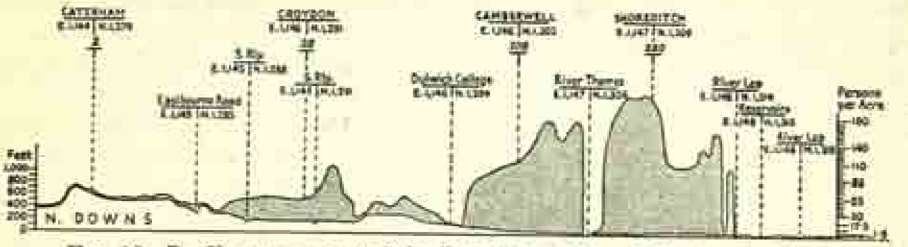


FIG. 82. Profile across part of the Population Map of Greater London.

On both maps grading has aimed at bringing out salient population densities. Consequently there is no straightforward numerical progression in the key, and as the range of densities to be covered on the two maps differs, the change-points are set at different intervals. This may be seen from the following statements:

Change-points in density grades in persons per square mile on (*a*) the 1 : 1 million map, and (*b*) the ½-inch map:

(*a*)	1,	25,	50,	100,	200,	400,	1,600,	6,400,	25,000,	64,000,	78,000.
(*b*)	0,	102,	960,	4,800,	11,200,	19,200,	35,200,	54,400,	70,400,	89,600,	115,200.

The first key shows a geometrical progression with a multiplying factor of 2 for rural areas, and 4 for urban areas, though it finally falls back to about 1¼ for the densest grade. The second key, to cover the greater density range, starts with a multiplying factor of almost 10, falling back fairly constantly to about 1¼ in the highest grade. It is obvious that a superficial examination of this type cannot reveal all that the cartographer had in mind when determining the grading.

It has been claimed that the chief hindrance to a completely accurate distribution map is the lack of detailed knowledge of distribution, but there is no doubt that with increasing subdivision, which forms a part of any attempt at more accurate mapping, the cartographical difficulties themselves increase, and with reduction of map scale they become a major problem.

7. Territorial Distribution Maps

It is appropriate to note at this point what may be termed Territorial Distribution Maps, though they have no connexion with density maps except that both employ shading and colour to show distribution. The best-known form is the coloured political map so universal in atlases before layer colouring became dominant.

Most territorial distributions, apart from those of political control, have no regard for administrative boundaries. Rocks, soils, vegetation, land utilization, and catchment areas, to quote examples, have boundaries of their own which are independent of others. Consequently it is usually necessary to ascertain them in the field. Further, though an attractive appearance is sought, it is otherwise immaterial what colours or shading-patterns are used since they are only to be compared in extent. There are, however, a number of recognized colour, shading, and symbol conventions which it is well to observe.

CHAPTER TWENTY-FOUR

ISOLINE MAPS

A DIFFERENT method of mapping is necessary to show distribution of such phenomena as temperature, pressure, and rainfall. Statistics are obtained for particular stations, and not for areas as a whole. In a sense the data are samples from which it is possible to draw a workably accurate map. The technique employed is very familiar. Statistics are entered on a map and points having identical readings are joined by continuous flowing lines, like those in Fig. 83. Frequently there are few identical readings, but it follows that, at least for many phenomena, interpolation of numbers is possible on a rational basis. Thus when a line joining places having an average temperature of 60° F. is required, it must be drawn to pass between those stations recording an average below 60°, and those recording above 60°. It can be assumed that the 60° line will pass midway between stations recording 55° and 65°, but nearer to a station recording 58° than to one recording 65°.

For precise work the problem of interpolation is of some importance and forms a separate study. At this stage, however, and until practice renders the course unnecessary, any pair of adjacent stations may be joined by a straight line to be treated as a scale-line along which changes are regarded as occurring at equally spaced intervals from one station reading to the next.

1. Application of Isoline Methods

The isotherm is only one of a series of lines having a variety of specific names to indicate particular functions. There are isobars, isonephs, isobaths, isohalines, isohyets, and many others. The word *isos* simply means equal and may be combined with any other word to indicate function. There is no generic name for all these lines. The word *isopleth* has been suggested, *pleth* meaning degree of fullness, but at times this name has been applied specifically to lines showing population densities. In any case, the conception of fullness is more applicable to densities mapped by this method than to climate and weather phenomena, though these are mapped by hardly any other means. The simplest inclusive name seems to be *isoline*, a term needing no explanation.

The variety of isoline names is itself an indication of the wide application of the method. It is used, for example, to map all sorts of climate and weather data, salinity of the sea, land relief, densities, and ratios. Two rather different ideas are involved in these numerous applications, one where representative samples are taken, as of weather phenomena, and another which involves reduction of areal symbols or density grades to points, but the procedure and results have so much in common as to render separate consideration unnecessary.

As a means of showing relief, isolines have been almost universally adopted under the familiar name of contours. The method of drawing them is perhaps unique in the production of isoline maps, as it is done in the field. The point is fully covered in Chapter X on Representation of Relief, and it is sufficient here to reiterate that contours are not drawn in an office by the simple method of interpolation between a number of spot heights, as are isopleths between density statistics.

It is possible to map degree of hilliness by means of isolines, and this aspect of topography is often as important as altitude. Contoured topographical sheets are divided into 1- or 2-inch squares, and the difference in altitude between the highest and lowest points in each is noted and written in the centre. These numbers are then plotted on a sheet of blank paper and isolines drawn at suitable numerical intervals.

Many commodity distributions are now shown by isolines, though both dot and density methods are available alternatives. The average density for each statistical unit is calculated and written at its geographical centre. When the whole region has been covered, lines are drawn at suitable interval values just like isotherms. These lines may well be called isopleths. Atlas population maps are often drawn in the same manner. Density of population statistics for administrative units are plotted on large-scale maps, and similar values joined by continuous flowing lines. The scale is then reduced and grading adjusted to suit the purpose. The method is therefore essentially different from that employed by the Ordnance Survey as described in the previous chapter in connexion with the 1:1 Million Population Map of Britain, though both methods result in the substitution of the original administrative boundaries by new density boundaries.

Ratios, as of crop area to total area, stock to crops, or yield per acre to annual or seasonal rainfall, are also mapped successfully by isolines. It is necessary that there should be an adequate number of statistical units, preferably about equal in area.

The isoline map is specially suitable to use in conjunction with other maps. Isotherms, isohyets, and frost-free period lines may be superimposed upon dot maps of crops, and limiting factors observed or demonstrated. There is much to be said for a judicious combination of dot and isoline methods to show distribution of a single commodity, for there is practically no confusion and the advantages of both methods are to hand.

Isolines may also be used to bring out small differences in distribution which are not readily observable when other means are employed. But whether differences are slight or substantial, a map should not be crowded with more isolines than are necessary to reveal distribution. Some atlas isotherm maps probably show this tendency.

The original of an isoline map may be worked out on a large-scale outline, and the isolines quickly and accurately copied on to a further map of any convenient scale. If the isolines arise from a study of administrative units, there is no need to trace boundaries. The necessary statistics are plotted on a sheet of tracing-paper overlying a base map on which the boundaries are marked. Base-map information may, however, be shown on the isoline map without confusion, the supreme example of this being the contoured topographical map.

Section drawing across contoured maps has already been described, but it should be noted that all isoline maps lend themselves to similar treatment. When relevant sections are compared, as of relief, rainfall, and crop density, significant correlations are sometimes revealed.

Reference has already been made to sections drawn across the Population Map of Greater London, and an example given in Fig. 82. It might be observed that while the relief is taken from an isoline map, the population profile is from a density map; also that the datum line to which all density values are referred is the profile of the topography. The sections as published bring out in a striking manner the sudden fall in population as the higher drier chalklands are reached.

2. Isoline Interval

Practically the same could be said about the choice of isoline values as about the choice of grades on density maps. On the whole a uniform interval gives the most easily interpreted picture. But this is not always practicable. On the International Million Map contour interval varies with increasing altitude from 100 to 1,000 metres, intermediate intervals being 200, 400, and 500 metres. The natural curve of erosion and the increased importance of relatively small variations of altitude at lower levels make this system desirable. Similarly isopleths may be drawn with a small interval value where changes of density are slight, but the interval may increase in dense areas. Intervals which bring out points of significance about a distribution are most worthy of consideration.

At whatever interval isolines are drawn on maps, some system of numbering or indication of value is essential. The simplest way of all is to put appropriate numbers on isolines and a statement beneath the map explaining what the numbers show. Minor considerations are whether a definite convention should be followed, such as breaking the isolines to insert numbers, attempting to number all isolines so that figures read horizontally, or so that the tops of all figures lie towards an isoline of greater value, which may involve some numbers appearing upside down. Useful ideas are gained by a study of contour numbering on topographical maps, and the same ideas may be applied to other isoline maps. It may be considered worth while to number every isoline in the margin where it runs off the map or, when isolines are few, to use distinctive lines for each value, as in Fig. 85. Spot densities or readings like spot heights may be used to advantage.

There is also the possibility of shading between isolines which has the effect, among other things, of taking attention from the isolines and focusing it upon the spaces, especially in regard to their shape. Increase of density should be shown by increase in density of shading, to make the map as graphic as possible. On some maps a large number of isoline values would seemingly swell the number of devices necessary to produce sufficient shading-patterns, but there is no need to change the pattern at every isoline. Half a dozen grades of shading are adequate, and differentiation within these grades may be shown by intermediate isolines. This practice is common on layer-coloured topographical maps.

Monochrome or colour-series may be used instead of shading. There are well-established colour conventions for climate, population, and relief maps. On the International Million Map colour changes occur with increase of altitude from dark green to light green, through yellows to browns, and finally through pinks to white for land over 7,000 metres. Since these colours represent height they are called hypsometric tints from *hypsi*, on high. The name isohypse has been suggested for contour, but it is unlikely to displace the established name. Whatever system of shading or colouring is employed on isoline maps generally, it is desirable to avoid a step-like effect.

3. Climate and Weather Maps

Climate and Weather Maps are so widely used and employ the isoline method to such an extent that they deserve separate mention, though remarks must here be limited chiefly to those maps which show temperature, pressure, and precipitation. Dependability is affected to a considerable extent by the standardization of method in taking readings, the number of stations employed, and their distribution. Temperatures, for example, should be taken under identical conditions, as when using the same type of thermometer, in the shade, at a uniform height above the ground, usually 5 feet, and at a certain time of day, unless the mean of maximum and minimum temperatures is employed. Stations should be numerous in relation to the size of the base map, and fairly evenly distributed. Large gaps between stations, or even large differences between readings at adjacent stations, tend to uncertain interpolation.

Often readings require adjustment before plotting is commenced. For some purposes it is desirable to eliminate temperature variations consequent upon relief, so 1° F. is added to the recorded temperature for approximately each 320 feet of altitude. This process is described as reducing or, better, adjusting temperatures to sea-level. Some atlases include maps showing actual average temperatures without adjustment. Isotherms then reveal the close association of temperature and relief.

All climate maps are based upon observations extending over a period of time, preferably thirty-five years. Hence the statement that climate is average weather. The mean temperature for any day is understood to be the mean of highest and lowest shade temperatures on that day or, for very accurate work, the mean of twenty-four hourly values. The mean for the month is the mean of daily means, and the mean for the year the mean of the twelve monthly means. When the average for a number of years is used the map is described as showing the Mean Average Annual Temperatures. Similarly a map may show the Mean Average January or July Temperatures. Since temperatures vary so much from day to day, season to season, and even from year to year, it is obvious that maps showing mean average conditions should be used with understanding.

Some of these points appear to be purely technical, but if distribution maps are to be of value and sound conclusions drawn from them, care must be taken to see that the statistics upon which they are based bear investigation and that statistical methods are understood. On the other hand, there is little point in quibbling about degree decimal places on a world temperature map drawn to a scale of 1:215 millions, or even on a map of North America on a scale of 1:50 millions, where the thinnest line covers territory 8 miles wide.

The meteorologist makes daily use of the isoline method in the preparation of isobar maps, which are of the utmost importance in forecasting weather. Average readings are not required, but as accurate a picture as possible of pressure distribution at a given moment, hence the name *Synoptic Charts*.

To ascertain comparable distribution of pressure free from differences caused by relief and other factors, mercury barometer readings are adjusted by formula for temperature, altitude, and latitude, standards being 12° C., and sea-level in latitude 45°. The less dependable aneroid barometer readings do not require correction for latitude and temperature.

Pressure is shown by isobars drawn at regular pressure intervals. Formerly pressure was expressed in terms of inches, the height of the mercury column in the barometer. On modern synoptic charts it is usually expressed in millibars, 1,000 millibars being equivalent to 29·531 inches on the mercury barometer read at 32° F. in latitude 45°.

For a long time isobars were shown as smooth curves, but research work, summarized in the *Polar Front Theory*, revealed that they often have sharp bends. The theory in relation to the north hemisphere may be stated briefly as follows. From lower latitudes there is a drift of warm moist air round the world from west to east, termed equatorial air. In higher latitudes there is a drift of cold dry polar air in the opposite direction. Along the friction zone, which is termed the Polar Front, where the streams come into contact, large shallow pockets of moist air from one to two thousand miles across are isolated and lifted by the colder heavier air. As the equatorial air approaches a station there is a marked rise in temperature, hence the statement that a *Warm Front* is approaching. There are also marked changes in pressure which give rise to sudden changes in the direction of isobars. Overcast sky, cloud, and rain caused by the cooling of the equatorial air as it is lifted by the polar air mark the oncoming depression. Behind the equatorial air is a *Cold Front*, marked by lower temperatures, sharp showers, high uprolling cumulous clouds, blue skies, and rising pressure. By the time a depression reaches Britain from America or the Atlantic, the equatorial air is often completely lifted from the ground by the polar air, and the fronts have merged. The depression is then said to be occluded.

Experience enables the meteorologist to anticipate the movement and development of pressure systems; and hence the synoptic chart, compiled from adjusted barometer readings received from hundreds of stations on land and ships at sea, complete with winds, precipitation, and sky conditions, enables him to make a reasonable forecast of the weather likely to prevail in a given district for a limited period ahead. The most important systems with which he deals are the closed isobar forms known as depressions or lows, and anticyclones or highs, but conditioned by these are other isobar forms such as troughs, wedges, and cols, as well as smaller secondary depressions within parent depressions, all of which have recognized weather associations.

Not infrequently a word description of pressure conditions is given, such as the following, and one is required to draw an isobar map to show the distribution:

'An extensive low-pressure area stretches south from Greenland, while other depressions are centred over Western Canada, North Africa, and the Black Sea. High-pressure areas cover the British Isles, Eastern Canada, and North-eastern Europe.'

All goes well in the early stages. A series of fairly close concentric circles is drawn to represent the depressions, and more widely spaced concentric circles, the anticyclones. But later two problems arise. The first is how to deal with the awkward spaces which appear between the different and seemingly isolated systems, and the second is the numbering of isobars, which sometimes leads one into difficulty and confusion.

A successful approach is made by noting that on nearly every weather chart the different systems are marked off from each other by isobars numbered 1,012 millibars, and then applying a general principle applicable to all isoline maps, namely, that between like systems, two highs or two lows, the same isoline is crossed an even number of times, whereas between unlike systems, a high and a low, the same isoline is crossed an odd number of times. The point is easily memorized by associating unlike and odd. These considerations give rise to the following procedure, which is illustrated in Fig. 83.

(*a*) Mark with the letters *H* and *L* the highs and lows where stated in the description of pressure distribution.

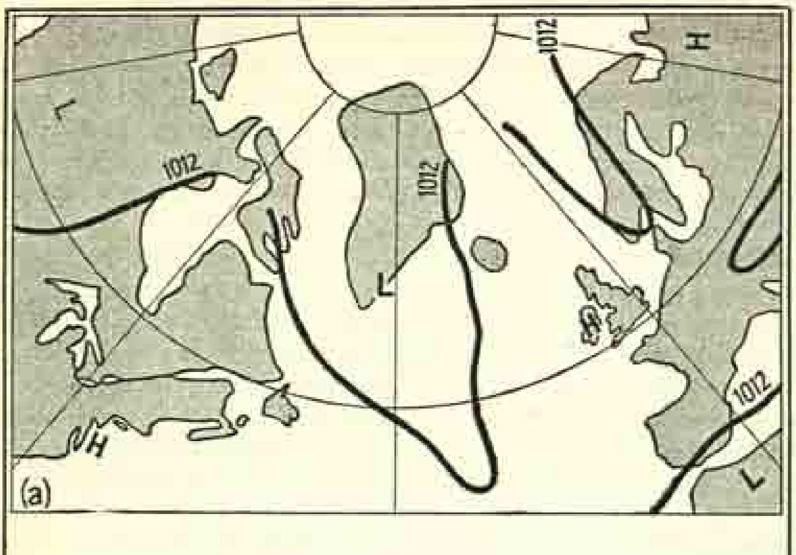


FIG. 83. Drawing the isobars of a weather chart from a description of pressure distribution. (*a*) First stage, (*b*) Second stage. *Zenithal Equidistant Projection.*

(*b*) Between like systems draw two 1,012-millibar-isolines, either separate isobars or a loop of one.

(*c*) Between unlike systems draw one 1,012-millibar-isoline.

(*d*) In the areas so marked off draw well-spaced isobars closer together in lows than in highs, avoiding sudden changes of spacing.

(*e*) Number all isobars outwards from the 1,012s. It will then be found that numbering offers no problem, and that the different systems do not suffer unnatural isolation.

Detail relating to probable winds, precipitation, temperature, and sky conditions may be added from a general knowledge of meteorology, which is outside the scope of present consideration, though a selection of symbols is given in Chapter XXVI in the section on Symbol Maps. Sufficient to say that the closer the isobars, the greater or steeper the pressure gradient, the stronger the winds, and the greater their degree of deflexion. The winds will, of course, always move from regions of higher to regions of lower pressure, with deflexion to the right in the north hemisphere and to the left in the south hemisphere.

Isobar maps which show adjusted mean average pressure, compiled from the means of twenty-four hourly readings for each day, are of value in the study of climate. A world map of mean average annual pressure reveals two belts of relatively high pressure, exceeding 1,015 millibars, lying approximately along the Tropics, with relatively low pressure, less than 1,010 millibars, in the Equatorial zone and again Polewards of the high-pressure belts. All the belts vary with the season in form, position, and extent, and these changes account for the movement of wind belts which play so important a part in determining climate.

Rainfall records are kept at more than 5,000 stations in Great Britain alone. Where stations are inevitably few, it is necessary to choose their sites with care in order to obtain representative samples, for rainfall varies rapidly from place to place, especially in hilly country. The amount of rainfall at a particular station is the depth of rain which would be caught in an exposed cylindrical jar. It is usually measured in inches or millimetres. Snow must be melted before its value in terms of rainfall is known, but a fair average is a foot of snow as equivalent to an inch of rain.

In many respects small-scale rainfall or isohyet maps are less satisfactory than isotherm and isobar maps. Too often they resemble a bad case of swine erysipelas, and there is rarely any indication of régime or seasonal distribution of precipitation, though this is very important.

Rainfall effective also varies enormously with temperature. Some years less than 12 inches of rain have been recorded in south-east England, with its orchards and crops, yet this amount in lowland tropical country would produce little but scrub. Such considerations as these open up the vista of mapping climatic phenomena by isoline methods.

4. Theory and Practice

In order to test some of the foregoing theory of distributional mapping, the different methods have been applied to map population in central Shropshire, and the results are shown in Figs. 84, 85, 86, and 87. The area covered is 24 by 26 miles. It is a particularly suitable area for demonstration because included in it are poor hill-grazing country, fertile agricultural lowlands, and the small but once world-renowned industrial district of the Coalbrookdale Coalfield.

(i) *The Dot Map.* This is seen in Fig. 84. Parish boundaries were traced on a scale of ½ inch to the mile, and population statistics and densities pencilled in

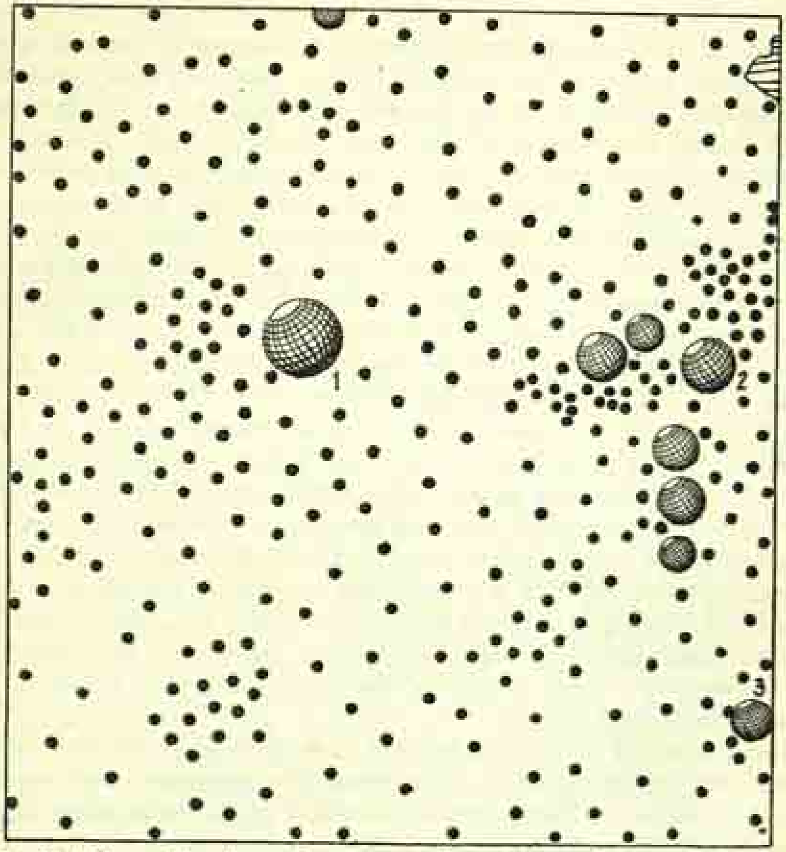


FIG. 84. Dot Map with spheres for urban agglomerations. 1 Shrewsbury 31,000; 2 Oakengates 11,000; 3 Bridgnorth 3,000. Each dot represents 200 people.

from the Official Census for 1931. The lowest round number of persons that could be assigned to a dot was 200. A lower number would have caused dots to merge in two or three of the densest parishes, though the appearance elsewhere would have been improved. Dots were made with a linoleum-tipped stick and printers' ink, and when this was dry the pencil work was rubbed out.

Production of the map presented three problems not previously discussed. The first was that often adjacent rural parishes each had slightly less than

100 people, and hence did not qualify for a dot as each had less than one-half of the requisite number. In these circumstances two parishes were treated as a unit, and one dot inserted in the geographical centre of the combined areas.

The second problem arose because parishes ran off the map at its edges, as seen in Fig. 87, where parish boundaries are shown. Although the population of the whole parish was known, that of the required portion was not. Here use

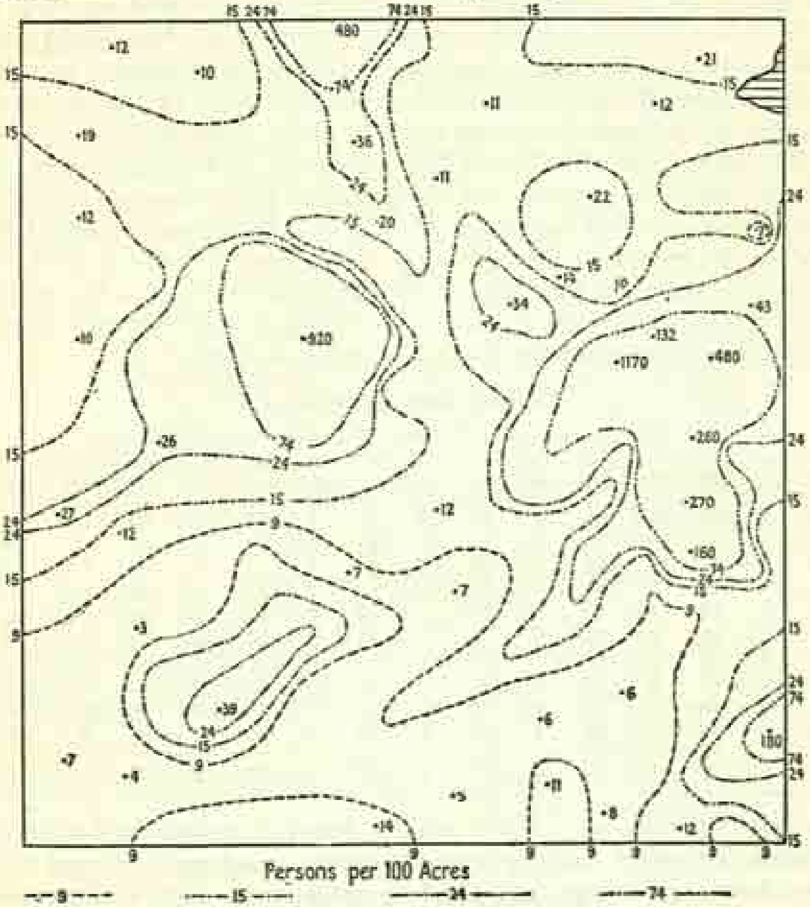


FIG. 85. Isopleth Map with spot densities.

was made of the density figure. Dots were inserted by eye in the required portion in the same density as they appeared in a complete parish, having the same official density figure elsewhere on the map.

The third problem was representation of urban agglomerations. Had the dot method been applied to these, dot value would have been so high as to render rural areas blank. Consequently resort was had to a three-dimensional figure, the sphere. The urban area with the greatest density of population determined the largest sphere size which could be accommodated in the space available. Having determined sphere size for this one area, the standard was set for the remaining urban areas, for any other sphere to scale could be accommodated within its appropriate administrative unit, because relatively smaller in size. This meant that a sphere might cover only a part of the district whose population it represented. If no modification were made, this might leave the sphere more or less surrounded by a blank area, which would probably be an unsound representation of actual population distribution. To avoid this, it seemed reasonable to adjust numbers so that some of the population is represented by dots near the sphere to break up the blank zone.

(ii) *The Isoline Map.* The Isoline Map seen in Fig. 85 was next drawn. Parish boundaries were again traced, and the density of population per 100 acres was written in the geographical centre of each parish. Densities ranged from 1 person per 100 acres to 1,170 persons per 100 acres, as shown in the following table, in which the left-hand figure (*a*) in each column shows the number of persons per 100 acres, while the corresponding figure (*b*) on the right shows the number of parishes having the given population density.

Distribution of Densities

(a) Persons per 100 acres; (b) number of parishes

(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
0	0	10	14	20	4	30	0	40	1	50	0	60	0	70	0
1	0	11	10	21	1	31	0	41	0	51	0	61	0	71	1
2	1	12	11	22	3	32	2	42	1	52	0	62	1	72	0
3	1	13	5	23	2	33	1	43	2	53	0	63	0	73	0
4	3	14	11	24	2	34	1	44	0	54	1	64	0	74	1
5	4	15	4	25	0	35	0	45	0	55	0	65	0	75	0
6	5	16	6	26	1	36	1	46	0	56	0	66	0	76	0
7	9	17	5	27	1	37	0	47	0	57	0	67	0	77	0
8	9	18	2	28	1	38	0	48	0	58	0	68	0	78	0
9	6	19	4	29	1	39	1	49	0	59	0	69	0	79	0
132	1	160	1	180	1	260	1	270	1	480	2	920	1	1,170	1

The chief difficulty is to choose suitable density numbers for isopleths. The temptation is to start drawing isopleths for the numbers 5, 10, and 15. It is soon evident that though successful in rural areas, such a small interval, building up in arithmetical progression, is incapable of dealing with the range of densities involved.

A geometrical progression such as 5, 15, 45, 145, &c., might cover the whole density range, but would mask small but significant changes of density in rural areas, as between the hill pastureland and the fertile ploughland.

If it is decided to choose isopleth numbers that will give a satisfactory territorial distribution to the various density grades, this is easily achieved.

There are about 150 parishes and if the density table is marked off at every thirtieth parish, four isopleths would be required. On this basis they would be numbered 8, 11, 14, and 23, but it is evident that too wide a range of densities falls in the group from 23 upwards.

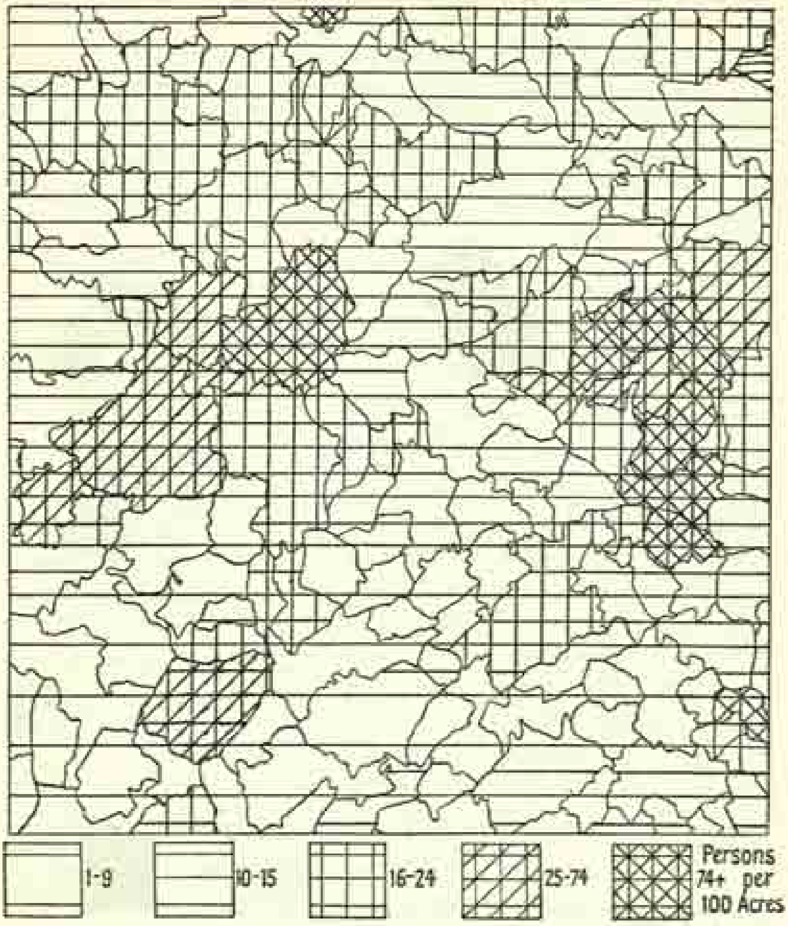


FIG. 86. Density by shading.

The system adopted was that of natural frequency distribution, obtained by graphing parish densities against numbers of parishes in each grade. The limiting densities of the various density groups appeared to be 9, 15, 24, and 74. The result at least justifies the statement that the unproductive hill land of the south is differentiated from the more fertile lowlands of the north, and the coalfield is also clearly differentiated with its high densities in the middle east of the area. It is interesting to compare these figures with those quoted in the chapter on Density Maps, since the map was drawn without reference to the latter.

(iii) *The Density Map.* Comparatively few points arose in drawing the density

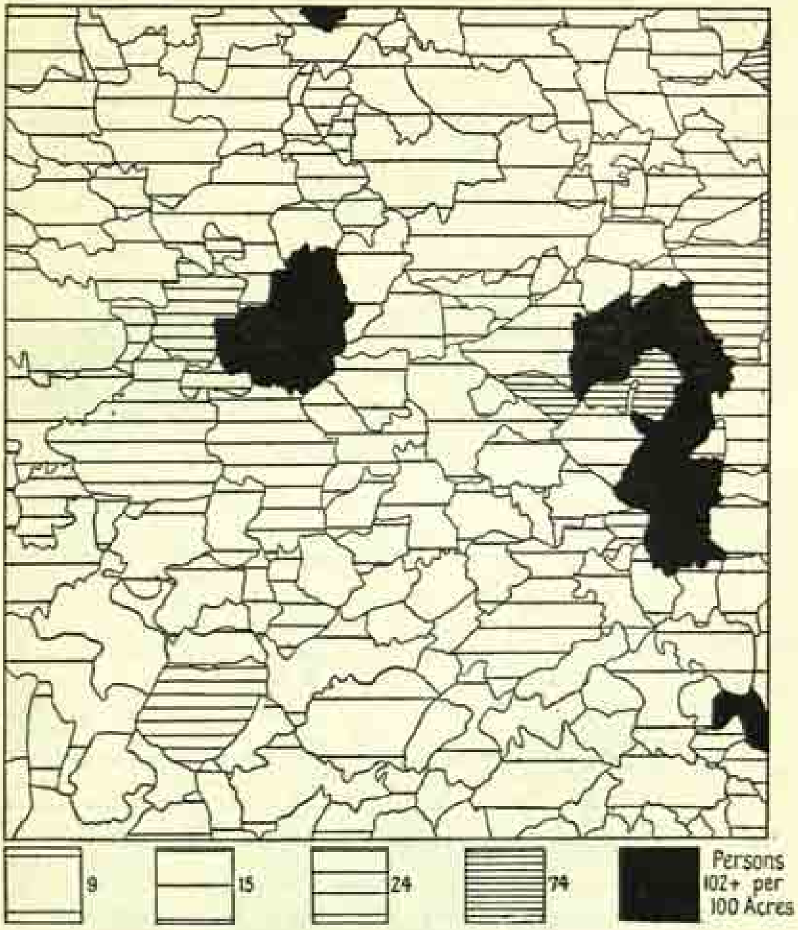


FIG. 87. Density by proportional shading.

map seen in Fig. 86. Consideration of density grades already set out in connexion with the isoline map, combined with the need for direct comparison with that map, suggested that the same density grades should be employed. Parish boundaries are allowed to remain. The shading patterns are among the simplest that could be chosen. They could be applied to the isoline map and comparison made of the areas covered by the same patterns on the different maps.

(iv) *Proportional Shading Map.* This map, as seen in Fig. 87, was drawn on the basis of one cross line per vertical inch for each person per 100 acres. Thus in parishes with 22 persons per 100 acres, 22 cross lines per vertical inch were drawn. Little difficulty was experienced in rural areas because density nowhere exceeded 74 persons per 100 acres. In urban areas, however, densities ranged from 132 upwards, and recourse was had to solid shading. This prevents differentiation within the high density areas. The map probably gives a truer visual impression of density distribution than the map in Fig. 86.

The statistical units are too small and numerous, and the range of densities too great, to render practicable an attempt to produce a fifth map having a uniform number of cross lines per inch, with each line of thickness proportional to the population density within its statistical unit.

CHAPTER TWENTY-FIVE

GRAPHS

MUCH statistical information has no relation to a space or territorial background, so does not lend itself to representation in map form. It can often be shown, however, by means of graphs or diagrams which reveal significant facts to the mind far more quickly than columns of statistics. Strictly speaking, these graphs and diagrams are outside the field of statistical mapping, but they are so often placed upon a map background that the principles involved should be understood.

There are several kinds of graphs, the chief of which are *Bar Graphs, Line Graphs, Clock Graphs*, and *Pie Graphs*. It is by no means easy to say when this or that type should be used. On the other hand, it is fairly easy to point out good and bad methods of graphing, and this will be done as each is considered.

1. BAR GRAPHS

Bar Graphs or Charts are among the simplest and most widely understood of graphs. The commonest form consists of a number of bars set up side by side as in Fig. 88, upper part, proportional *in length* to the numbers represented. Thus by *Simple Bar Charts* a variety of facts can be exhibited, such as the values of a country's leading manufactures, imports, or exports, the rainfall at a town month by month, or the calorific value of various foodstuffs.

Bars are drawn either vertically or horizontally. When a time element is present, as in a graph of monthly rainfall, it is customary to use the vertical form. Since the eye is accustomed to read from left to right, January is graphed on the left, and the months follow through to December on the right.

The same practice should be followed when the graph shows a succession of years, as in the example given, the earliest year being placed on the left and the latest on the right. If the time change is constant, the bars should be placed at a constant distance from each other, but if for some reason a break occurs in the time element, a gap should be left between the bars at the appropriate place to avoid misrepresentation. If a horizontal arrangement is chosen, as in Fig. 89, the date order should always be in sequence from top bar to bottom bar, again because the eye reads horizontal lines starting at the top and working down the page.

When there is no time element, bars may be drawn either vertically or horizontally and order is immaterial. A traditional arrangement may be followed as in setting out the names of provinces, but more often the arrangement is in order of magnitude.

Bar graphs used nearly always to be drawn on mathematical graph-paper,

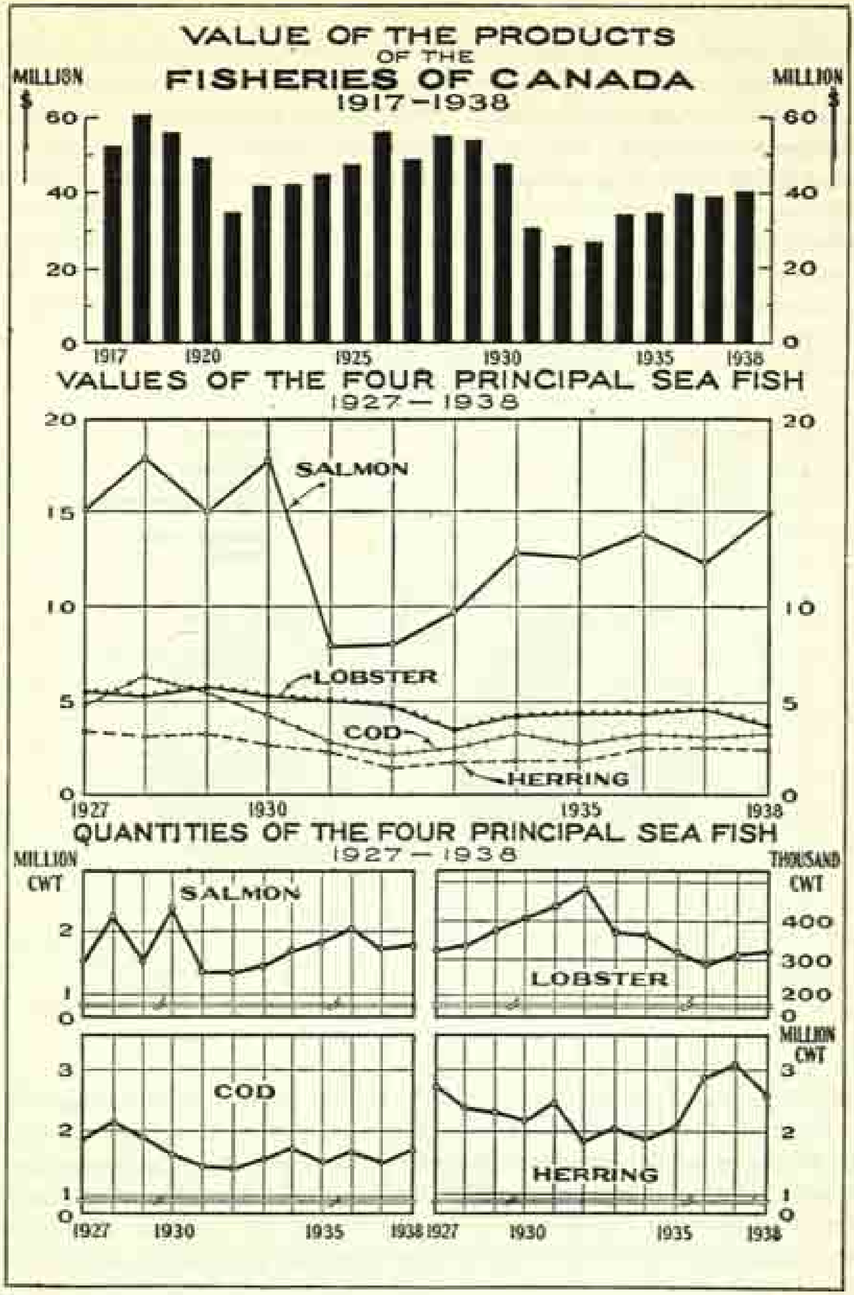


FIG. 88. Bar Graph upper part, Group Curve Graph middle part, Simple Curve Graphs lower part, all drawn in connexion with the Fisheries of Canada. Note incomplete fields and different scales in lower series.

commonly ruled in $\frac{1}{2}$-inch squares with subdivision into $\frac{1}{10}$-inch squares. The tradition dies hard. It should be considered whether such a complete and small grid aids interpretation of the graph, or whether it detracts from its appearance and induces eye fatigue. On the whole, it is far better to cut down the number of co-ordinate lines to a minimum, remembering that the graph is drawn to give a visual impression, and not to propound a puzzle. If graph paper cannot be procured with only essential co-ordinate lines upon it, tracing-paper can be laid over mathematical graph paper and essential co-ordinates ruled.

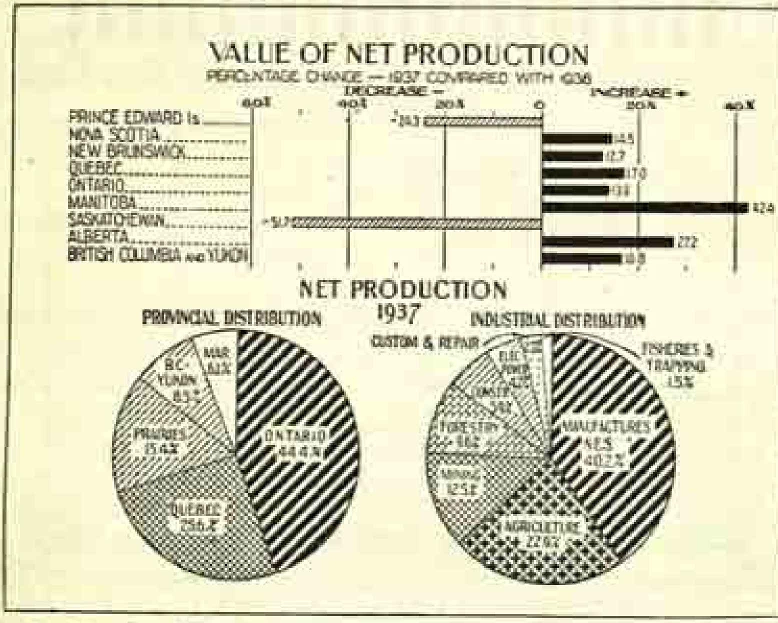


Fig. 89. Bar Graph and Pie Graphs. The Bar Graph, which is arranged as a Divergence Chart, shows percentage change in net values of industrial production in Canada in 1937 as compared with 1936. The Pie Graphs show the net values of production by provinces and industries.

Business men often insist that the statistics employed in preparing graphs should be not only readily accessible but actually visible. This may be achieved in either of two ways. A small statistical table might be set out on the same sheet of paper as the graph, or better, the statistics may be accommodated within the layout of the graph. This is seen in Fig. 89, where the percentage represented by each bar is printed at the end of the bar, but not in Fig. 88, where values of bars might have been inserted just above the 60-million-dollar level.

Some people prefer all statistics to be moved out to the top or side of the bar series. On a horizontal bar graph showing infant mortality from specified causes, the causes of death could be named in one column, the number of deaths from each entered in a second, and the numbers would then be represented by horizontal bars of appropriate length to the right.

The horizontal arrangement makes the setting out of names and numbers fairly easy, as there is plenty of room at the beginning or end of bars, whereas there is a very limited amount of horizontal space beneath vertical bars. This difficulty is often met by printing some words and numbers vertically, but it is worth while trying to arrange all printing so that it can be read without turning the graph round or straining the neck. Reference to Fig. 94 illustrates the point and is as originally published. An attempt might be made to redraw this diagram so that all numbers and printing, including the key, stand the same way.

There is much to be said for inserting scale numbers at both sides of a graph having vertical bars, or beneath and above a graph with horizontal bars.

So long as each bar is the correct relative length, its actual length is immaterial, subject to convenience and reason. Usually the longest bar, through limitations of space, determines the lengths of the other bars. Sometimes one or two bars so far outstrip others that they cause undue dwarfing. One must then consider whether the most suitable method of graphing has been chosen, or whether recourse might be had to bending the longest bars at right angles towards the limit of the graph field. Such a problem arises in graphing annual rainfall of stations in India, for rainfall ranges from 428 inches at Cherrapunji to 3 inches at Leh.

One point which deserves special emphasis is that bars should always start at the zero-line. A totally wrong impression is given if the bottom portion of the graph is cut away, like useless stumps of asparagus. Imagine that in Fig. 88 the 30-million-dollar line had been treated as the base of the graph. The value of products for 1929 would then appear to be several times that for 1932, and the true facts would not be represented graphically.

Similarly, when several graphs are drawn and arranged in juxtaposition so that comparisons are inevitable, all bars should be drawn to the same scale. Even when the fact that they are not is indicated by figures up the side scale of the graphs, reinforced by such a device as printing in full a multiplying factor, as, for example, on one graph at the tenth cross-line $10 \times 10{,}000$ bushels, and on another $10 \times 5{,}000$ bushels, the visual effect is inescapably misleading.

The width of bars is of little consequence, but extremes are to be avoided. A solid bar drawn with one stroke of a lettering or conical pen looks effective and is quickly executed. All the bars of a single graph should be uniform in width. The effect of bars of different widths is seen in Fig. 94, though this figure is not to be regarded as a bar graph.

Annual rainfall, graphed month by month, is usually shown by fairly narrow bars packed closely together. Their individual lengths are not as important as their collective effect in showing both total annual rainfall and rainfall régime. The only statistics usually required on such unit groups are the totals for the year. When printing is used in conjunction with vertical bars, increased width provides more space and cross-shading may be preferable to solid.

The spacing of bars varies a good deal from graph to graph. When mathematical graph paper was chiefly used, bars were often drawn without any spaces between them, but present practice seems to favour interbar spaces as in the two examples given. There is something to be said for drawing lines between bars, as these are not conspicuous and form convenient dividing lines for names or statistics relating to the various bars.

So far, it has been presumed that all bars are drawn on the same side of the base- or zero-line. But for divergent facts bars may be shown to advantage lying on opposite sides of zero. Fig. 89 provides an example, increase being shown to the right and decrease to the left. In contrast to the former type, such graphs may be described as *Divergence Bar Charts.* All that has been said about bar length and width, horizontal and vertical arrangement, applies equally here. The zero-line should be plainly marked, and the scale shown outwards from zero. Profit and loss, or imports and exports, could be graphed by this means, but if the bars are to be distinguished by different shading, it is to be questioned whether a change of direction is a help or hindrance. Elaboration should always be subservient to purpose.

Some statistics are shown to advantage by *Bar Groups.* Thus total rainfall and yield per acre of rice or maize in different areas might be shown by bars arranged in pairs. It is very doubtful whether Fig. 89 gives as much information in its present form as it would if the net values of production for 1936 and 1937 had been shown separately by bars arranged in pairs for each province. Increase or decrease, and relative net production, would then have been apparent.

Quantity and value of output of various provinces offers another application of the group method, though in such cases it must always be borne in mind that often the influence of such important factors as province area and population are not taken into account. The graphs may be factually correct and yet offer little to an inquiring mind.

If colour is available it is a great aid to comparison of bar groups, as the same colour is used in each group to show the same fact. Without colour, three or four bars per group seem about the maximum number that the eye can usefully retain for comparative purposes.

Another arrangement of the bar group in appropriate cases is to put all members end on, giving a series of what may be termed *Compound Bars* or *Bars of Component Parts.* Thus a firm's monthly sales might be shown as divided between home and foreign markets, yearly income as between spending and saving. Bars may consist of more than two component parts, as when the total number of unemployed is divided into several age or occupation groups, or when different strata are drawn to scale as encountered in borings. An advantage over the previous arrangement is that compound bars are easily compared in length. There is difficulty, however, in comparing the lengths of the various components, and the value of any one part is not easily read from the scale since its base often does not stand on the zero-line. There is probably a case for values to be written on all component parts, or for a fairly detailed division of the scale or an open divided scale-line as on topographical maps to assist in overcoming the difficulty.

A series of bars of uniform length is sometimes drawn and subdivided on a percentage basis. This *Percentage Bar Chart* may be illustrated from Fig. 94, disregarding for present purposes the significance of different bar widths. Analysis of various soil samples is suitably shown by this method, bars of uniform length being subdivided according to the percentage of clay, fine silt, sand, lime, humus, and moisture. The eye is often aided when bars are placed side by side, separated by spaces, but with the division lines carried across from one bar to the next. The varying thickness of any band is then quickly followed by divergence and convergence of link-lines.

It is hardly necessary to add that pictorial representation, as by drawing men of different height, should not find a place in serious graphical representation. There is much to be said, however, in favour of repetitive patterns in such forms as small men, pigs, or money bags on appropriate bar charts or in place of bars. These may succeed in attracting the attention of the unwary, and should not unduly annoy the purer soul in search of knowledge. Whether or not such decorative devices are employed, an adequate descriptive title should accompany every graph.

2. Line or Curve Graphs

Line graphs are as easy to understand as bar graphs. Most people are familiar with the bedside chart showing rise and fall of a patient's temperature, and many have seen barograph charts showing rise and fall of atmospheric pressure. When the elementary notion of a graph layout is understood, with dates along the bottom, and values up the side, it is as easy to show a given value for a specified year by a dot as by a bar. Thus in Fig. 88 the value of the products of the fisheries of Canada could have been shown by a series of dots at the places occupied by the tops of the bars. A line joining the dots would have called attention especially to the rise and fall in values, whereas the bars probably call attention rather to the value of each year in turn.

The line method has been adopted in Fig. 88, lower part, to show separately the quantities of the four principal sea-fish. These graphs may be termed *Simple Curve Graphs*. There is no accepted principle as to when lines or curves should be used instead of bars, but psychologically the line graph appeals as particularly suitable to show continuous changes, as of temperature, pressure, and population, and the bar graph to show discontinuous change, as of rainfall, price, output, and value, or of independent quantities unrelated by a time element, as of wheat production for a single year in different countries.

The layout of a line graph is like that of a vertical bar graph. If times or dates are involved they usually form the horizontal scale of the field, and should proceed in order from left to right. Quantities are then marked on the vertical scale. In such cases time is spoken of as the independent variable, and quantities as the dependent variable, though the reverse is sometimes true as when graphing the time taken by a child to increase a certain amount in weight. In graphing temperature changes with altitude, to show what is termed *Lapse Rate*, altitude is the independent variable and temperature the dependent. There should be no difficulty in determining which is which. The independent variable should always form the horizontal scale, so that the curve always reads from left to right, significance being attached to its rise and fall. No line version of the horizontal bar graph should be drawn.

When the vertical co-ordinates refer to periods, the first and last on the graph field should not be made thicker than the rest, unless the field represents a complete period, as, for example, when graphing the output of a mine from start to finish, or of a person's weight from birth to death.

There is some difference in practice in placing dots on the vertical scale. On some graphs the vertical *lines* are used to represent periods and dots are placed on the lines. On others the *spaces* between lines are treated as periods, and the dots are placed centrally in the spaces, just as bars are usually drawn in the vertical spaces of bar graphs. Another variant is seen where the spaces are treated as periods, but the dots are placed on the vertical line immediately to the right of each, as though to represent the state of affairs at the end of the period. The space system at least offers some convenience in inserting dates along the bottom of the graph, and statistics along the top.

The horizontal co-ordinates of the scale, and never the horizontal spaces, represent quantities. Hence scale numbers should be placed so that they are cut by the horizontal lines, or would be if these were produced. They should never stand on the lines. It is often a help in reading, when scale numbers appear on both sides of the graph. Numbers are often not written in full as in Fig. 91, but their value is expressed in words, as seen in Figs. 88 and 89, or a multiplying constant is written adjacent to one of the side-scale numbers at a convenient place on the field.

Unless circumstances are exceptional, the zero-line of the scale should appear in its true position in the layout. If it must be omitted, attention should be called to its absence by some device such as a wavy line at the bottom of the field, or a break as seen in the lower graphs of Fig. 88. Even then it is difficult to make mental allowance for an abbreviation which gives rise to visual misrepresentation. The position is rather different when graphing temperatures, as absolute zero is so far below ordinary temperatures as to render it an unsuitable base. For climate graphs at least, it is sound practice to mark clearly the co-ordinate representing freezing-point and to use a common base-line temperature for all curves that are likely to be compared with each other.

On some graphs the dots are clearly marked and on others they are not shown at all. It is a matter mainly of discretion. Dots should be joined by a series of straight lines, thus differing from the flowing lines used on isoline maps and the sections drawn across them. The resultant component line or curve as it is called should be distinct and clear, and in no way subject to confusion with co-ordinate lines. There is a distinct advantage in reducing the number of these to a minimum. Thus, if quantities are graphed monthly over a period of years, it is usually sufficient to draw one co-ordinate only for each twelfth month. There is no objection to the insertion of an occasional note on the graph field, for instance to explain any abnormal feature of the curve, but all printing should be readable without twisting the graph about.

Normally statistics are graphed directly from tables which show actual or average figures. Sometimes, as with trade statistics, rise and fall are so rapid and frequent that little can be gleaned of general trend, which may be the object of inquiry. It is often possible to reveal trend by finding a moving period total before graphing commences. For example, value of trade for each month in turn might be added to that of the eleven months immediately preceding it, resulting in a series of figures which show value of trade over periods of twelve months each. This moving annual total or progressive average tends to smooth out rapid short-period variations and so to reveal general trend.

Divergence Line Charts, like corresponding bar charts, require a field below and above the zero-line. They are useful to show such matters as profit and loss, the difference in value between imports and exports, or population changes due to migration, over a period of time. It is desirable in these circumstances to make the zero-line thicker than the other co-ordinate lines, and to indicate clearly the significance of the upper and lower fields. The scale of the dependent variable is naturally numbered outwards from the zero-line.

When cost-of-living or price-index numbers are compared over a period of time, an initial period is taken as standard, and usually expressed as 100 or 1,000. This number then forms the base against which fluctuations are measured. On a base 100, a fall of 17 would read 83, and a rise of 17 would read 117. This eliminates any danger of confusion which might arise were the standard called 0, and plus and minus signs used to indicate rises and falls. It is also a more convenient form for descriptive purposes. When the statistics are graphed, the standard or base might well be thickened like the zero-line of the divergence chart. There is no point in carrying the field down to zero because no one can imagine that the cost of living would ever fall to zero in a country civilized enough to keep reliable statistical records.

When more than one curve is shown on a single field, as in the middle series of Fig. 88, the graph may be termed a *Group Curve Graph*. Provided care is taken to draw lines which are easily distinguished from each other the arrangement is exceedingly useful for comparative purposes, but too many curves spoil the graph. It is better to limit the number at most to three or four on any one field, and to use a second field for further curves, repeating, if desirable, any one as a standard for comparison. An alternative method is to draw each curve on a separate field, as in the four bottom graphs of Fig. 88, and to arrange the fields so that comparison is easy. In this example visual comparison is impossible because the scales are not uniform, and fields are neither complete nor uniformly broken at the base.

It is frequently convenient to graph related items such as quantity and value on one field. One side of the graph is then scaled in unit quantities and the other in unit values. The two scales are independent of each other, though they make use of common horizontal co-ordinates. Values are chosen which keep the lines usefully close together on the field. There is a tendency to strike a balance in scale units. Thus, if one scale reads 1, 2, 3 million tons, the other scale might be selected to read at corresponding levels 1, 2, 3 million dollars, or 10, 20, 30 million dollars, rather than a sequence like 7, 14, 21.

The question of scale is sometimes complicated when items are alike in kind, but differ enormously in quantity, because a very long field is necessary to take in the complete range. In such circumstances it is possible to use a simple number scale on the graph, and to use different units for different curves. For example, on a graph relating to railway development, capital may be shown in millions of pounds, number of miles in thousands, and profits in hundreds. Unit values are then written on the appropriate curves, or an indication given of the number of noughts omitted. Another method of dealing with the problem is by means of semilogarithmic paper, as seen in Fig. 91. Both solutions are satisfactory from an accommodation point of view, but they limit the use of the graph for quantitative comparisons.

Fig. 90 shows a different arrangement of several curves on one field. The value of gold output has first been graphed, and then the value of gold plus copper, with other minerals added in turn. Thus, the final curve shows the total value of mineral production. This *Compound Curve Graph* is the line version of the compound bar chart, and has about the same advantages and disadvantages. The use of shading to distinguish different minerals might be noted. Solid black would be appropriate for coal, but as the area involved is extensive, it might unduly dominate the field. Value of agricultural production could be graphed by this method, distinguishing between field crops, farm animals, dairy products, fruit and vegetables, poultry, and eggs.

Values might also be graphed on a percentage basis, as described in connexion with bar graphs, but the results are rarely of distinctive value. Sometimes the percentage basis is misleading, as when mean monthly distribution of rainfall as a percentage of the average annual rainfall is represented in a simple line graph, for régime is shown devoid of quantity, a feature of paramount importance especially in tropical regions.

Just as the compound curve graph shows the quantities or values of different items and the totals of these for any one period, so a *Cumulative Curve Graph* shows the accumulated total at any given date. Thus, instead of showing the total value of minerals year by year, as in Fig. 90, a curve could have been

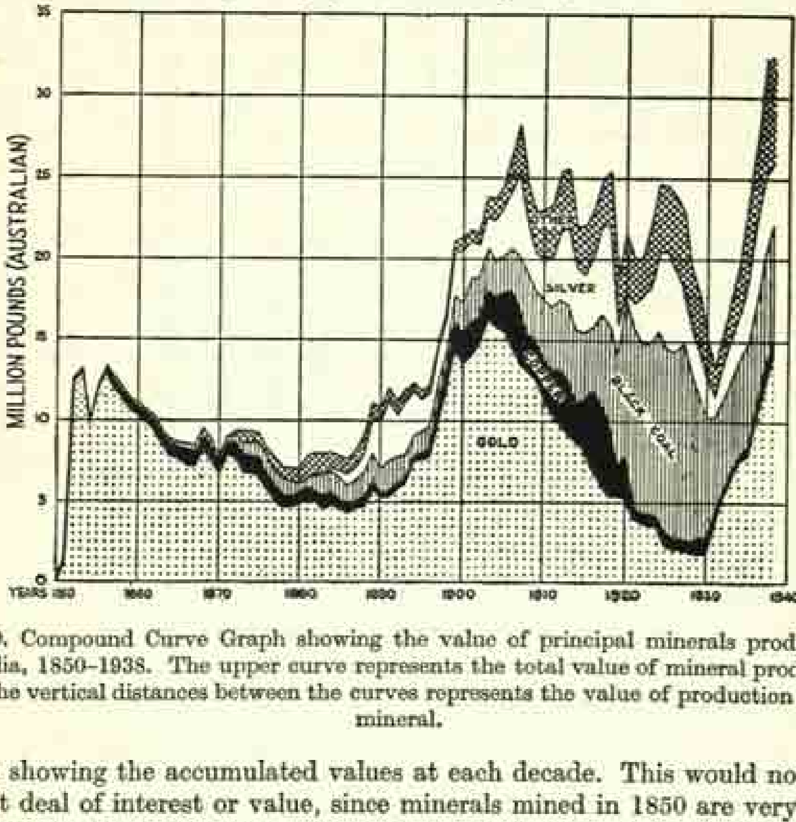


FIG. 90. Compound Curve Graph showing the value of principal minerals produced in Australia, 1850-1938. The upper curve represents the total value of mineral production, while the vertical distances between the curves represents the value of production of each mineral.

drawn showing the accumulated values at each decade. This would not have a great deal of interest or value, since minerals mined in 1850 are very much a thing of the past. But cumulative curves are of value to show such features as total water-power installation, mileage of railways, or factory output. For obvious reasons, the curve never falls, but may become parallel to the zero-line. Other curves, not necessarily cumulative, are usefully shown on the same field. On a railway development graph, for example, additional curves to show current construction cost per mile, traffic receipts, and net profits, may be drawn.

Frequency Curve Graphs are designed to show how often a certain phenomenon occurs. In graphing a year's weather statistics of a given station, daily minimum temperatures might be scaled along the horizontal co-ordinate, and the number of days on which each was recorded as the minimum on the vertical co-ordinate. The curve when plotted would show at a glance such information as the number of days any given temperature was experienced as the minimum, and from it could be found quite quickly on how many days temperature did

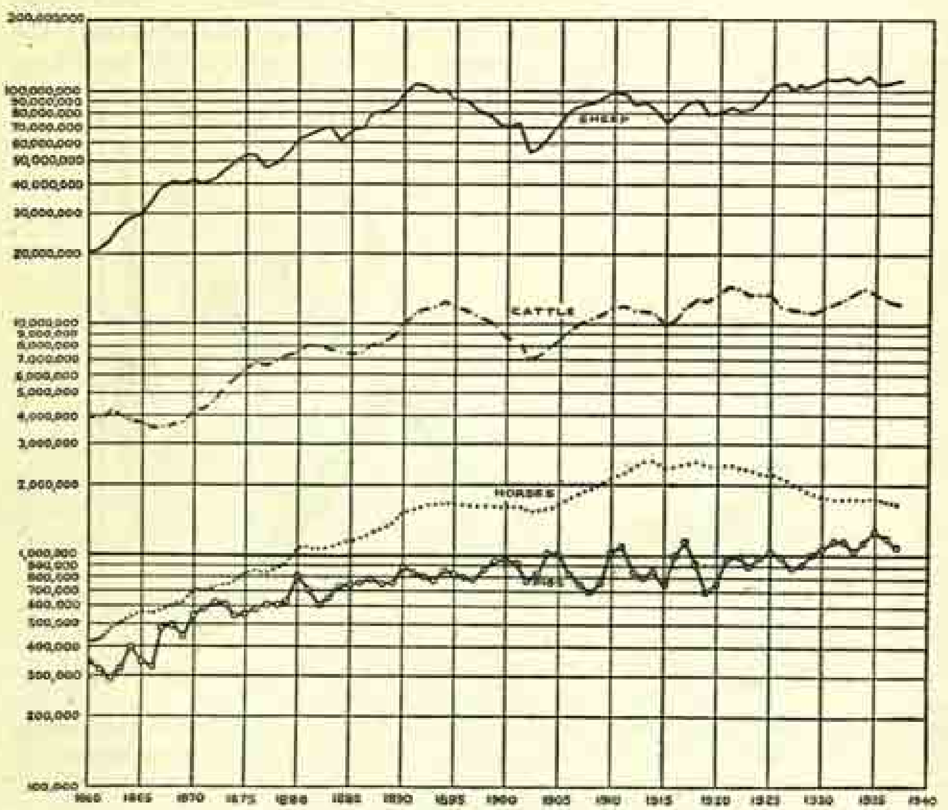


FIG. 91. Rate of change or ratio graph of livestock in Australia, 1860–1937. The vertical scale is logarithmic and the curves rise and fall according to the rate of increase or decrease. Actual numbers are indicated by the scale at the side of the graph.

not fall below a given degree, information valuable perhaps in considering crop production. Similarly, the length of drought periods experienced at a station might be plotted against the number of times each period occurred in half a century. Such a graph would be instructive in an examination of the possibilities of successful crop farming in a semi-arid region. Frequency graphs are also of use in biological investigation.

Reference has already been made to the convenience of a side scale like that of Fig. 91 to represent widely differing numbers on a single field. To show the range of numbers in this example but using an ordinary arithmetical scale, and allowing one-tenth of an inch for each hundred thousand animals, the field would have to be about 3 yards long. If, on the other hand, percentage variations had been graphed using 1860 as the starting-point, no indication of absolute numbers would have been given, and they are of great importance.

On close examination of the scale it will be observed that the base is numbered 100,000, and that horizontal co-ordinates become closer till the number 1,000,000 is reached, and then there is repetition of spacing to 10,000,000 and again to 100,000,000, but each time the numerical build-up increases. It would manifestly be impossible in the upper part of the graph to draw horizontal co-ordinates for every 100,000 increase. This system of spacing is not then proportional to the numbers themselves, but it is proportional to their logarithms. Thus, because the logarithms respectively of 100,000, 1,000,000, and 10,000,000 are 5, 6, and 7, their co-ordinates are equally spaced. This logarithmic ruling in one direction, combined with arithmetical ruling in the other, gives what is termed *Semilogarithmic Graph Paper*.

From examination of the repetition of spacing it is evident that the same amount of vertical rise occurs between any number and double that number, for example, between 200,000 and 400,000, as between 30,000,000 and 60,000,000. This means that if any items double in number or value over a given period, the increase is shown by identical slopes or curves, regardless of numbers involved and place on the field. Generalizing, all rates of change are shown by identical curves, and consequently semilogarithmic paper is indispensable for these *Rate of Change* or *Ratio Graphs*.

When expenses and turnover are graphed by these means, it is apparent whether expenses are increasing at a greater rate than turnover, and this is more significant than absolute increase. Other subjects for treatment on semilogarithmic paper might be passengers carried and passengers killed, this for the enlightenment of the management rather than for public entertainment; sales of vehicles and of spare parts; areas devoted to permanent grass and to specific cultivated crops; total number of sheep and of breeding-ewes; value of imports from different countries and of total imports; and also graphs of population, immigration, or output, where rate of change is more important than absolute change.

Logarithmic paper is available in one, two, three, four, or five cycles, and is scaled at will. There is no zero, but a power of 10 should always be used, and each new cycle or deck commences at ten times the value of the previous one. Single-deck paper may be scaled from 1 to 10 or 100 to 1,000. If this range is not sufficient double-deck paper may be used, with range 100 to 1,000 on the first deck and 1,000 to 10,000 on the second. With five-deck paper the bottom figure can be 10, and the top of the fifth deck is then 1,000,000. A big advantage of this system is not only in the range of values which can be plotted, but what is also inherent in the previous discussion, that variations in low numbers and in high numbers can both be plotted on the same field without undue suppression of low-number changes.

3. Combined Bar and Line Graphs

Good use is often made of combined bar and line graphs on a single field. Probably the commonest seen are of rainfall and temperature. Rainfall is usually shown by means of twelve bars, one for each calendar month. It might be noted in passing that the bars are, therefore, for unequal periods. Temperature is graphed by a simple curve. Rainfall régime is made apparent and an impression given of the amount. Range of temperature is also shown. Rainfall scale is written up one side of the field and temperature up the other. Since the temperature scale has no suitable zero and, therefore, cannot coincide with rainfall zero, matters can be so arranged that the temperature line does not become obscured by the rainfall bars. Arrangements should be made to draw all such graphs as are likely to be compared with each other, on a common scale. This might apply to all graphs in a single book on climate. The advantage of leaving spaces between bars is apparent, for should the line of necessity cut the bars, its course may still be traced.

Actual and average figures are of interest in a survey of climate, and despite the objection that is sometimes expressed to graphing rainfall by curves, or temperature by bars, there seems a case for graphing, say, the average temperature or rainfall by a curve and the temperature or rainfall record of a specific year by bars on the same field. The difference revealed may prove surprising. In Western Australia, where only about 2 per cent. of the area has an average of over 40 inches of rainfall a year, 9 stations have recorded a fall of between 14 inches and 30 inches in 24 hours. The heaviest fall, of 29·4 inches, was at Whim Creek, where the average is about 15 inches a year.

Use may also be made of bars and curves on a divergence chart. Thus, monthly profit and loss may be shown by bars above and below the zero-line, while a curve shows the net or cumulative result.

4. Clock Graphs

The perfect symmetry of the circle makes a universal appeal, and perhaps for this reason attempts are made to employ the circle to represent statistical information. Add to this symmetry a symmetrical division into twelve parts, as made by the hour numbers on a clock face, and the coincidence in number of these subdivisions with the twelve months of the year, and the origin of the *Clock Graph* is explained. Twelve rays are drawn and named after the months of the year, starting with January at twelve o'clock and proceeding in clockwise order. The quantity to be graphed for each month is scaled outwards from the centre as zero, along the appropriate ray. Quantity marks are then joined, and the resulting figure by its shape shows monthly changes.

The clock graph has been justifiably condemned because information can nearly always be graphed by better means. One of the few points in its favour is that the layout suits line graphs of certain phenomena which go through a cycle of time, as average temperature from January to January.

An example of application to climate graphing is seen in Fig. 92. As a matter

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Alt. (feet)*
Temperature (° F.)	65	70	70	85	86	85	83	82	83	80	72	65	21
Rainfall (inches)	0·4	1·1	1·4	2·0	5·0	11·2	12·1	11·5	9·0	4·3	0·5	0·2	..

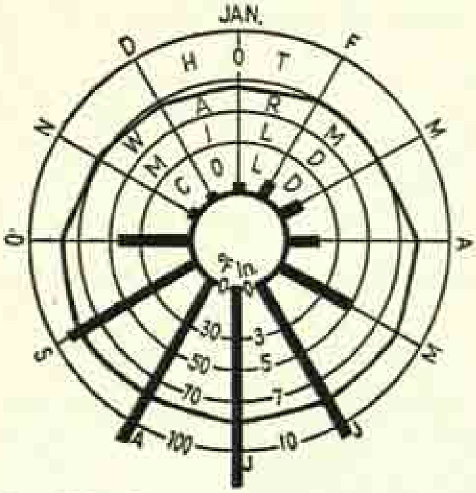


FIG. 92. Clock Graph or Polar Chart to show temperature and rainfall of Calcutta, drawn from figures in table above.

of convenience the zero of the scale is an inner circle. The concentric co-ordinates are spaced at temperature intervals to accord with the descriptive words inscribed. As temperature rises, the temperature curve moves away from the centre. Strictly speaking, the temperature scale should be a geometrical progression to avoid slope distortion, but here an arithmetical progression is used. A numerical balance is struck between scales for temperature and rainfall, which is shown by the bars. The information on this *Polar Chart*, which is an alternative name to clock graph, should be graphed as described in the previous section, and the results compared.

The wind-rose is a form of clock graph, though with eight or sixteen rays instead of twelve. The rays are drawn proportional in length to the number

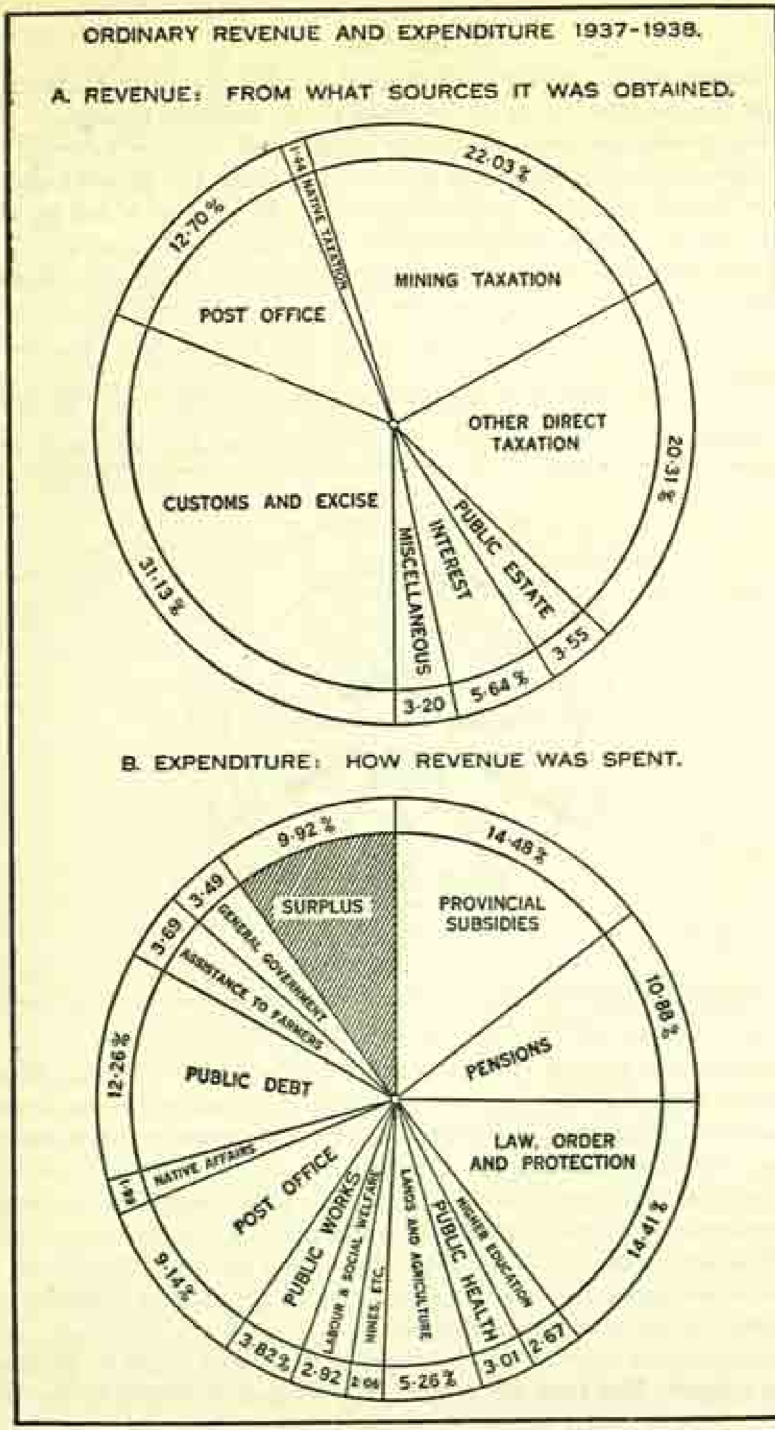


Fig. 93. Pie Graphs to show revenue and expenditure of the Union of South Africa, 1937–8.

of days on which wind of given direction is recorded. The wind direction is indicated by that of the ray, regarded as pointing inward towards the centre. Calms may be shown by a number or percentage inscribed in a circle about the centre, or by a horizontal line of appropriate length beneath the rose.

5. Pie Graphs

Pie Graphs are also widely condemned, but still more widely used. Examples are seen in Figs. 93 and 96. The method of production is quite simple. A circle of any convenient radius is drawn and subdivided into sectors proportional to the numbers represented. Each degree of arc is $\frac{1}{360}$ of the total. If statistics are given in a percentage form, it is convenient to work on the basis that 1 per cent. is equivalent to 3·6 degrees. The smallest quantities should be dealt with first because any slight error that accumulates does not seriously affect a remaining large sector but may halve or double a very small one. Useful limits are probably from four to ten sectors, with optimum about six.

There is little difficulty in setting out statistical values of sectors, but lettering is not so simple. Appropriate words may be written in the sectors, or round the circumference. Neither is wholly satisfactory, because a change of face is necessary to aid easy reading. Both methods and the need for the change are seen in Fig. 93, while Fig. 89 shows one method of dealing with sectors which do not provide enough space for words.

This much at least may be said in favour of the pie graph. It is popular, it is inherently interesting, and it gives a sound impression, sometimes even a vivid one, of component parts. The eye is not untrained in the estimation of angles. But the exact comparative quality of the bar graph is lacking, and hence for business purposes the pie graph is out of favour. The chief trouble arises when an attempt is made to graph statistics by drawing a series of pie graphs proportional in area to the numbers represented. Comparison of circle areas is itself difficult, but comparison of sectors of different circles is impossible. Such misuse of the pie-graph method justifiably causes condemnation. The case is not fairly represented in Fig. 93 because the circles are the same size, but reference to Fig. 96 should make the matter clear.

Thus the pie graph is not to be ruled out as a means of showing components, but it should not be employed to compare sets of components in circles of different sizes, nor should circles be made the same size if they represent different total amounts. The solution is to employ a different method, as by using bars, or to include all components in a single circle, marking major divisions first, and subsequently subdivisions of each.

An unusually large collection of pie graphs in colour is to be found in the *Chambers of Commerce Atlas*, and these, with bar charts, supplement and summarize the information shown by dot maps. There is much to be said for such a combination of methods in statistical representation.

CHAPTER TWENTY-SIX

DIAGRAMS AND DIAGRAM MAPS

DIAGRAMS are usually regarded as different from graphs, though the line of demarcation is at times ill defined. Both are used to convey statistical information in a form that renders conscious calculation unnecessary. In some circumstances it is desirable to relate the diagrams or graphs to particular places or areas, and a positional problem arises which may best be satisfied by spacing the drawings on suitable base maps. The resultant diagram maps, as they may be collectively called, are distribution maps just as surely as the dot, density, and isoline maps already described. There are, however, distinctive subtypes which merit special notice and are given specific names.

1. Two-dimensional Diagrams

Two-dimensional diagrams differ from bars of a bar graph in that *areas* are proportional to the numbers represented. The chief figures used are circles, squares, and rectangles.

(*a*) *Circles.* To draw circles proportional in area to give numbers, it is necessary to find the radii of the circles. These are obtainable by equating the numbers in turn to πr^2, and finding the value of r. For example, if a circle is required to show 10 units of value, then

$$\pi r^2 = 10, \quad \therefore r = \sqrt{\frac{10}{\pi}}.$$

It will be realized that π enters as a divisor every time, and consequently in finding appropriate radii lengths, their *relative* lengths are unaltered if the division by π is omitted each time, and r^2 is equated to the number without reference to π. Thus the radii of circles vary directly in length as the square roots of the numbers the circles represent. When the relative lengths of the radii have been calculated in terms of linear units, a suitable value may be ascribed to the units, such as millimetres, centimetres, or inches.

The chief objection to the use of circles is the difficulty of estimating relative areas. Most people tend to undervalue the larger circles, and some even tend to value circles according to diameters, though by doubling a diameter, circle area is increased fourfold.

The simplest arrangement of circles is in line, in order of magnitude. A concentric arrangement has some attraction, but this gives rise to doubt as to whether the whole of each circle is to be interpreted as the value represented, or whether values are shown by the zones between circle circumferences. The former is probably the more spontaneous interpretation, though the correct one depends on the method by which radii lengths have been determined. A third arrangement, which is calculated to remove the doubt arising from the second, and yet make comparison easier than in the first, is to draw the circles within each other, but touching a common tangent, like plates of different sizes reared in front of each other on a shelf. The first arrangement alone is possible if circles are to be filled in solid.

(b) *Squares.* Practically the same applies to the use of squares as to circles, but squares probably give a more accurate impression of relative values. The length of sides is determined by the square roots of the numbers to be shown. Arrangement may take the form of squares in a row, or all may be drawn with a common corner. This aids comparison, especially if shown on mathematical graph paper. An arrangement by which all squares have common diagonals, corresponding to the concentric arrangement of circles, has little to recommend it, nor has that in which all squares have a common vertical centre-line and stand on a common base.

(c) *Rectangles.* Instead of treating numbers separately they may be added together and a single rectangle drawn to represent the total. The rectangle may then be subdivided into component parts. An example is seen in Fig. 94. The whole rectangle represents Australia, and an area scale is shown along the base. The rectangle is cut into strips to represent the states by area. Each state strip is then subdivided to indicate the condition of land tenure within it. A percentage scale of subdivisions is shown up the side. Thus the original rectangle is divided into twenty-eight lesser rectangles without confusion.

Many statistics require far less subdivision of the representative rectangle than the above. Thus the chief products of a region might be ham, jam, sugar, and bacon, requiring only four subdivisions. Nor is it essential to draw a simple rectangle. The chief crops of India in 1935–6, by acreage, were rice, wheat, cotton, ground-nuts, sesamum, rape and mustard, and sugar-cane, totalling 163 million acres. By using squared paper an initial rectangle may be drawn with dimensions 10 by 16, and the outstanding 3 units added as a small projection. This figure is then conveniently subdivided so that each part contains the appropriate number of unit areas, but not necessarily in simple rectangle shape. Thus rice, occupying 82 million acres, might be shown by half the large rectangle, namely, 10 by 8 units, with 2 more added. Objections may be raised to such a method, as indeed to any method, but there is something to be said for making graphical representation attractive, and departing at least occasionally from prosaic forms.

More complicated rectangular diagrams are possible in which a rectangle representing a region is subdivided to show statistical units, and each occupies not only the correct relative area but also the same relative position in the rectangle as on the map. On this basis the rectangle may be redrawn and again subdivided into units proportional in area to population, wealth, or productive capacity of the component statistical units. The name rectangular statistical cartogram has been suggested for this form of diagram, but it might be noted that the word cartogram is at present used without exact definition. It is

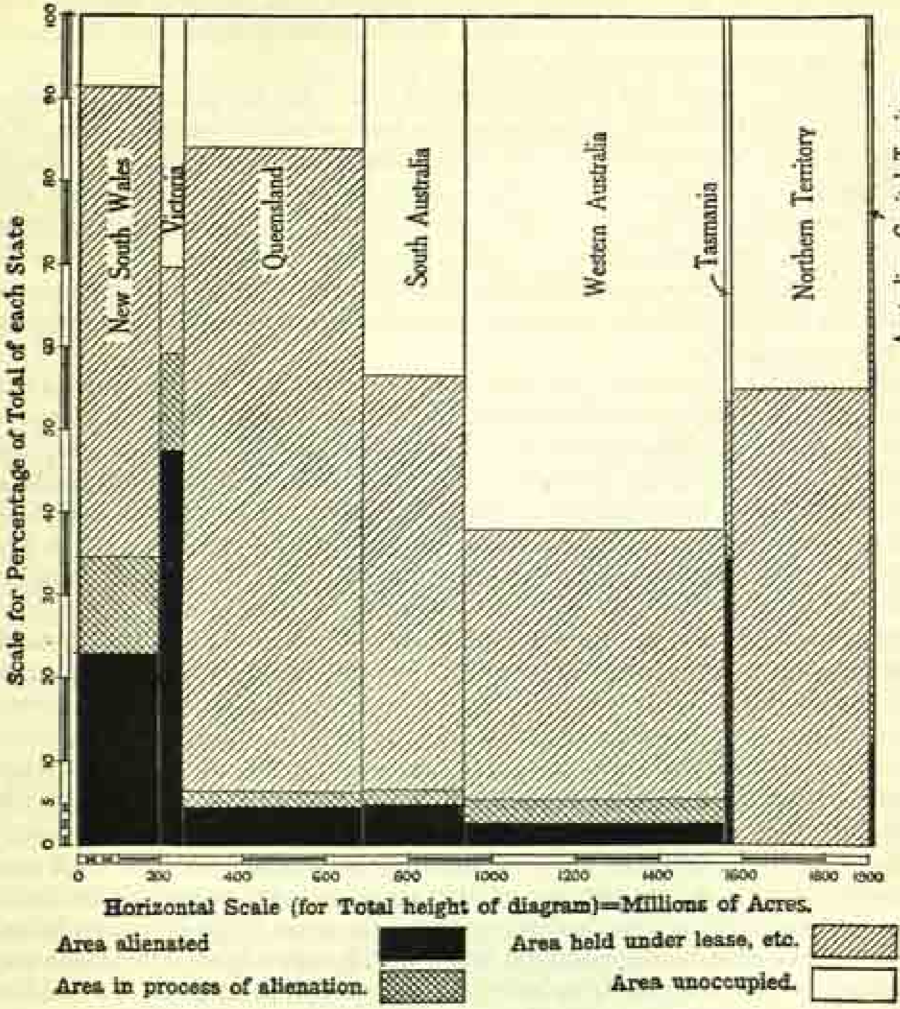


FIG. 94. Rectangular diagram to show land tenure in the several states of Australia at the end of the year 1937.

commonly employed to denote a simple diagrammatic map like some of those described in section 3 of this chapter.

Despite the frequent objection that areas are so difficult to compare with each other that two-dimensional diagrams should not be used, but should give place to such as bar graphs, it seems legitimate at least in representing areas to use two-dimensional figures. Thus the crop areas of a country seem quite properly represented by rectangles. Further, areal representation is accepted as the basis of mapping distributions of the territorial type as on political or geological maps, though the problem of comparison is more complicated because the different areas are of irregular shape.

All two-dimensional diagrams, no less than the graphs previously described, should have descriptive titles and relevant statistics plainly inscribed. It would be worth while redrawing Fig. 94 with all writing the same way up and with statistics on the subdivisions to render side and base scales unnecessary.

2. Three-dimensional Diagrams

One advantage of three-dimensional or volumetric symbols is the wide range of numbers which can be represented with little variation in the amount of space required. Thus 1 unit might be shown by a cube with edges 1 cm. long, and 1,000 units by a second cube with edges only 10 cm. long. If a sphere one-tenth of an inch in diameter is drawn to show an agglomeration of 1,000 persons, a sphere only 2 inches in diameter is required to show an agglomeration of 8,000,000 people, the greatest agglomeration in the world. Such a range of numbers could not be shown by one- or even two-dimensional figures. Spheres and cubes are the chief volumetric figures used in graphical work.

(a) *Spheres.* The volume of a sphere is $\frac{4}{3}\pi r^3$, and hence values of r can be found by equating this in turn to the numbers it is desired to represent. But as with circles, one part of the formula, this time $\frac{4}{3}\pi$, is a constant factor, so that it is only necessary to find the cube roots of numbers to get radii of appropriate relative lengths for the spheres. Cube roots may be found by trial with sufficient accuracy for graphical purposes, or if trial proves obstinate, resort may be had to logarithms.

One of the chief troubles about the sphere is the difficulty of drawing it. The outline is simple as it is made with compasses. Successful examples are seen netted and shaded to look like golf balls, rather than smooth orange-like forms. If spheres are few, hand shading is possible. If many are required recourse might be had to photostatic reduction by stages to produce a series from one good example. Sheets can then be printed from which spheres of appropriate sizes may be cut at will. Tables may also be prepared to show the value of each sphere when the smallest is equivalent to 1, 2, 3 units, and so on. This method was used in the preparation of Fig. 84.

Three-dimensional figures offer even more difficulty in value interpretation than the two-dimensional. It is difficult to realize that a sphere of 1-inch diameter has the same volume as eight spheres each $\frac{1}{2}$-inch in diameter. Consequently resort should only be had to three-dimensional figures when there is no reasonable alternative. Statistical values should as a rule be stated. They may be placed beside spheres or written upon the faces of cubes.

(*b*) *Cubes.* Cubes may be used instead of spheres, and they are easier to draw. Cube roots of the numbers to be represented must be found, and these show the relative lengths of cube edges. Difficulty arises with perspective, but any suitable convention may be employed. One arrangement shows a square front face on which cube value is inscribed, and side edges half the full length, sloping back at 45°. An attempt to draw cubes within cubes is to be deprecated as the complication gives no compensatory advantage. When cubes are placed in a row, the front bottom edges should be in line. Squared paper is an aid to drawing, but detracts from the finished appearance. In such circumstances recourse may always be had to tracing-paper pinned over squared paper.

Another conventional perspective view is the isometric, with one vertical edge as centre-line, and side edges sloping back at 30° from the horizontal. Ruled isometric paper is available, rendering execution quick and easy.

3. Diagram Maps and Cartograms

Diagram maps are drawn by applying graphs and diagrams to a space background, most commonly a base map on which is shown relevant statistical units or stations. Salient points may be considered by taking in turn the graphs and diagrams already described, and seeing how far they are applicable to a space background.

One disadvantage that is common to many such maps may be dealt with first. It is the difficulty of evaluating quantity in relation to area. The possibilities of a solution have been discussed in connexion with dot and density mapping, but here the problem takes a new form. How, for example, is one to interpret, except in the vaguest terms, the significance of a small circle in a large statistical unit and a large circle in an adjoining small statistical unit? Yet this problem is constantly presented to the reader by the nature of the diagram map, and no solution is offered. The problem does not arise in all diagram maps, such as those in which statistics apply to specific points. Thus rainfall of given stations may well be represented by bars, or trade of ports by squares.

(*a*) *Bar Chart Maps.* An example of the application of horizontal bars to a map is seen in Fig. 95, which shows the principal ports of Britain which receive timber. There is perhaps little need for statistical values to appear at the end of bars in this example as bars are divided into black and white units to facilitate evaluation, though they are generally to be recommended. The outstanding position of London has necessitated recourse to an arrangement of bars giving the appearance of a rectangle.

Bar groups may be shown to advantage on a map background provided that the number of bars in each group is strictly limited, their range of length is not excessive, and the number of groups is not more than can be carried in the eye. A county map of Britain or state map of the United States would provide too many units, but the major divisions of Canada, Australia, or South Africa could be used to produce Bar Group Maps of leading minerals, agricultural products, population at the previous five censuses, and so on. Horizontal bars in pairs provide a suitable means of showing the trade of ports as divided between imports and exports.

The end-on arrangement of bars resulting in the Compound Bar does not lend itself in general to map work because its length causes it to stretch beyond the boundaries of normal statistical units, nor is there the advantage of direct comparison in length with other compound bars as seen in the graph form, simply because on the maps the bars have no common base line.

Bars of uniform length divided to show percentages offer possibilities, but suffer because they give the illusion of identical total quantities. Examples are seen where each bar is made the full north–south length of the particular unit to which it relates, and subdivisions are made on a percentage basis to show areas under various crops, different kinds of live stock, or areas devoted to a specific crop in various years. The objections are obvious, but experimental work is desirable, and there are numerous untried possibilities.

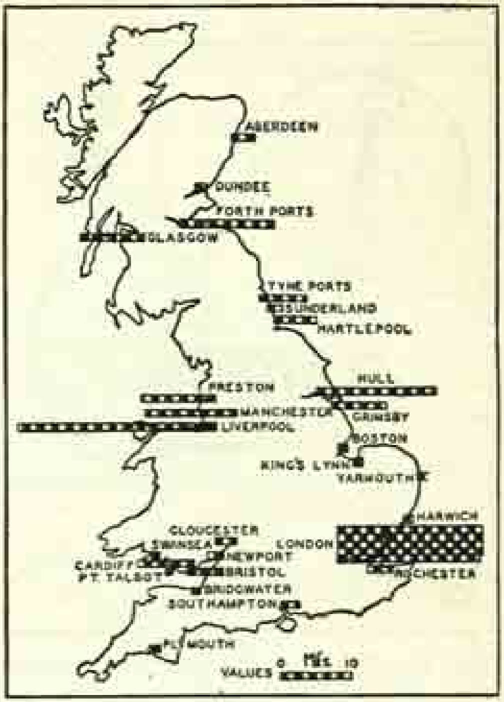


FIG. 95. Bar Chart Map showing the principal timber ports of Britain. Bars show value of timber imports in the five-year period 1928–32.

(b) *Line Graph Maps* are not common, presumably because the information which would be shown is better exhibited by other means. Attempts are often made with combined temperature curves and rainfall bars to show the climate of a country, but often so many graphs are placed on the map that no features of significance attract the eye, hence the map is not cartographically successful.

Better results are obtained by reducing the number of graphs to about half a dozen, one for each distinctive climate type. Boundaries between the types clarify the position, and take the place of normal administrative boundaries.

If the purpose of the map is to exhibit transition of climate, then a series of graphs, carefully chosen from a set of stations along a particular line of transition, achieves the purpose. One of the difficulties of distribution mapping is to see the result through the eyes of others, for much that is clear to the map-drawer is not clear to the map reader who scans in a matter of minutes work which has taken hours to prepare.

(c) *Clock* and *Pie Graph Maps* are not infrequently seen. The clock version is moderately successful in the form of windroses. Examples are seen in *A Barometer Manual*, published by the Stationery Office, London. On all these maps the windroses are laid out in rectangles bounded by lines of longitude and latitude, and though the number shown is very large, the confusion noted in connexion with climate mapping does not arise.

Fig. 96. Pie Graph Map or Cartogram to show woodland area in England, Scotland, and Wales. The inset map shows the total area in woodland drawn to the same scale as the larger map.

The Pie Graph Map inevitably suffers from the worst defects of the pie graph, the difficulty of comparing circles of different sizes, and of sectors within the circles. Fig. 96 provides an example. In order to show the total area of woodland respectively in England, Scotland, and Wales, the circles have been drawn different sizes and subdivided to show principal forest types. The area represented by each circle is stated, but not the percentage make-up of sectors. The small inset map shows the total woodland area on the same scale as the larger map, and is a corrective to any idea that forest area is great simply because the circles are large.

It is doubtful whether numerous pie graphs distributed over a map would ever be successful cartographically, and so few as those in Fig. 96 gain little except in interest by the existence of a space background.

(d) *Maps with Two-dimensional Diagrams.* In the pie graph, relative quantities are judged by the angular dimension of sectors rather than by areas. Many maps, however, make use of squares or circles proportional in area to the quantities represented. They are drawn within statistical units, and often look attractive. Usually only one circle or square appears within each unit.

The weakness of the method is the impossibility of taking into account relative areas of statistical units and of figures at the same time, though this is usually necessary if useful conclusions are to be reached.

When areal statistical units are not involved, as in mapping the number of people employed at various collieries, iron-works, and factories, the method is less open to objection. Distinction is often obtained by using a series of squares for one industry, circles for another, and triangles for a third, but this gives rise to the difficulty of comparing areas in different forms. Such difficulties, however, do not rule out the method if reasonably sound and useful graphic representation is obtained thereby.

(c) *Maps with Three-dimensional Diagrams.* Of three-dimensional figures, the sphere has been employed almost exclusively in map work, and chiefly in connexion with population mapping. The problem differs from that of most other mapping, because of the huge variation in density over small areas as from one person per square mile to several thousands, the detailed statistics available, and the importance of the matter. Detailed investigation was made by Sten de Geer, and the results published in the *Geographical Review* of January 1922. De Geer arrived broadly at the conclusion that rural population was best shown by the dot method and urban agglomerations by spheres. The idea is seen in the population map of Central Shropshire, Fig. 84. There is no means visually of evaluating spheres in terms of dots, and the spheres bear no relation in shape to the areas whose populations they represent. On the other hand, urban agglomerations are shown by symbols similar in kind, a great range of numbers may be portrayed without an embarrassing range in the map space required, and none would deny the pictorial vividness of the spheres standing out among the lower order dots.

4. Dynamic or Flow Maps

Dynamic or *Flow Maps* are designed to show movement. Direction or route is indicated by a line, and weight, volume, value, or frequency by line width. Fig. 97 shows various embellishments, and a useful distinction in the means of transport employed. An exact interpretation is aided through the statistical information on the map. The same method may be employed to show cyclone-track frequency, or the trade of a country, rail or ocean routes being drawn proportional in width to the amount of trade carried along each. Government transport departments find the method useful to map the volume of traffic on roads.

An alternative method is to employ a series of lines uniform in thickness, and all of equal value. This method has advantages in interpretation, but difficulty may be experienced in balancing line value against the number of lines which can be accommodated on the map.

Ocean currents are sometimes mapped by means of arrows which show direction only. But given the necessary information, it is possible to make the width of arrows show speed and the length show stability. Wind force or speed is more often distinguished by adding barbs to the arrow shaft.

5. Variation Maps

The *Variation Map* may be contrasted with the flow map, because while the latter shows change of location without change of quantity, the former seeks to

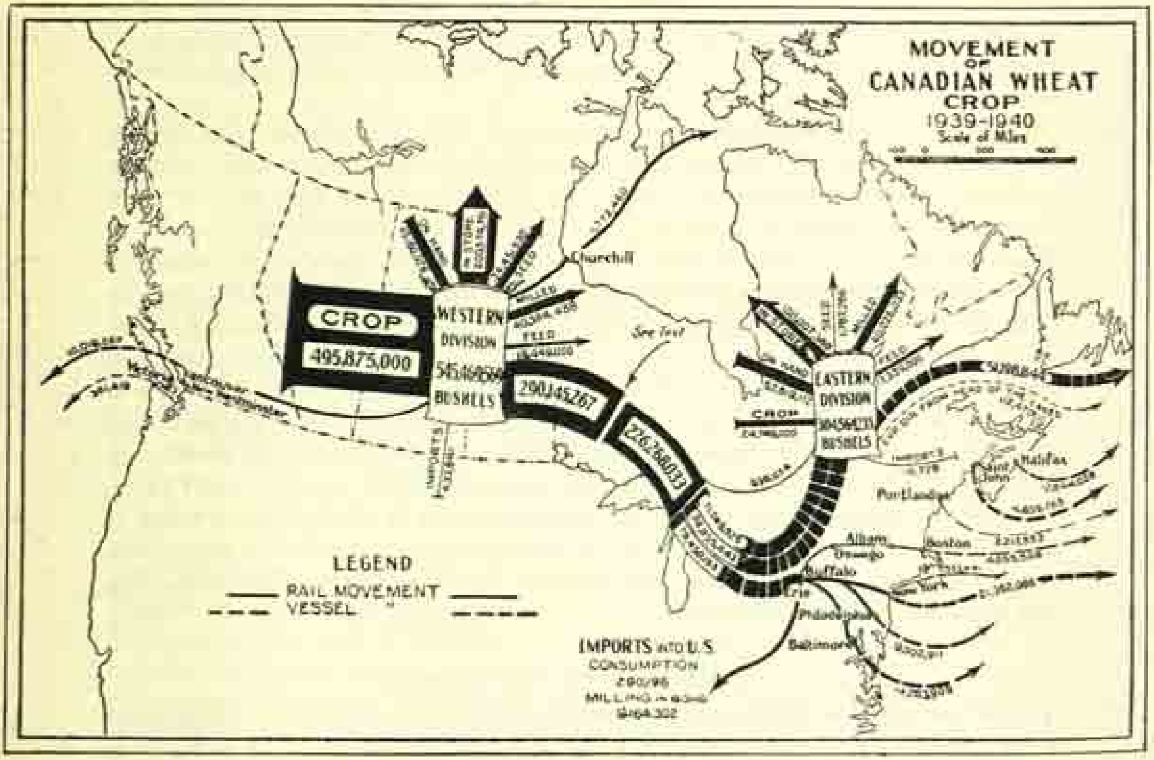


Fig. 97. Flow Map showing movement of Canadian wheat crop 1939–40. Lines are proportional in width to the crop carried.

show change of quantity without change of location. This is one of the most troublesome problems in statistical cartography, and the following observations only serve to show lines along which solutions have been or may be sought, apart from density and isoline methods which have been discussed elsewhere.

One method to show variation, as of population at two different periods, is to represent both by diagrams within statistical units, differentiating by colour or shading. Thus open bars, circles, or squares may show the earlier population, and unfilled bars, circles, or squares the later population. The advantage of bars over two-dimensional figures for comparative purposes is evident.

A very common method of dealing with the matter is to add together the pairs of numbers for the two periods and to represent them by circles proportional in area to the totals. Each circle is then cut into two sectors which are differentiated by shading to show the original and subsequent numbers. This is really a simple version of the pie graph map. Pictorially it is often impressive, but how far it succeeds in showing the facts graphically is a matter of opinion.

Both methods show the facts of distribution at two periods, but leave estimation of variation to the map reader's judgement. It is obviously possible to map variation only, by subtracting one set of statistics from the other set. The result is likely to yield a set of positive and negative quantities, positive for gains, negatives for losses. These can then be mapped in any suitable diagrammatic form, distinguishing gains and losses by shading, or the addition of plus and minus signs, or by using the divergent bar method with a zero line across the centre of each statistical unit. Instead of mapping absolute changes, it is equally possible to show percentage variation over the period and this often gives a more useful picture.

In compiling weather maps, barometric change, known as barometric tendency, is indicated simply by writing the number of millibars change during the previous three hours in black ink when positive, red ink when negative. In meteorological services that make much use of this pressure variation, stations showing the same tendency are joined by isallobars, thus employing the isoline method.

The weakness of mapping variation only, lies in what is omitted, namely, any idea of distribution at either of the periods. Regions showing no change simply appear blank. In suitable cases, as when regions are few and statistics cover a series of years, absolute quantities and variation may be shown by simple line graphs distributed about the map.

6. Symbol Maps

Some indication might be given of the possibilities of using symbols other than types already discussed. Admiral Beaufort in 1806 devised a system of abbreviations for weather conditions, which consisted mainly of using initial letters of the words describing the conditions, e.g. *b* for blue sky, *o* for overcast, and *r* for rain. Phenomena described by words beginning with the same letter were distinguished by a second letter from one of the words, thus *h* for hail but *z* for haze. This system, though suitable for register records, has two great drawbacks. It is neither graphic nor international.

The Daily Weather Maps published by the Air Ministry in London achieve graphic representation of sky conditions by drawing circles at stations and shading these according to the degree of cloudiness. Thus a clear sky is shown by an open circle and an overcast sky by a circle with four vertical lines across it.

An even simpler form is adopted in U.S.A. and Canada in which the circle is either open, half-filled, or completely filled, as shown below.

The International Meteorological Organization at Warsaw in 1935 approved a series of symbols for weather conditions, which are to a degree graphic, and hence achieve both conditions which Beaufort's early scheme lacked. A selection of these with Beaufort letters is given below. When combined with arrows which fly with the wind, barbed according to strength, and with isobars to show pressure distribution, they give at least to the observer who has an elementary knowledge of meteorology and cartographical method a graphic picture of weather distribution. The state of the sky, however, is still indicated in this scheme by letters, though some countries make arbitrary arrangements and employ their own graphic symbols.

Selection of Beaufort Letters and International Symbols

Letter	*Symbol*	*Weather condition*
b		blue sky
c		cloudy
o		overcast
r	●	rain
d	,	drizzle
s	✻	snow
h	▲	hail
l	☇	lightning
tl	☈	thunderstorm
f	≡	fog
z	∞	haze
m	=	mist

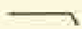
Sky Conditions

Symbols used on British, United States, and Canadian Weather Maps:

British	*U.S.A.*	*Canadian*
○ clear	○ clear	○ 0–2-tenths overcast
 less than 3-tenths clouded	◑ partly cloudy	◑ 3–7 ,, ,,
 4–6-tenths clouded	● cloudy	● 8–10 ,, ,,
 7–9 ,, ,,		
 overcast		

Typical Wind Symbols

Arrows fly with the wind

Number	*m.p.h.*	*Force*
1 	1–3	light
5 	19–24	fresh breeze
9 	47–54	strong gale

Symbols may be chosen at will, but should always be simple to draw, easy to read, and graphic wherever this is possible. If capable of international application so much the better.

The following scheme for representing climate according to type may be considered as fulfilling the first three conditions, but initial letters taken as they are from current English words, as in the Beaufort Scheme, would be a deterrent to international usage. Temperature and precipitation are taken for typical winter and summer months, such as January and July.

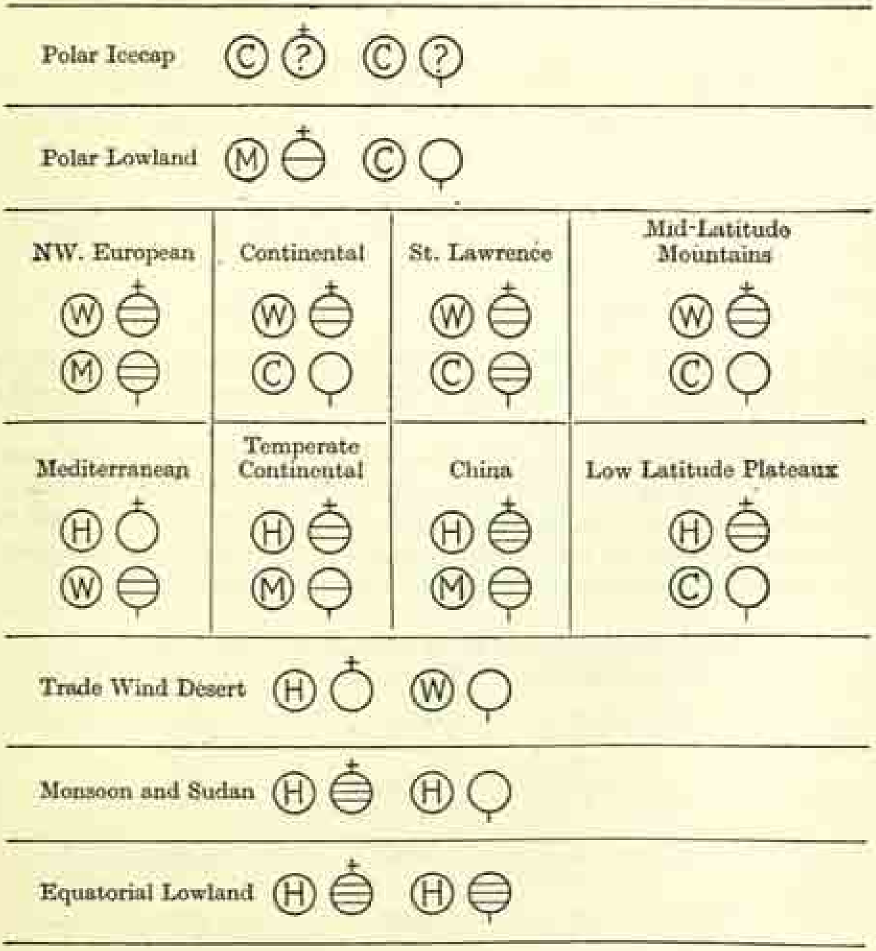
A Scheme of Symbols for Representing Climate Types

Temperature	*Description*	*Symbol*
Over 70° F.	Hot	Ⓗ
50–70° F.	Warm	Ⓦ
30–50° F.	Mild	Ⓜ
Below 30° F.	Cold	Ⓒ

Precipitation	*Description*	*Symbol*
Over 4″	Wet	
2–4″	Fairly wet	
1–2″	Fairly dry	
Below 1″	Dry	

Summer distinguished by + attached to summer month rain symbol.
Winter „ „ | „ „ winter „ „

Climate Types and Symbols



A division of the world or of any part of the world into primary climate regions may then be made and climate mapped symbolically by a choice from the table on p. 216. Each regional symbol is read in full. Thus the Mediterranean symbol reads: Hot dry summer, warm fairly wet winter.

These examples from meteorology and climate are sufficient to show something of the possibility of employing symbols to depict conditions of a complex nature at any point or in any region. So long as general principles are observed, the method is capable of useful adaptation.

Finally, and this applies to all forms of cartography, it should be remembered that maps are tools and are worthy of careful fashioning. There is no virtue in drawing maps badly. The standard of topographical mapping is already high, but in statistical mapping the problem is still to find maps to act as guides for the future. The one field has been fairly fully explored, the other awaits development.

QUESTIONS AND EXERCISES

PART I. TOPOGRAPHICAL MAPS

CHAPTERS II AND III. MAPS AND PLANS

1. Discuss the advantages of a large-scale national survey.

2. Enumerate, with reasons, the aspects of a region which could be represented in map form to illustrate a detailed geographical survey of (*a*) a rural, and (*b*) an urban, area. What published maps would you expect to be of assistance, and how would you use them?

3. Discuss the advantages and difficulties of producing an International Million Map of the World in its present form. What other international maps on the same scale do you consider desirable, and why?

4. Describe what maps would be of greatest assistance in arranging the following:
   (*a*) a week's walking tour;
   (*b*) a cycling tour;
   (*c*) a motoring holiday;
   (*d*) a school or scout camp.

5. Describe the main differences between Plans, Topographical Maps, and Atlas Maps.

6. Discuss the limitation of scale in showing natural and cultural features on Plans, Topographical Maps, and Atlas Maps.

CHAPTER IV. CHAIN SURVEY

7. Describe the equipment used in Chain Survey.

8. Describe the use of the field note-book.

9. Illustrate and describe how you would survey the field to the south of Range View House in Fig. 20.

10. From the field-book entries given in Fig. 13, set out Line 4 and the nearby fence on a scale of 1 inch to the chain.

CHAPTER V. THE PRISMATIC COMPASS

11. Describe the prismatic compass and the precautions necessary in its use.

12. What checks are possible on a simple closed traverse, and how is a small error of closure dealt with?

13. Explain the process of fixing position by compass resection. How would you determine the position of the sheep-fold in Fig. 20, if Dickhampton Church and Finney Farm were marked on the plan and were visible from the sheep-fold?

14. Set out in field note-book form a traverse on Fig. 20 from *A* to *F* via *D*, with appropriate offsets.

15. Redraw on tracing-paper the route from *A* to *F* from the field-book entries of Exercise 14, using the same scale as in the original figure. Check accuracy by placing the tracing over the printed figure.

16. Explain the difference in purpose between the chain and the prismatic compass used as survey instruments.

Chapter VI. PLANE-TABLE SURVEY

17. Describe the instruments commonly used in conjunction with the plane-table.

18. Describe the various ways in which the plane-table may be oriented, referring briefly to the triangle of error.

19. Explain what is meant by the triangle of error and how to deal with it in setting the plane-table.

20. Illustrate the meaning of intersection and resection in plane-table survey, and show when each is employed.

21. Describe briefly how you would make a plane-table traverse along the route from *A* to *D* on Fig. 20.

22. Why has the plane-table become a popular survey instrument in hitherto unmapped countries?

Chapter VII. AIR-PHOTO SURVEY

23. Give a brief résumé of how photography is applied to surveying.

24. Describe the difficulties associated with aerial survey.

25. Describe the benefits to be derived from aerial survey in (*a*) highly developed countries, and (*b*) undeveloped countries.

26. Discuss the relationship between ground survey and aerial survey.

27. Explain how detail may be added to a map from a single vertical photograph of unlike scale.

Chapter VIII. THEODOLITE TRIANGULATION

28. Describe the basic construction of the theodolite.

29. How is a base-line measured in accurate theodolite triangulation, and what is a base of verification?

30. Define Latitude, Longitude, and Azimuth, and explain how each may be determined.

31. What are the essential differences between theodolite triangulation and plane-table survey?

32. Describe how the theodolite may be used in making a traverse.

33. Explain the terms Apparent, Mean, and Sidereal Time.

34. Explain what is meant by the Equation of Time.

Chapter IX. DETERMINATION OF ALTITUDE

35. Describe the various instruments with which altitude may be determined, and briefly explain the principle on which each works.

36. Explain how the altitude of an inaccessible mountain summit may be determined with reasonable accuracy.

37. How are variations of atmospheric pressure dealt with, apart from those due to differences of elevation, in determining altitude with the aneroid barometer?

38. How is levelling performed, and why are two staves used?

39. Illustrate and describe how you would set about contouring one area shown in Plate VII, supposing that you had the map void of contours but with bench marks and spot heights, and that the area was clear of trees.

Chapter X. REPRESENTATION OF RELIEF

40. Describe the methods employed to show relief on maps.

41. Describe how contours are drawn on (i) plans, and (ii) small-scale maps. Contrast the drawing of contours with the drawing of form lines.

42. Discuss the relation between map-scale and the method employed to show relief. Quote as many official maps as possible in support of your statements.

43. What factors have caused methods of showing relief to change in the past century or so?

44. What useful purposes are served by showing relief on maps?

Chapters XI–XV. MAP PROJECTIONS

45. Complete the following table from any atlas:

(a) Name of area mapped	*(b) Features shown*	*(c) Projection used*	*(d) Characteristic features by which recognized*	*(e) Suitability for the purpose*

46. Construct graticules with intervals of 15° for the following regions:
   (*a*) NW. Europe on the Conical with One-standard Parallel.
   (*b*) World on the Cylindrical Equal Area.
   (*c*) North Hemisphere from 45° N. to the Pole on the Polar Equidistant.
   (*d*) South America on Sanson–Flamsteed.
   (*e*) Asia on Bonne.
   (*f*) Europe on the Conical with Two-standard Parallels.

Number the parallels and meridians, and describe the method employed in construction.

47. Draw the meridians at 20°-intervals for a world map on Mollweide's Projection. Insert parallels from the following table which gives approximate distances from the equator, of the parallels for each 20° in terms of the radius r of the initial circle about the central meridian.

Parallel	*Distance from equator in terms of circle radius* r	*Ditto in terms of globe radius* R *which is smaller than* r
10°	0·14r	0·20R
30°	0·41	0·57
50°	0·65	0·92
70°	0·86	1·22
90°	1·00	1·41

Note. Since the ellipse must equal the equivalent globe in *area*, its axes in terms of the radius R of the globe are $\sqrt{2}R$ and $2\sqrt{R}$ respectively, and distances of parallels from the equator on the projection in terms of R approximate closely to those given in the third column above.

48. From the following table construct a Mercator net to 85° N., choosing a convenient scale for R, the radius of the globe. The equator will be equal to the circumference of the globe, namely, $2\pi R$. The distance of parallels from the equator is expressed in terms of R.

Parallel	*Distance from equator in terms of globe radius* R
10°	0·18R
30°	0·55
50°	1·01
70°	1·74
85°	3·13

49. On a globe draw great circle routes between the following places:
(*a*) London and Melbourne.
(*b*) New York and Melbourne via Cape Town.
(*c*) Washington and Tokyo.
By noting the intersection of these great circle routes with lines of latitude and longitude on the globe, plot them on a Mercator map traced from an atlas. What do you observe about the form the routes take?

50. Name three projections belonging to each of the following projection types, and say how you would differentiate between the three members in each group:
(*a*) Conicals.
(*b*) Polar Azimuthals.
(*c*) Normal Cylindricals.

51. Describe three important equal-area map projections and discuss their uses and relative merits.

52. What characterizes an orthomorphic projection? Which projections are termed orthomorphic, and for what purpose is each suitable?

53. Describe the modified Polyconic Projection, and explain its suitability for the International Million Map.

54. State what projection you would choose to show the following, and briefly justify your choice:
(*a*) World production of cotton.
(*b*) Distribution of forests in the Americas.
(*c*) Regions where English is the official language.
(*d*) Cereal production in Asia.
(*e*) European air routes.
(*f*) Polar exploration.
(*g*) Britain's health resorts.
(*h*) Distribution of rainfall in Australia.
(*i*) Direction of Mecca from places within a radius of 2,000 miles.

55. What problems are encountered in showing the whole world on one map? By what methods do the Sinusoidal and Mollweide's projections overcome the difficulties?

56. What factors would you take into consideration in choosing a projection for a topographical map?

57. Describe the National Grid used by the Ordnance Survey.

58. Explain the statement that the ground area enclosed by the square of an over-printed grid is not necessarily square.

59. Explain the terms (*a*) true north; (*b*) magnetic north; (*c*) grid north. In what circumstances would they all coincide?

Chapter XVI. MAP SCALES

60. Describe and discuss the merits of an open divided scale and a fully divided scale.

61. Draw metric and British open divided scale lines with suitable primaries and secondaries for maps on the following scales:

(*a*) 1 inch to the mile.
(*b*) ¼-inch to the mile.
(*c*) 1 : 50,000.
(*d*) 1 : 100,000.
(*e*) 1 : 62,500.

Note. In all questions of scales involving conversions it is best to resort to the appropriate representative fraction. Thus in drawing a scale line in kilometres for (*a*) proceed thus:

1 inch shows 63,360 inches.

$\therefore$ 1 centimetre shows 63,360 centimetres.

$\therefore$ 1 centimetre is shown by $\frac{1}{63{,}360}$ centimetre.

$\therefore$ 1 kilometre is shown by $\frac{1 \times 100{,}000}{63{,}360}$ centimetres $= 1{\cdot}58$ centimetres.

A line representing 10 kilometres can be drawn and divided geometrically into 10 parts, and one of these into 10 further subdivisions.

62. Draw a time scale line for an air map, scale 1 : 1 million, marked on one side to show 10-minute intervals at 250 m.p.h., and on the other, units of 20 miles each.

63. Draw a diagonal scale for use with a 1-inch to the mile map, to read in miles, furlongs, and chains.

64. If the frontiers on maps are shown by lines $\frac{1}{100}$ inch thick, what width does this represent on maps on the following scales:

(*a*) 1 : 50,000.
(*b*) 1 : 80,000.
(*c*) ¼-inch to the mile.
(*d*) 1 : 1 million?

65. What fraction in area of the landscape it represents is the paper of a map on a scale of (*a*) 1 : 31,680; (*b*) 1 : 50,000; (*c*) 1 : 1 million?

66. Name countries on whose true-to-scale maps length of minutes of latitude is approximately (*a*) the same, (*b*) double, the length of minutes of longitude.

Chapter XVII. SECTION DRAWING AND CONTOUR PATTERNS

67. Redraw a square foot of a topographical map on one-half the scale of the original.

68. What is the vertical exaggeration of sections drawn across maps on the following scales, if 1 inch vertical shows 500 feet:

(a) 1 : 62,500.

(b) 1 inch to the mile.

(c) 6 inches to the mile?

69. If true-to-scale sections were drawn across maps on the following scales, how many feet vertical would be shown by 1 inch:

(a) 1 : 100,000.

(b) $\frac{1}{2}$-inch to the mile.

(c) 1 : 31,680?

70. Draw sections about 10 inches long across various topographical maps, stating on each any vertical exaggeration.

71. Repeat suitable sections from the previous exercise (a) true to scale; (b) doubling the horizontal scale.

72. From suitable maps, draw sections about 10 inches in length along a road, railway, and a river.

73. Within rectangles 5 inches by 4 inches, draw contoured sketch maps to represent the following:

(a) Cirques and a glaciated valley in an upland area.

(b) River erosion in a dry plateau region.

(c) A meandering river in a low region of boulder clay.

(d) A river valley with one side concave and the other convex.

(e) River capture.

Chapters XVIII and XIX. MODELS AND BLOCK DIAGRAMS

74. Discuss the relative merits of different methods of making relief models.

75. Make models from topographical maps of various land forms using the different methods described. Insert horizontal and vertical scales, and state the vertical exaggeration, if any.

76. Describe the various problems which arise in modelling landscapes from maps, under the headings:

(a) Difficulties arising from the maps.

(b) Difficulties arising from the media employed.

77. Discuss the merits and shortcomings of relief models as representations of landscape.

78. Compare the merits of maps and models as means of showing topographical features.

79. Draw block diagrams from topographical maps showing physiographical features.

80. Trace an outline map of North America, and show relief pictorially.

81. Make a model of an area having strong relief, as described in Chapter XVIII, section 6, under the heading *Model Illusion*.

CHAPTER XX. INTERPRETATION OF LANDSCAPE FROM MAPS

82. Take a 6-inch square from any suitable topographical map and list direct evidences of occupations. Make a second list of probable occupations within the same area, setting out supporting evidence.

83. Discuss the relationship between physical features and communications as shown on specific topographical maps.

PART II. STATISTICAL MAPS

CHAPTER XXII. DOT MAPS

84. (*a*) Draw a dot map to show the following:

Population of Australia, 1938. (Estimated population, excluding aboriginals.)[1]

New South Wales	2,721,196
Victoria	1,867,818
Queensland	1,000,749
S. Australia	592,579
W. Australia	459,977
Tasmania	235,678
Northern Territory	5,726
Federal Capital Territory	11,124
Total	6,894,847

(*b*) Record the difficulties experienced and how overcome.

(*c*) What advantages and weaknesses of the dot method are apparent in this example?

85. (*a*) On a second dot map, make allowance for metropolitan populations which are included above, showing these by circles, squares, or spheres of appropriate sizes.

Metropolitan Populations, 1938

Sydney	1,288,720
Melbourne	1,035,600
Brisbane	325,890
Adelaide	321,410
Perth	220,330
Hobart	63,250

(*b*) Discuss the effect of this modification on the accuracy of representation.

86. Draw a dot map to show the Barley Acreage of Northern England, having regard to the fact that the chief barley areas have a rainfall of less than 30 inches annually, and do not exceed 200 feet in altitude.

Barley Acreage in Northern England, 1934

Northumberland	12,560
Durham	7,142
Cumberland	445
Westmorland	124
East Riding	51,142
North Riding	44,938
West Riding	14,910
Lancashire	404

(*Agricultural Statistics: Production*, H.M.S.O.)

[1] Aboriginal population, 51,379, mainly in W. Australia and Queensland (*Australia Year Book No. 32, 1939*).

87. Attempt to show on a single dot map the European and Native (Bantu) population of South Africa for 1939. Statistics are in Exercise 93. Criticize the result.

88. Trace a map of the Census Divisions of Western Canada as shown in Fig. 98, and from the following statistics make a dot map to show distribution of population in Western Canada. How far does the map help to explain the geographical nature of Western Canada? In what way is the dot map likely to be at variance with the facts of population distribution?

Western Canada: Area and Density of Population by Census Divisions, 1931

Province and county	*Land area sq. miles*	*Population*	
		Total no.	*Per sq. mile*
Manitoba	219,723	700,139	3·19
Division No. 1	4,281	22,817	5·33
2	2,320	38,810	16·73
3	2,577	26,753	10·38
4	2,466	18,253	7·40
5	5,256	46,228	8·80
6	2,436	283,828	116·51
7	2,578	36,912	14·32
8	2,160	19,846	9·19
9	1,217	45,414	37·32
10	2,377	17,916	7·54
11	2,914	28,100	9·64
12	3,240	24,344	7·51
13	3,324	24,263	7·30
14	3,636	25,978	7·14
15	2,304	10,008	4·34
16	176,637	30,669	0·17
Saskatchewan	237,975	921,785	3·87
Division No. 1	5,944	41,544	6·99
2	6,686	42,831	6·41
3	7,646	46,881	6·13
4	7,579	28,126	3·71
5	5,760	53,948	9·37
6	6,787	109,906	16·19
7	7,471	63,230	8·46
8	9,264	49,361	5·33
9	5,010	60,539	12·08
10	4,860	41,890	8·62
11	5,979	87,976	14·71
12	5,982	40,612	6·79
13	6,848	42,632	6·23
14	13,419	46,222	3·44
15	8,082	83,697	10·36
16	8,912	48,736	5·47
17	6,913	27,315	3·95
18	114,833	6,339	0·06
Alberta	248,800	731,605	2·94
Division No. 1	7,323	28,849	3·94
2	6,342	57,186	9·02
3	7,018	15,066	2·15

Province and county	Land area sq. miles	Population Total no.	Population Per sq. mile
Alberta—*contd.*			
Division No. 4	6,119	29,067	4·75
5	7,681	26,651	3·47
6	10,595	140,624	13·27
7	6,684	38,106	5·70
8	6,510	61,016	9·37
9	14,415	24,503	1·70
10	6,180	58,049	9·39
11	4,753	126,832	26·68
12	13,083	13,815	1·06
13	8,103	24,936	3·08
14	8,731	39,508	4·53
15	22,845	13,664	0·60
16	11,100	27,945	2·52
17	101,318	5,788	0·06
British Columbia	359,279	694,263	1·93
Division No. 1	15,984	22,566	1·41
2	13,343	40,455	3·03
3	10,729	40,523	3·78
4	9,764	379,858	38·90
5	13,206	120,933	9·16
6	31,420	30,025	0·96
7	22,187	12,658	0·57
8	71,985	21,534	0·30
9	88,128	18,698	0·21
10	82,533	7,013	0·08
Yukon	205,346	4,230	0·02
North-west Territories	1,258,217	9,723	0·01

89. (*a*) What maps would be of help in arranging the position of dots in the following
(i) A Population Map by Parishes or Townships, scale ½ inch to the mile.
(ii) A Dairy Cow Map of Britain by Counties, scale 1 : 1 million.
(iii) A Sheep Map of Australia by States, scale 1 : 25 millions.
(iv) A Population Map of New England by States, scale 1 : 1 million?

In each case give reasons for your choice of maps, and indicate how you would use them.

(*b*) What projection would you choose for the Australia and New England outlines, and why?

90. Write an essay on the dot method as a means of mapping distributions.

Chapter XXIII. DENSITY MAPS

91. Draw two Density Maps to show Woodlands of Southern England, one with a graded key and the other with proportional shading. Statistics are on p. 151. Compare the advantages and disadvantages of the two methods.

92. (*a*) From the following table of South Atlantic and East Central United States, using different methods, draw maps to show:

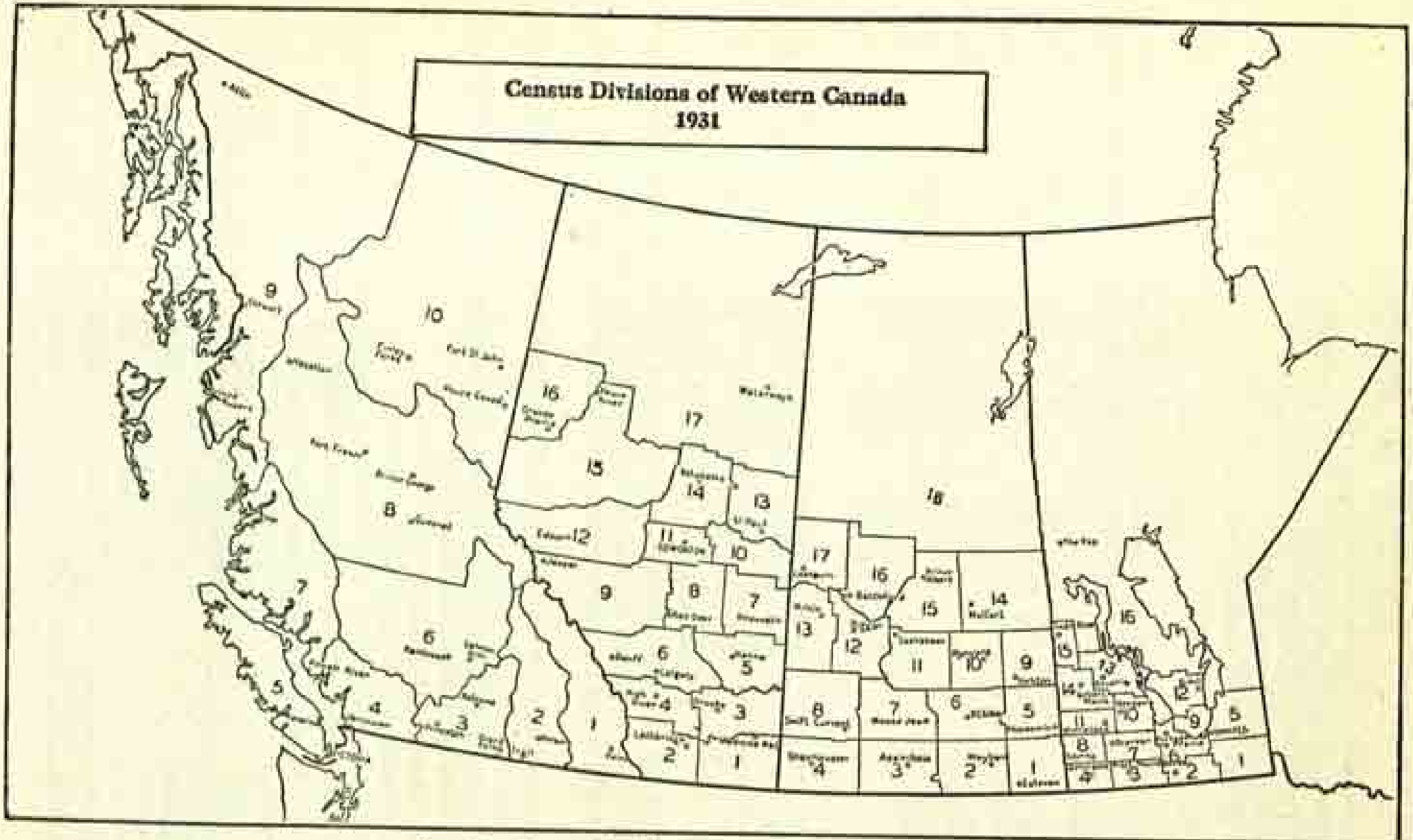


FIG. 98. Census Divisions of Western Canada, 1931.

(i) Density of Population per square mile.
(ii) Density of Negro Population per square mile.
(iii) Percentage of Negro Population.
(iv) Density of Unemployed.
(v) Percentage of Unemployed.

	1. Area sq. miles	2. Total population	3. Negro population	4. Population per sq. mile	5. Unemployed	6. Per cent. unemployed
South Atlantic						
Delaware	2·0	238	33	121	3·2	1·3
Maryland	9·9	1,632	276	164	24·4	1·5
D. of Columbia	0·06	487	132	7,853	9·0	1·8
Virginia	40·3	2,422	650	60	26·5	1·1
W. Virginia	24·0	1,729	115	72	21·4	1·2
N. Carolina	48·7	3,170	919	65	28·6	0·9
S. Carolina	30·5	1,739	794	57	12·0	0·7
Georgia	58·7	2,909	1,071	50	27·7	1·0
Florida	54·9	1,468	431	27	33·1	2·3
East South Central						
Kentucky	40·2	2,615	226	65	29·5	1·1
Tennessee	41·7	2,617	478	63	20·4	0·8
Alabama	51·3	2,646	945	52	21·4	0·8
Mississippi	46·4	2,010	1,010	43	10·8	0·5

Figures in thousands except in columns 4 and 6.

(*b*) What are the chief difficulties encountered in drawing these maps, and what means have you employed to deal with the District of Columbia?

(*c*) Indicate briefly the relative merits of the maps as compared with the statistical table.

(*d*) What points of interest emerge from the maps considered (i) singly, and (ii) in conjunction with others?

93. (*a*) From the following statistics draw three maps of S. Africa to show by Provinces:
(i) Density of European Population.
(ii) Density of Non-European Population.
(iii) Percentage of European Population.

(*b*) What general criticism could be raised against statistical map exercises based on statistics for States in the Union of S. Africa?

South Africa: Estimated Population, 1939, in thousands (000)

	Cape of Good Hope	*Natal*	*Transvaal*	*Orange Free State*
European	819	199	898	201
Native (Bantu)	2,130	1,641	2,645	581
Asiatic	11	192	28	—
Coloured	724	20	54	18
Total Non-European	2,865	1,853	2,727	599
Total all races	3,684	2,052	3,625	800

94. (*a*) Draw a Density of Cattle Map from the following statistics for the Union of South Africa, making what you consider a reasonable density allocation within States based on vegetation or other relevant influences.

(*b*) Set out fully the bases and procedure adopted in adjusting distribution within the several states.

Cattle in South Africa, 1938

State	*Area (000) sq. miles*	*Cattle (000)*
Cape	277·2	3,711
Natal	35·3	2,510
Transvaal	110·5	3,339
Orange Free State	49·6	2,018

95. (*a*) Trace a map of the Census Divisions in Western Canada from Fig. 98, and from the appropriate statistics given in Exercise 88 make a Density Map, using the method of shading or colouring which seems most appropriate.

(*b*) Write a short critical account of difficulties encountered and steps taken to meet them.

96. Write an essay on the relative merits of Density and Dot Maps, mentioning circumstances in which one or the other appears preferable.

97. (*a*) State and remark upon the colours used on the following territorial distribution maps:

(i) Atlas Vegetation Maps.
(ii) Atlas Geological Maps.
(iii) Land Utilization Survey Maps of Britain.

(*b*) What would be the advantages and difficulties of an international colour convention for such maps?

Chapter XXIV. ISOLINE MAPS

98. From the following adjusted statistics draw a map of Great Britain to show isobars at intervals of 2 millibars.

Adjusted Pressure in Millibars

London	982·3	Tiree	985·5
Felixstowe	985·9	Stornoway	986·2
Birmingham	982·0	Aberdeen	989·1
Ross-on-Wye	981·4	Lerwick	988·8
Plymouth	982·7	Blacksod Point	984·6
Pembroke	983·2	Malin Head	985·3
Holyhead	984·5	Birr Castle	986·8
Manchester	982·7	Valentia	986·6
Tynemouth	987·4	Calais	986·2
Inchkeith	988·3	Le Havre	985·4
Point of Ayre	986·5	Brest	988·7

Air Ministry, 29 January 1936

99. On a map of North America show the following distribution of pressure, adding appropriate weather symbols for a day in April:

A large depression is approaching the coast of British Columbia, while a shallow depression extends northward from the Mexican border. An anticyclone covers NE. North America.

100. On a map of Europe and the Atlantic show the following:

An elongated anticyclone centred over Britain stretches westward over the Atlantic while a subsidiary high-pressure area covers Eastern Europe. Low-pressure areas are centred over Greenland, Iceland, North Africa, and the Black Sea.

101. Show both the above distributions on a single map, using a Polar Zenithal Projection like that in Fig. 83.

102. Adjust the following temperatures, allowing 1° F. for 300 feet of altitude, and from the adjusted figures draw January and July isotherm maps of North America, using a constant degree interval between isotherms; also draw a Range of Temperature map.

Station	*Altitude feet*	*January °F*	*July °F*
Fort Chipewyan . .	699	−13·2	61·9
Dawson City . . .	1,200	−23·9	59·7
Victoria	85	39·2	60·3
Calgary	3,389	11·3	60·7
Winnipeg . . .	1,492	− 3·5	66·2
Ottawa	294	12·0	69·7
Halifax	88	24·1	64·6
Maine	13	− 7·1	46·2
Albuquerque . . .	5,200	33·8	77·1
Bismarck . . .	1,674	7·0	69·3
Boston	124	27·0	71·3
Charleston . . .	48	49·3	81·3
Chicago	824	24·0	72·3
Helena	4,110	20·0	66·9
New Orleans . . .	51	53·9	81·5
Salt Lake City . .	4,366	29·0	75·5
San Diego . . .	93	54·0	66·9
San Francisco . . .	207	49·5	57·3
St. Louis . . .	568	31·0	79·1
Washington	75	32·9	76·8

103. Using a base map of scale about ¼ in. to the mile, draw:

(*a*) A Density Map of parishes or townships over a rural area about 28 by 16 miles.

(*b*) An Isoline Map of the same area.

Shade both maps, using a uniform key with about six density grades. Compare areas allotted to each density grade on both maps.

Compute the probable population of a number of parishes that are subdivided by isolines and compare it with the population according to original statistics.

104. Describe the nature of and reason for adjustment of certain statistics before they are used to draw isoline maps.

105. Draw a 2-inch grid on a topographical map, scale about 1 inch to the mile, and

from it draw a Range of Relief Map reducing linear scale by one-half. State any points which emerge on the new map which were not equally apparent on the original map.

106. Discuss the points in common between Density Maps and Isopleth Maps. Describe distributions and ratios which could be mapped by both methods, and give reasons for any preferences you have.

107. What advantages and disadvantages arise in mapping a commodity by Dot and Isoline methods on a single map?

108. Discuss methods of numbering isolines, and the relative merits of shading, monochrome, and colour on Isoline Maps.

109. Describe three different methods of mapping distribution of population, and discuss their relative merits. What methods are most commonly used in atlases, and what method was adopted by the Ordnance Survey of Britain to produce the 1 : 1 Million Population Map?

110. Discuss the advantages and disadvantages of using three-dimensional figures combined with dots as a means of showing distribution of population. Refer specifically to the example in Fig. 84.

Chapter XXV. GRAPHS

111. (a) Regraph the values of the four principal sea fish shown in Fig. 88 using
   (i) The Bar Group method.
   (ii) The Compound Bar method.

(b) Discuss the apparent advantages and disadvantages of each of the three forms.

112. (a) Graph the following climate statistics:
   (i) By simple bar and line methods.
   (ii) By the polar chart method.

(b) Which pair of graphs contrasts the climates most effectively, and why?

(a) San Francisco; (b) Charleston

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
(a) Temp. °F. .	50	51	53	54	56	57	57	58	59	58	56	51
Rainfall (inches) .	4·8	3·6	3·3	1·7	0·7	0	0	0	0·3	1·0	2·6	4·7
(b) Temp. °F. .	49	52	57	64	72	79	81	80	76	67	58	51
Rainfall (inches) .	3·1	3·1	3·3	2·4	3·4	5·3	6·2	6·7	5·2	3·9	2·7	3·3

113. (a) Draw Pie Graphs to show the exports of fruit from S. Africa in 1932 and 1938:
   (i) Making separate circles the same size for 1932 and 1938 values.
   (ii) Making circles proportional in area to the total values represented for each year.
   (iii) Combining both years in a single circle.

Exports of Fruit from S. Africa, 1932 and 1938. Value in Thousand £s

	1932	*1938*
Citrus (Oranges, &c.)	945	1,383
Deciduous (Pears, &c.)	413	644
Grapes	231	662
Others (Pineapples, &c.)	12	28
Totals	1,601	2,717

(*b*) Discuss the relative merits of the three methods as a means of clear and comparative representation.

114. (*a*) What facts emerge from a study of the graph in Fig. 99?

(*b*) Comment upon the appropriateness of the method.

(*c*) Graph the given information by some other means, showing if necessary, production for every fifth year only.

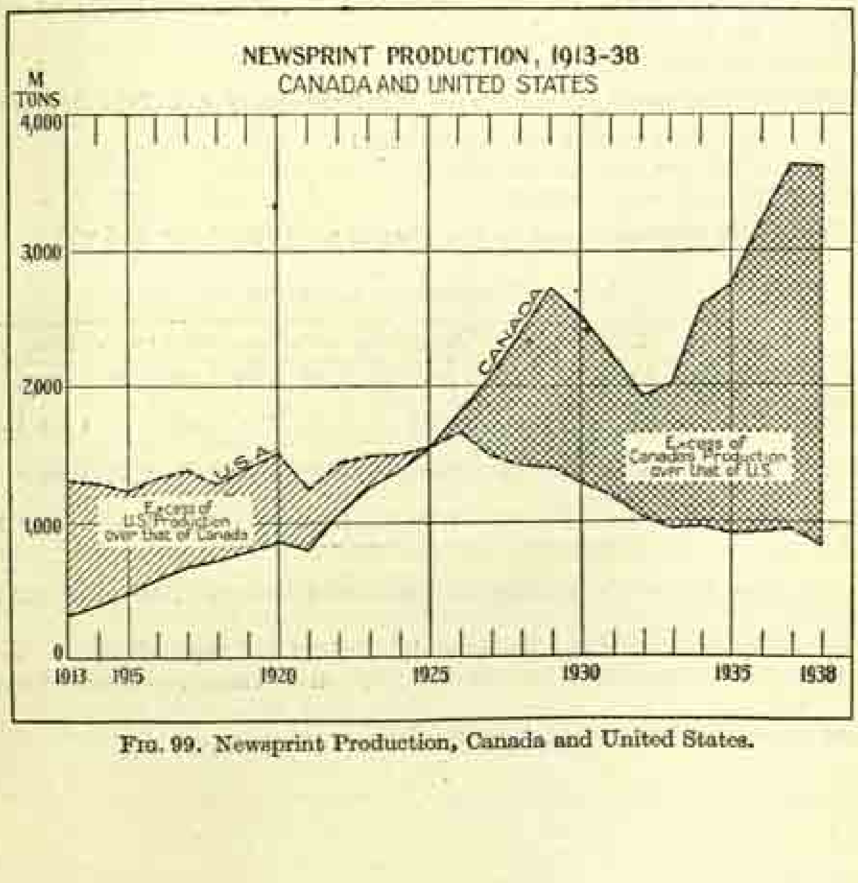


FIG. 99. Newsprint Production, Canada and United States.

Chapter XXVI. DIAGRAMS AND DIAGRAM MAPS

115. Represent the following statistics in a two-dimensional diagram. Inscribe names of crops and areas.

Acreage of Chief Crops in India, 1939–40

Areas in Million Acres

Rice	74
Wheat	34
Cotton	21
Groundnut	8
Rape and Mustard	6

116. (*a*) Represent the export values of fruit from S. Africa in 1938 by means of

(i) A series of squares.

(ii) A series of circles.

(iii) A single rectangle with subdivisions.

Statistics are given in Exercise 113.

(*b*) Which method seems most successful, and why?

117. (*a*) Draw a map to show the states in the Union of South Africa, and in each state draw a circle proportional in area to the number of cattle in 1938. Statistics are in Exercise 94.

(*b*) How far does this map help to demonstrate the facts?

118. Redraw the diagram of Australian Land Tenure, Figure 94, so that all printing is the same way up, and inscribe statistics to render the side scales unnecessary.

119. Show the following statistics by means of cubes, and comment upon the method:

Chief Coal-producing Countries, 1938

In Million Long Tons

Germany	375
U.S.A.	349
United Kingdom	227
France	47
Poland	38
Japan	37[1]

[1] Production in 1936.

120. Draw and shade spheres to represent the population of the six largest cities in the United States.

Population of Cities in U.S.A. 1940

Numbers in Thousands

New York	7,455
Chicago	3,397
Philadelphia	1,931
Detroit	1,623
Los Angeles	1,504
Cleveland	878

121. (*a*) Draw an enlarged sketch map of the Census Divisions of British Columbia shown in Fig. 98, and from the statistics in Exercise 88 make a Bar Chart Map of the population.

(*b*) Discuss the merits and defects of the map, and compare the result with those obtained by dot and density methods.

122. (*a*) Draw a Pie Graph Map to show the leading subdivisions of population in the states of S. Africa from the statistics in Exercise 93.

(*b*) What objections could be raised to the method as seen in application on this map?

123. Using two different methods, make two diagram maps to represent the following statistics:

Mineral Production in Australia: Values to end of 1937
Value to nearest Million £s

	N.S.W.	*Vict.*	*Q'land*	*S. Aust.*	*W. Aust.*	*Tas.*	*Nor. Ter.*
All minerals .	503	328	170	60	220	69	4
Gold alone .	66	308	91	2	205	10	3

124. (*a*) From the statistics in Exercise 92, draw a diagram map to show the total population and negro population in South Atlantic and East South Central United States.

(*b*) Discuss the merits of the method adopted.

125. Make a critical cartographical analysis of any official daily weather map.

SOURCES OF INFORMATION

The books and articles noted below are among those to which reference has been made in writing this book, and consequently the list may be of assistance to any who wish to pursue the various topics discussed.

PART I. TOPOGRAPHICAL MAPS

1. HISTORICAL CARTOGRAPHY

CLOSE, COL. SIR CHARLES, *The Early Years of the Ordnance Survey.* Institution of Royal Engineers, Chatham. London, 1926. An indispensable account of the Ordnance Survey built on contemporary letters and documents.

DICKINSON, R. E., and HOWARTH, O. J. R., *The Making of Geography.* Oxford University Press, 1933.

FORDHAM, SIR HERBERT GEORGE, *Maps.* Cambridge University Press. 2nd edition. A short but valuable account.

FORDHAM, SIR HERBERT GEORGE, *Some Notable Surveyors and Map-Makers of the 16th, 17th and 18th Centuries and their Work.* Cambridge 1929.

JERVIS, W. W., *The World in Maps.* Philip, London. A general account covering a wide field without over-simplification.

KEANE, JOHN, *The Evolution of Geography.* Stanford, London. Published in 1899 but still useful.

LYNAM, EDWARD, *British Maps and Map-Makers.* Collins, London, 1944. A short but valuable account, especially well illustrated.

RAISZ, ERWIN, *General Cartography.* McGraw-Hill, 1938. Contains a good historical introduction covering a wide field.

STEVENSON, EDWARD LUTHER, *Portolan Charts, their Origin and Characteristics.* New York. A short well-written account, illustrated by numerous facsimile plates.

2. MAPS AND PLANS

BYGOTT, JOHN, *Mapwork and Practical Geography.* University Tutorial Press, 2nd edition 1938. A clear account covering mapwork generally, with an analysis of those portions of Ordnance Survey Maps which are reproduced in the book.

CARTER, C. C., *Land Forms and Life.* Christophers, London. Consists mainly of an extremely useful analysis of selected topographical sheets, mainly Ordnance Survey 1-inch maps. The maps are essential to an understanding of the book.

CLOSE, COL. SIR CHARLES, *The Map of England.* Davies, London. An extremely interesting book for the general reader.

CLOSE and WINTERBOTHAM, *Textbook of Topographical and Geographical Surveying.* This book, noted in connexion with Survey, contains portions of various official maps in colour.

GARNETT, ALICE, *The Study of Topographical Maps.* Harrap. Studies in the analysis of topographical maps illustrated by an atlas of maps drawn mainly in black and white from the original sheets.

HINKS, ARTHUR R., *Maps and Survey*, as listed in Survey references. The 1st edition, published in 1913, has portions of various foreign maps in colour.

ORDNANCE SURVEY, *Large Scale Maps*; ORDNANCE SURVEY, *Small Scale Maps*. H.M. Stationery Office, London. These two catalogues have now been superseded by three entitled respectively, *Large Scale Plans*, *Medium Scale Maps*, and *Small Scale Maps*. All are illustrated.

TARR and MARTIN, *College Physiography*. Macmillan, New York, 1931. A text-book of Physical Geography containing portions of United States Geological Survey topographical maps in colour, to illustrate land forms. There are references to further topographical maps at the end of each chapter.

THIELE, WALTER, *Official Map Publications*. American Library Association. A bibliographical handbook including an outline history of cartography and an account of contemporary government maps in U.S.A., Canada, Latin America, Great Britain, and Germany, and summaries of map publications of Austria, Hungary, Netherlands, and Norway. There are no illustrations.

WINTERBOTHAM, H. ST. J. L., *A Key to Maps*. Blackie, London. Eminently readable and extremely informative.

3. SURVEY

(*a*) *Ground Survey*

BRYANT, V. S., and HUGHES, T. H., *Map Work*. An extremely useful and well-illustrated first book on survey.

CLOSE, SIR CHARLES, and WINTERBOTHAM, BRIGADIER H. ST. J. L., *Textbook of Topographical and Geographical Surveying*. 3rd edition, 1925. H.M. Stationery Office, London. This compilation is best described as the Official Text-book on Topographical Survey and is indispensable to advanced study of Ordnance Survey methods.

HINKS, ARTHUR R., *Maps and Survey*. 4th edition, Cambridge University Press. An advanced and excellent study of survey methods and apparatus.

HOTINE, MAJOR M., *The Re-triangulation of Great Britain*. Empire Survey Review 1935. A valuable record of the re-triangulation commenced in 1935.

JAMESON, A. H., and ORMSBY, M. T. M., *Mathematical Geography*, vol. i: *Elementary Surveying and Map Projection*. Pitman, 1927. A brief and straightforward account of the work indicated by the title.

THOMAS, N. NORMAN, *Surveying*. Arnold, 1932. A standard text-book written primarily for surveyors and engineers, but so lucid that it can be recommended equally to non-specialists.

(*b*) *Air Survey*

BAGLEY, W. JAMES, *Aero-Photography and Aero-Surveying*. McGraw-Hill, 1941. Intended for students who desire to make a systematic study of the subject. The geometrical problems are lucidly treated.

HART, C. A., *Air Photography applied to Surveying*. Longmans, Green & Co., 1940. This book is both technical and descriptive, and is written from the point of view of the prospective user rather than of the official surveyor. There is an extensive bibliography.

WAR OFFICE, *Manual of Map Reading, Photo Reading, and Field Sketching.* H.M. Stationery Office, London. Two chapters deal very simply with Photo Reading and sketching from Air Photographs.

4. MAP PROJECTION

HINKS, ARTHUR R., *Map Projections.* Cambridge University Press. A standard text-book indispensable to advanced study.

JAMESON, A. H., and ORMSBY, M. T. M., *Mathematical Geography,* vol. i, as noted under Survey. Vol. ii contains more advanced studies.

STEERS, J. A., *An Introduction to the Study of Map Projections,* University of London Press. This is an excellent book, particularly to those who seek a non-mathematical treatment of map projections.

5. MODELS AND BLOCK DIAGRAMS

BIRCH, T. W., 'Creative and Constructive Work in Geography', *Geography,* March 1942.

DEBENHAM, FRANK, *Exercises in Cartography.* Blackie, 1937. A series of exercises with explanatory text and excellent illustrations, representing in a modified form what has been done for some years by First-year Students in the Geography Department, Cambridge.

RAISZ, ERWIN, *General Cartography.* McGraw-Hill, 1938. Profusely illustrated, and deals with most aspects of cartography except surveying.

PART II. STATISTICAL MAPS

Few books deal at length with Statistical Mapping, and most of the following references are to articles in geographical journals.

6. DOT MAPS

An Agricultural Atlas of England and Wales. Ordnance Survey, 1932.

BERRY, J., 'Use of Dot Maps for Showing Distribution of Population', *School Science and Mathematics,* Nov. 1927, pp. 814–16.

BUCK, C. D. J., 'The Construction and Interpretation of Statistical Maps', *The Australian Geography,* vol. ii, no. 2, 1933, pp. 29–37.

BYGOTT, J., *Map Work and Practical Geography.* University Tutorial Press, 1938. Chapter VIII contains a general account of statistical mapping.

Chambers of Commerce Atlas. Philip, 1928.

FAWCETT, C. B., 'Population Maps', *Geographical Journal,* Feb. 1935, pp. 142–59.

FINCH, V. C., and BAKER, O. E., *Geography of the World's Agriculture* (Atlas) 1917.

GEER, S. DE, 'A Map of the Distribution of Population in Sweden', *Geographical Review,* Jan. 1922, pp. 72–83.

JONES, LL. R., 'Commodity Maps', *Geography,* 1922, pp. 223–32.

RAISZ, ERWIN, *General Cartography.* McGraw-Hill, 1938. Considerable space and illustration are devoted to statistical maps.

SMITH, G. M., 'A Population Map of Ohio for 1920', *Geographical Review,* 1928, pp. 422–7.

WHITEHOUSE, W. E., 'Representation of Populous Centres and Populated Areas', *Geography*, 1925, pp. 90–100.

WINTERBOTHAM, H. ST. J. L., 'Dots and Distributions', *Geography*, 1934, pp. 211–13.

WRIGHT, J. K. (Editor), *Atlas of the Historical Geography of the United States*, 1932.

WRIGHT, J. K., and others, 'Notes on Statistical Mapping', *Special Brochure*, American Geographical Society and Population Association of America, 1938.

7. DENSITY MAPS

FAWCETT, C. B., 'Population Maps', as listed under Dot Maps.

ORDNANCE SURVEY, (*a*) *1 : 1 Million Population Map of Great Britain.* (*b*) *Population Map of Greater London.*

WRIGHT, J. K., 'A Method of Mapping Densities of Population', *Geographical Review*, January 1936.

8. ISOLINE MAPS

BALLINGER, C. J., 'A Population Map of Central Oklahoma for 1920', *Geographical Review*, 1930, pp. 283–7.

FAWCETT, C. B., 'Population Maps', as listed under Dot Maps.

JONES, W. D., 'An Isopleth Map of Land under Crops in India', *Geographical Review*, 1929, pp. 495–6.

JONES, W. D., 'Ratios and Isopleth Maps', *Annals of the Association of American Geographers*, Dec. 1930, pp. 177–95.

WALLACE, B. C., 'Distribution of Nationalities in Hungary', *Geographical Journal*, March 1916, pp. 177–88.

WHITEHOUSE, W. E., 'Representation of Populous Centres', as listed under Dot Maps.

9. GRAPHS, DIAGRAMS, AND DIAGRAM MAPS

BIRCH, T. W., 'Representation of Regional Climates by Symbols', *Geography*, Sept. 1934.

BIRCH, T. W., 'Identification of Climate Types', *Journal of Geography*, Jan. 1936.

BRINTON, WILLARD C., *Graphic Methods for Presenting Facts.* McGraw-Hill. This book is comprehensive and practical. It has 371 pages and 256 illustrations, and though published in 1914, is still very useful and full of interest.

Chambers of Commerce Atlas. Philip, 1928. This atlas contains an exceptional collection of line, bar and pie graphs to supplement dot maps.

RAISZ, ERWIN, 'Rectangular Statistical Cartograms', *Geographical Review*, 1934, pp. 292–6.

ROSE, T. G., *Business Charts.* Pitman. A very short but useful book with a comprehensive annotated bibliography.

INDEX

[Italic numbers refer to figures.]

PRINTED IN GREAT BRITAIN
AT THE UNIVERSITY PRESS, OXFORD
BY CHARLES BATEY, PRINTER TO THE UNIVERSITY

9.1.75