MAPS AND SURVEY

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MAPS AND SURVEY

BY

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PREFACE

THIS book is designed as an introduction to the study of Maps and the processes of Survey by which they are made.

In planning the work it was necessary to decide in the first place whether to call it Maps and Survey, or Survey and Maps: that is to say, whether to take the logical order, of Survey before Maps, or the order of general interest and use, which is Maps before Survey.

Since many more people use maps than are engaged in making them, or than need to know the details of how they are made, it seemed better to begin with the consideration of the map as it is published and used. A clear understanding of the best results that have been produced up to the present time, leading to an appreciation of the ways along which progress is desirable, will make a convenient basis for the study of the methods of Survey, and the manner in which our representation of the world's surface may be extended and improved.

Some years of experience in teaching the elements of Geodesy and of Topographical Survey to the students of the Department of Geography in the University of Cambridge have shown me that there is need of a book which shall give a general account of the many-sided art of Survey. The two official military textbooks, the *Textbook of Topographical Surveying*, by Colonel C. F. Close, and the *Manual of Map Reading and Field Sketching*, are invaluable for instruction in all the details of the various processes, and there is no need to make any attempt to replace them. But it seems to me that the student needs some explanatory introduction, unobscured by much detail, which shall exhibit the general nature of the operations, and the relations to one another of the various parts of the subject.

It is certain, also, that the student of geography requires an elementary account of the operations of Geodesy proper, that is to say, of the higher survey whose aim is to contribute to the knowledge of the size and shape of the Earth; and which has in recent years extended its enquiries into the constitution of the Earth's interior. These subjects are entirely excluded from the official books mentioned above, and I do not think that there is any book which gives a general account of this most interesting part of the subject.

The ultimate refinements of Geodesy cannot affect the maps in the slightest degree, cannot be said to be of any practical use whatever, can offer no return in cash for the money which may be, and which ought to be, spent upon them. Their justification is on a higher plane. A nation is judged, and rightly judged, by the public spirit and the public taste which it shows in its buildings, its pictures, and its gardens, which any educated man is, or thinks he is, competent to appreciate. And equally a nation is judged, though by a smaller circle of judges, for the contributions which it can make to pure knowledge. An exquisite piece of Geodesy may give as real a pleasure, and be as genuine a source of pride, as the masterpieces of art and literature.

I have made no attempt to describe the minutiae of instrumental adjustments or processes, believing that a general view of the subject should not be obstructed by a mass of detail which is tedious to read, but had better be avoided until the student comes to deal with the instruments themselves, and carry out an actual piece of survey with them. Nor have I been able to give anything more than the slightest sketch of the large subject of cadastral survey. This is an intricate subject whose methods are to a great extent governed by the system of land registration and taxation in force in the country to be surveyed. There is a recent treatise on the subject—*The Cadastral Survey of Egypt*, by Captain H. G. Lyons, F.R.S., Surveyor-General—to which students may be referred if they wish to find a lucid account of the most interesting problems involved in this class of survey.

In the treatment of the topographical and geodetic survey I have tried to follow as closely as possible the principles underlying the methods employed by the Ordnance Survey, the Survey of India, and the School of Military Engineering at Chatham, to whose hospitality I owe my first introduction to the subject. I have profited also by the publications of the Geodetic Survey of South Africa, the United States Coast and Geodetic Survey, and the Survey of Egypt. Part of the charm of Geodesy is due to the general compatibility of the ideas which govern the operations of all countries, which may be traced without doubt to the influence of the International Geodetic Association, and to the benevolent authority exercised by the illustrious Director of its central bureau at Potsdam.

While the literature of Geodesy and Topographical Survey is extensive, comparatively little has been written on the subject of topographical representation on the map. The subject is new, because until the introduction of the present processes of colour printing there was not a great deal of scope for enterprise. It is still in the experimental state, as is evident from the continual change in the style of the publications issued by the principal map reproduction offices. Under these circumstances discussion and criticism are doubly interesting, and

I have devoted more space than might seem necessary at first sight, to the detailed analysis of typical sheets produced by the leading surveys of the World. But since it is impracticable to give adequate specimens of these maps, this analysis can be effective only if the student is able to study a selection of the actual sheets. For this reason I have given the sheet numbers of good specimens, in the hope that the schools of geography who may be interested in the subject may find little difficulty in procuring a characteristic series of maps.

By permission of the Controller of H.M. Stationery Office, and with the very kind assent and help of Colonel C. F. Close, C.M.G., R.E., Director-General of the Ordnance Survey, I am able to give in Plates I to V small specimens of the maps of the Ordnance Survey of Great Britain and Ireland. It is not possible to do justice to these maps in the small page of this book; but I trust that these specimens are sufficient to show the high quality of the work of the Survey, and to serve as an incentive to the study of the complete sheets. I am especially indebted to Colonel Close for undertaking the complete production of these plates in the printing department of the Ordnance Survey at Southampton.

Plates VI to IX I am able to give by the kindness of Colonel Hedley, R.E., Chief of the Geographical Section of the General Staff. He has been so good as to take great interest in the choice of specimens from the wide range of maps produced by his department; and in particular he has kindly placed at my disposal a specimen of the new edition of the beautiful map of Persia and Afghanistan which is in course of preparation. These four plates have been printed in the map reproduction department of the War Office. I owe to Colonel Hedley my sincere thanks for thus making it possible to include in my book four attractive examples of small scale maps.

The material for the plates showing instruments and methods I owe to many sources. Commandant Lucien Durand, of the 11th Regiment of Artillery of the French Army, was so kind as to give me the three pictures reproduced in Plate XVII, showing the reconnaissance ladder and beacon scaffold which he introduced into the equipment of the Service Géographique de l'Armée. To Captain E. M. Jack, R.E., British Commissioner in the survey and delimitation of the Uganda-Congo boundary, I owe the two pictures of beacons which make Plate XVIII, and the two pictures of base measurement on Plate XIX. The two latter were given me by Captain Jack to illustrate a paper read before the Research Department of the Royal Geographical Society, and the Society has kindly lent the blocks from which this plate is printed.

The three figures of Plate XXI are taken from the Account of the Principal Triangulation of Great Britain, published by the Ordnance Survey, and those of Plate XXII from recent volumes of the Survey of India. The view of Banog mountain in Plate XXIII is from the same source.

The diagrammatic figure of the plane table used by the United States Coast Survey is borrowed from one of their official publications, and the picture of the geodetic level on Plate XXIII was given me by Messrs E. R. Watts and Sons, who make this pattern. The remaining figures are from photographs of instruments belonging to the Department of Geography of Cambridge University.

A. R. H.

CAMBRIDGE,
May, 1913.

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CHAPTER I

MAPS

TOPOGRAPHY means, in the original Greek, the description of a place. A map is a drawing to illustrate such a description. By gradual steps it has been found possible to make these drawings in such a way that they convey the necessary information without the description in words, and what is now called a topographical map can give, to those who know how to read it, all the information which is wanted to enable a man to judge of the natural obstacles which may hinder his getting about the country, or the means of communication which have been established by man to facilitate his journey. In this book we shall be concerned chiefly with these topographical maps.

The amount of information which can be compressed into a map depends in the first place upon the perfection of the system of conventional signs in which the map is drawn, and secondly upon the size of the map in comparison with the ground which it represents, or, in other words, upon the scale of the map. It is clear that the larger the scale, the more detailed is the information which can be given. But, on the other hand, the larger the scale, the greater is the number of sheets required to cover a given area, and the more cumbrous is the map to use. For purposes of local administration and government it is necessary to have maps on which every separate property, however small, is distinctly shown; but such detail would be only confusing to those who wished to learn the way about the country. And again, the details of roads, the shapes of the hills, and all the other information essential to the traveller on foot or on wheels, are equally unessential to those who use the map for the study of broad questions of history, of commerce, or any such matters.

Hence we shall find that maps may be classed in three principal divisions:

Cadastral maps, on large scales, show boundaries of property, and individual buildings. They are required for local administration and taxation; the management of estates; the identification of property in legal documents; and for detailed affairs of every kind.

But it should be remarked that the English map on the scale of 1 in 2500, commonly called the 25 inch map, shows the visible hedges and fences, whereas the real boundary of the property is very frequently some feet beyond the hedge. Hence the 25 inch map is not strictly a cadastral map, though it is commonly called so.

Topographical maps show the natural features of the country, hills and rivers, forests and swamps; and in addition such artificial features as man has added to the country in the shape of towns and villages; roads, railways and canals; bridges and telegraphs. They serve as guides for travel on business or pleasure, or for the operations of war. They are on smaller scales than the cadastral maps, and cannot show the boundaries of individual properties. The inch to the mile map is the standard topographical map of the British Isles.

Atlas maps are on scales still smaller. Most of the topographical details have been suppressed; only the principal ranges of hills and the main streams of the rivers, the chief towns, and perhaps the main lines of the railways can be represented, for they aim at representing on a single sheet a whole country, a continent, or even the World.

The necessity for maps.

It is a little hard for one who lives in a country long settled and completely mapped to realise the difficulties which confront at every turn those who find themselves citizens of a new and unmapped country. The need of maps appears most urgently in case of war, and in the past it has usually happened that military necessities first compelled the production of a map.

The beginning of the Ordnance Survey of Great Britain may be traced, for example, to the Highland Rebellion of 1745. In peace the necessity of maps for all purposes of administration is less conspicuous, but none the less real. Until a country is mapped it is impossible to devise any well considered schemes of communication; until it is surveyed on a fairly large scale it is impossible to make grants of land to settlers, or at least it is impossible to give them a clear and undisputed title to their holdings. In larger affairs the need of maps is equally great. Until a country is mapped it is impossible to agree upon a boundary which shall be satisfactory to both sides, and in the absence of maps the most costly mistakes have been made through sheer ignorance.

Let us take two or three examples.

During the war in South Africa the British army in Natal, advancing to the relief of Ladysmith, found the Boers entrenched in a strong position at Colenso, on the north bank of the River Tugela. On the right of the British was Langwane Hill, which appeared to lie to the north of the river, though in reality the river turned away sharply to the north, leaving the hill easily accessible to the British troops. Although the country had been settled for many years there were no maps in existence. Langwane Hill was the key to the position. The failure of the British commander to realise that it was accessible cost the country many hundreds of lives and weeks of prolonged fighting. The mistake could not have been made had the country been mapped.

Again, until a country is mapped there is continual waste in making surveys for special purposes. If a railway is projected it is necessary to make a special survey of the proposed course of the line. This survey costs a large sum of money, but since it is made for a special purpose it is not complete; it is never published, and cannot be made use of as a contribution to the proper mapping of the country. In the earlier part of the nineteenth century, while the Ordnance Survey was in the initial stages, several million pounds were spent in England on railway surveys, surveys for the commutation of tithe, enclosure of common lands, and so forth, nearly all of which money might have been saved had the regular survey of the country been finished earlier. It is the truest economy to push forward the survey of a country at the earliest possible moment.

To take a somewhat different case: it is most important that the responsible officers of Government should be trained to discriminate between maps which are reliable and those which are not. It frequently happens that the first rough maps of

Fig. 1. True position of the 30th meridian, which was supposed to pass through the middle of the lake.

a newly explored country are compiled from inaccurate observations made under great difficulties by the early explorers. For example, the early maps of central Africa showed the thirtieth meridian passing through Lake Albert Edward, and on the partition of Africa in 1894 it was agreed that the boundary between Uganda and the Congo Free State should follow this meridian, so that both countries should have access to the lake. Some years afterwards it was found that the thirtieth meridian was actually some miles to the east of the lake. Prolonged negotiations were necessary for a rectification of the frontier, and some considerable sacrifice of territory was required to gain that advantage which the treaty was in the first instance supposed to secure. This costly mistake would have been avoided had the diplomatists realised the necessary limitations of the maps which they were using.

We need not spend more time in insisting on the importance of making maps, and of understanding how to use them.

Conventional signs.

In order that it may be possible to compress as much information as is required into the minimum of space, to ensure clearness and legibility, it is necessary to adopt a carefully considered scheme of conventions, so that the character of every line and the style of every letter may convey a definite meaning. The map thus becomes a kind of shorthand script, whose full meaning cannot be understood without a thorough knowledge of the system employed. It is therefore clearly advantageous that mapmakers should come as soon as possible to some general understanding on the subject of conventional signs, in order that it may not be necessary to learn, as it were, a new language whenever one tries to read a new map.

The resolutions of the International Map Committee, which met in London in 1909 to frame a scheme for the one-in-a-million map of the World, are in this respect of great importance, and we shall often refer to them in what follows.

The characteristic sheet.

The characteristic sheet is the key to the system of conventional signs employed on the map. It is usually, though not invariably the case, that each sheet of a map bears a small characteristic sheet of the principal conventions (see Plate I); but for a complete understanding of the system it is always necessary to refer to the complete characteristic sheet that is published separately.

Conventional signs for use in the field.

These are necessarily simpler and less minute than the signs which are employed on the engraved or carefully drawn sheets that are issued from the reproduction office. The surveyor in the field has neither the skill nor the time to imitate the finely devised style which is suitable for the engraved map. We must therefore be careful to distinguish between the systems to be employed in the two cases. (For a conventional sign sheet for field use, see the *Manual of Map Reading and Field Sketching*.)

Roads.

In reading the representation of roads on a map, it is necessary to remember first of all that the road is not represented true to scale in width, but that the width is conventional, signifying the class of the road. Such a convention is clearly necessary. On the scale of one inch to the mile a road sixteen yards broad would, if shown true to scale, be only one hundredth of an inch broad ; and this is far too little for legibility, or to allow distinctions between the representation of different classes of roads. Hence roads must be shown of a conventional width ; and when the scale of the map is doubled it is by no means necessary that the road shall be drawn twice as broad as before.

There are considerable differences in the conventional signs for roads in use in different countries. We will examine three typical cases: the British Ordnance Survey; the French 1/50,000 map published by the *Service Géographique de l'Armée* ; and the 1/1,000,000 International Map.

Ordnance Survey. 1/63,360, or one inch to the mile. (See Plates I and IV.)

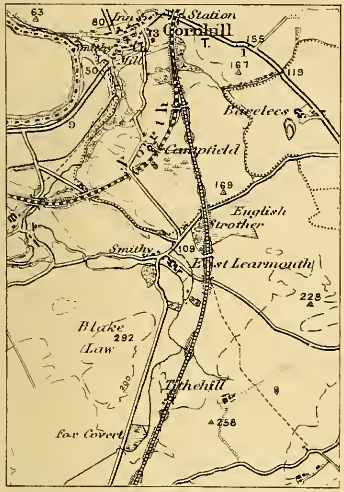
A distinction is made between fenced and unfenced roads, the former being shown by double continuous lines, the latter by dotted lines. The distinction is of military importance, since fenced roads afford cover and obstruct the free passage of troops across country. Three grades of metalled roads are distinguished by differences in breadth, and the first two grades are coloured orange. Unmetalled roads or cart tracks are shown by still narrower double lines, and footpaths are long-dotted, but are with difficulty distinguished from parish boundaries, which are not needed on a topographical map. (See Plate I.)

It is often found that the distinction made on the map

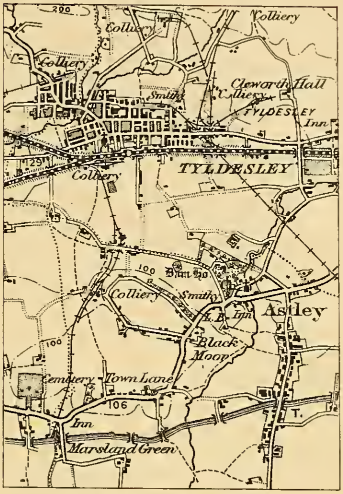
CONVENTIONAL SIGNS

PLATE I

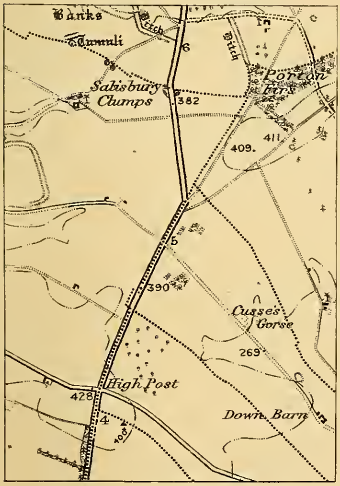
One Inch Ordnance Survey Map



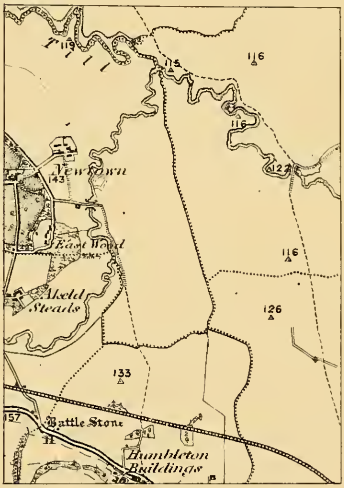
Double and Single Railways



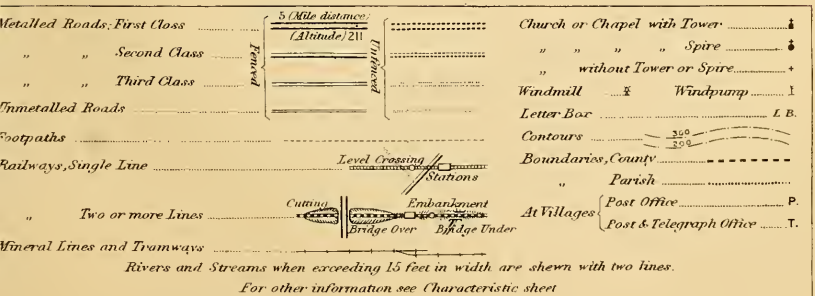
Mineral Lines and Canals



Roads of Different Classes



Footpaths and Parish Boundaries



Characteristic Sheet attached to One Inch Map. O.S.

between first and second class roads has little relation to the actual condition of the road. Roads which should be in first class condition are pulled to pieces by heavy motor traffic, while second class roads are constantly being brought up to first class condition. Generally speaking all the roads coloured orange are fit for motor traffic, and the uncoloured roads are not.

Ordnance Survey. 1/126,720, or two miles to one inch. (See Plate V.)

First and second class roads are shown narrower, but still coloured orange. The distinction between metalled roads of the third class and unmetalled roads disappears.

"So far as the half-inch maps are concerned the old classification of roads is somewhat inadequate to present day needs. A committee was formed during 1911–12 to discuss the matter....It is not possible to obtain absolute unanimity of opinion on such a subject as the classification of roads on a map, but there is no doubt that the classification proposed by the committee is a good one, and is an improvement on the former classification. It will be applied to the new engraved issue of the half-inch maps of Great Britain." (*Report of the Progress of the Ordnance Survey*, 1912.)

Ordnance Survey. 1/253,440, or four miles to one inch.

First class roads only are coloured orange. Second class roads are shown by double line uncoloured, and other roads by single line. On this smaller scale minor roads are sometimes omitted, and this often leads to mistakes, since what ends in a farm track often begins as a well made road. In using the smaller scale maps it is most important to bear in mind a time scale, as explained under that heading.

France. 1/50,000.

The principal differences from the system of representation employed on the Ordnance Survey are:

None of the roads are coloured.

Variety in the signs is obtained by making the two lines bordering the road of different intensities.

Where a road passes through a town (shown in red) the black lines cease, and the absence of colour belonging to the road is then an especial disadvantage.

International Map. 1/1,000,000. (See Plates VIII and IX.)

On this small scale the representation is naturally less elaborate. Roads of all classes are shown in red:

First class by double red line.

Second class by one continuous and one dotted line.

Third class by single red line.

Footpaths, or tracks not suitable for wheeled traffic, by single dotted red line.

None of the roads have any body colour, such as the orange of the Ordnance Survey; and they are all shown very lightly. They are scarcely conspicuous enough under the best of circumstances, and when they fall on the redder tints of the layer colouring they become almost invisible. (See Plate IX.)

In general it may be said that all existing topographical maps fail in the representation of hill paths. These have an importance quite different from paths of equal quality on the level. They are very generally well marked and permanent features of the ground, and should be shown much more conspicuously than they are. On most maps they are very hard to follow when they run through hill-shaded and wooded ground. It seems reasonable to demand that all well made and easily followed paths in mountainous parts of Great Britain should be shown by a single line of orange and black.

The want of some such convention is particularly marked in holiday country. For example, in the Lake District there are many paths well made, and as permanent in location, and very nearly as obvious to follow, as the high roads. Such are the principal ways up Helvellyn, or the path over Grisedale Pass from Patterdale to Grasmere. On the half inch map with layers these are not shown. Again, in Switzerland the principal paths are well made and most elaborately marked with signs and patches of colour on the rocks. But it is almost impossible to follow these paths on the 1/50,000 map. It would seem that from the military point of view also it must be of importance to show these paths.

On the other hand, there is a tendency in the modern coloured maps to over accentuate the main roads. This arises, no doubt, from the fact that as they were originally engraved, in black, it was necessary to mark the importance of the main roads by showing them in heavy double black lines. Now that they have in addition a filling of colour they are often unduly prominent, and much diminish the legibility of the contours.

There is also a tendency to confuse the representation of towns by multiplying the yellow coloured roads. A residential road in a good neighbourhood is always a first class road in the sense that it is broad and well made; but it is not a main road, and probably it should not be coloured yellow. It would be, for example, far more easy to discover the main roads out of London if all the well made suburban roads were not coloured.

In a modern coloured map, especially on those of smaller scale, it would probably be enough to represent the main roads by a single broad line of dark grey, and the lesser roads by a narrower line.

Railways.

These are almost universally shown in black. There is generally a distinction between double or multiple and single tracks, narrow gauge railways, and tramways. No provision has been made as yet to distinguish between railways worked by steam and by electricity; but it is clear that the distinction is important, especially from the point of view of public safety on the one hand, and of military adaptability on the other.

Ordnance Survey. 1/63,360. (See Plate I.)

Railways are elaborately engraved, with distinction between double and single lines as in the figure. Embankments and cuttings, very important as obstacles or cover, are clearly shown.

Ordnance Survey. Smaller scales.

Railways are shown as heavy single black lines, and there is no representation of embankments or cuttings.

France. 1/50,000.

Four and two way tracks are in heavy black; single tracks somewhat like the British double track; narrow gauge lines like the British single track; and tramways distinct from narrow gauge lines. There is no general way of showing embankments and cuttings.

International Map. 1/1,000,000. (See Plate VIII.)

A simpler system, as shown in the plate. A feature not generally found is that lines under construction, and also projected lines, are to be distinguished. The latter seems to be open to objection, since it must be difficult to decide at what stage a projected line establishes its right to be shown.

It is often useful to have special railway maps, in which the other topographical features are subordinated. The Swiss railway maps are excellent examples of the best system for this purpose. The general map is printed in light brown, and the railways, with names of the stations, are overprinted in heavy black. This is far better than suppressing the topographical detail, as is too often done in railway maps.

The representation of railways running underground through towns involves difficulties which have not been successfully overcome.

In a country such as India, where there are several different gauges in use, it is most important to distinguish between them. And it is even more important in mountainous countries, as Switzerland, to distinguish between railways of the ordinary kind, rack railways, and funiculars.

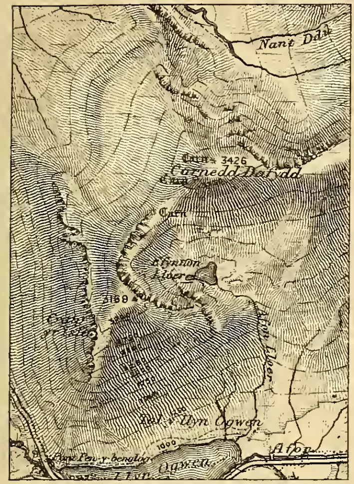
Scale.

The question of scale is of prime importance; the aim of the map-maker is to show as much as the scale on which he works will permit, and he must learn in the first place what are the possibilities of the different scales, and secondly how to make the most of them.

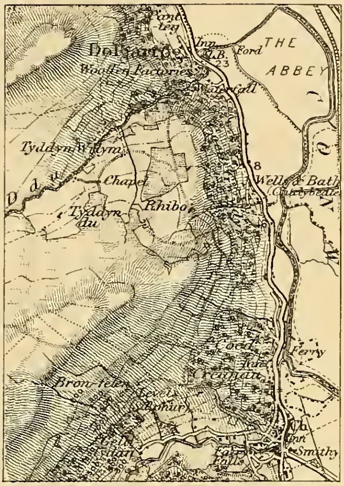
The scale of the map is defined by a statement of the relation between a distance measured on the map and the corresponding

REPRESENTATION OF HILL FEATURES

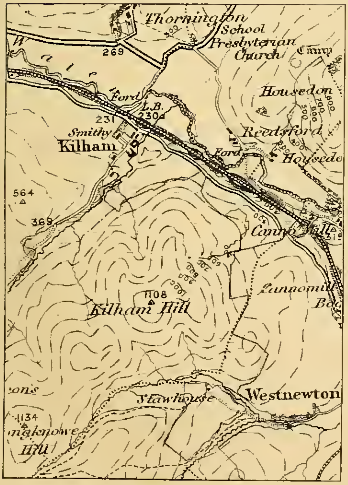
One Inch Ordnance Survey Map



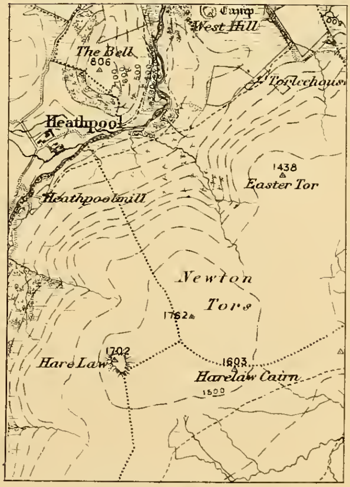
Hachures and Cliff Drawing



Confusion of Contours with other Detail



Correct Method of Figuring Contours



Misleading Effect of Unequal Vertical Interval in Contours

Ordnance Survey, Southampton, 1913

distance on the ground. The distance on the map will be measured in one of the smaller units of length, that on the ground by one of the larger; thus, we say that the map is on the scale of one inch to the mile, or one centimetre to the kilometre, or again, we may invert the statement and say, that the scale is one mile to the inch, or one kilometre to the centimetre.

There is no very definite rule in English practice, whether to say, one inch to the mile, or one mile to the inch. In general one avoids the use of fractions in the statement: thus, one says one inch to the mile, but four miles to the inch, not one quarter of an inch to the mile. On the other hand it is common to speak of the equivalent in inches of one mile as the characteristic of the scale, and to speak of the inch map, the half or quarter inch map, and so on.

This is the common way of speaking, but it is being superseded by the more accurate method of giving the "representative fraction," that is to say, the ratio of the distance on the map to the distance on the ground. There are 63,360 inches in a mile. Therefore the representative fraction of the one inch to the mile map is 1/63,360; and the representative fraction of a map on the scale of one centimetre to the kilometre is 1/100,000.

We shall note at once that the British system of measures of length produces awkward fractions: for the half inch map the R.F. (usual abbreviation for representative fraction) is 1/126,720; and for the quarter inch map it is 1/253,440. This arises of course from the fact that the number of inches in the mile is not a round number. In countries where the metric system is used this difficulty does not arise, since all the units of length, large and small, are related decimally. It follows that the R.F. for a map of such a country is naturally a round number, and it has become the practice to speak of "natural scales," meaning thereby, scales for which the R.F. is a round number, 1/250,000, 1/100,000, 1/80,000, and so on. The term does not seem to be a good one, since there is not anything natural in the use of a decimal system of units, but rather the contrary, if it is proper to argue from the fact that the metric system, a late creation, has not yet displaced altogether the complicated non-decimal systems which natural man had evolved. Natural scales, in fact, are natural only in countries which have become habituated to the decimal system of measures; in other countries they are not natural, but their scientific convenience has led to their gradual introduction.

We may notice that there is some diversity of opinion as to the choice of a convenient range of so-called natural scales: Shall the series run

1/200,000, 1/100,000, 1/50,000,

or shall it run

1/250,000, 1/125,000, 1/62,500 ?

There is an undoubted convenience in subdivision by two, so that a sheet on one scale is subdivided into four sheets on the scale next larger, and so on. This appears in either series. But the second series is derived by such steps from the one in a million scale, while the first is not. On the other hand the numbers in the first series are simpler, more round, than the numbers in the second. The divergence illustrates very well the difficulty that continually occurs in the application of any purely decimal system, that for many purposes continual division by two is more convenient than division into so many tenths.

Again, there is the advantage in the second series of scales that it differs very little from the series in inches to the mile.

Half an inch to the mile is 1/126,720. This differs from 1/125,000 by little more than one per cent., or about the uncertainty in the scale of the printed map which is due to the expansion of the paper with damp. Hence in all ordinary use of the map there is no practical difference between the two, and this fact certainly tends to the choice of the series derived from the one in a million by continual division into halves. Moreover, the recent standardisation of the one in a million map, and the convenience of making all other sheets subdivisions of this, must tend to the adoption of the second series rather than the first.

It seems probable, therefore, that the series

1/250,000, 1/125,000, 1/62,500

will gradually be adopted more and more widely.

Method of writing the Representative Fraction.

It is not unimportant to remark that the R.F. is better printed 1/126,720 or 1 : 126,720, than in the fractional form $\frac{1}{126720}$, which requires figures so small that they are read with difficulty.

There can be no hard and fast rule as to the scales suitable for maps intended for definite purposes. But in general one may say that cadastral maps are larger than 1/15,000; topographical maps between 1/20,000 and 1/1,000,000, the larger scales being for military purposes tactical maps and the smaller strategical; while anything on a smaller scale than one in a million can hardly be considered topographical, but may be called for convenience an Atlas map.

Construction of scales for maps.

The word scale is used in two senses. In an official manual we find on consecutive pages these two statements:

"The scale of a map is the relation between a measured distance on the map and the corresponding distance on the ground."

"The scale of a map should be, for convenience, about six inches long."

In the second sense the scale of a map is the diagram which allows one to translate distances on the map into distances on the ground expressed in any unit desired—not necessarily that employed in the first instance when the map was made. Thus it may be convenient to put on an inch to the mile map a scale of hundreds of yards; or to construct a scale of miles for a French map on 1/80,000.

A scale should be constructed so that any length taken from the map with a pair of dividers can be read off at once from the scale.

Suppose that the scale is to give thousands and hundreds of yards.

The main scale is divided simply into thousands of yards, set off to the right of the zero. To the left of the zero one additional space of a thousand yards is subdivided into hundreds, and if it is numbered at all, which is usually not really necessary, it is numbered to the left, that is to say, in the opposite direction to the numbering of the main scale.

A few moments' trial will show the advantages of this plan. Suppose that the distance is between 3000 and 4000 yards. One leg of the dividers is set on the division 3000; the other leg reaches beyond the zero, and the odd hundreds are read off from the subsidiary scale. On this system the actual figures required are read directly from the scale. On any other system the figures shown by the scale must be modified in some way or other.

EXAMPLE: For the one inch to the mile map, construct a scale of thousands and hundreds of yards.

1000 yards = 1000/1760 inches = 0·568 inches.

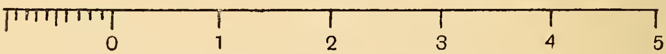


Fig. 2. Scale of thousands of yards, for the one inch to the mile map.

Note that:

(1) If the zero were placed at the extreme left of the scale,

or (2) If the subdivided portion were numbered from left to right,

or (3) If the scale had been constructed for the unit 500 yards instead of 1000 yards,

it would not have been so convenient as in the above form.

The scales given on the Field Service Protractor will generally serve for the construction of any desired scale without calculation.

Problems in the construction of scales.

Exercises in the construction of scales are often set in military examinations, and many rules for the solution of these problems are given in the military textbooks. It seems to the author that these rules, like the old fashioned multiplicity of rules in arithmetic, defeat their purpose by suggesting that there is a rule to be remembered, instead of a common sense sum to be worked.

Thus, for example: Given a map on the scale 1/100,000: To construct a scale of miles.

On the scale one mile to the inch the R.F. is 1/63,360. For the smaller scale 1/100,000 one mile is obviously 63,360/100,000 or 0·63 inches, and the scale is easily constructed with a rule graduated to inches and tenths, or with the diagonal scale of the protractor.

Rivers.

Rivers and streams should be always shown in blue. Their importance is great, not only the obvious importance which they possess as sources of water supply, means of communication, or obstacle to getting across the country, but the subsidiary yet very real importance which they derive from their use in helping realisation of the relief of the land. When the streams are shown conspicuously in blue they make it easy to follow the run of the valley bottoms, and to distinguish valleys from ridges. (See Plates IV and V.)

The characteristic sheets attached to the maps of the Ordnance Survey (see Plate I), give no information as to the methods of representing rivers and streams. In general a stream more than fifteen feet broad is represented by a double blue line on the one inch map, and perhaps also on the maps of smaller scale. There are no special signs for locks, wiers, or falls; and there is no indication of the navigibility or otherwise of the stream. Nor is there any distinction between natural streams, canalised streams, and wholly artificial canals. Confusion is avoided, however, by the consideration that the shape of natural and artificial waterways is very different, and that the latter tend always to run along the contours.

But the need for some distinguishing sign is sometimes very conspicuous, as in the map of Dartmoor. Here there are many "leats" or small canals for water supply of towns or of mines. These naturally run along the contours, or nearly so. Occasionally they cross the course of a natural stream by an aqueduct. But there is not on the Ordnance Survey maps any sign for or representation of this aqueduct; and consequently the maps show the impossible feature of a stream dividing into three. At first sight it appears that a contour has been shown blue instead of red, in error. The absence of any sign of the aqueduct by which the leat crosses the stream is a serious blemish on the map.

A further difficulty is sometimes caused by the failure to show streams that run in deep ditches by the roadside, which is not uncommon in flat country such as the fen districts of

England. It should be easily possible to show the necessary blue line alongside the black line which borders the road; its absence makes it impossible to discover what becomes of a stream which runs by the roadside.

In general a stream will cut a contour at right angles to its general direction, the contour being thrown back upstream where it crosses. When the fall of the stream is rapid, and particularly when the ground is rocky, the contours are V-shaped at the crossing; when the ground is flat and alluvial the crossings of the contours are more rounded. It is clear that in general a stream cannot cross a contour more than once. There are, however, exceptions to this rule which are at first sight puzzling. They occur in very flat country, where the streams are sometimes confined by banks much above the level of the ground on each side. In such cases it is possible for a stream to cross a contour several times. It would be well that streams of this character should be distinguished by some special sign, for they are important from the fact that it is easy to breach their banks and flood the surrounding country.

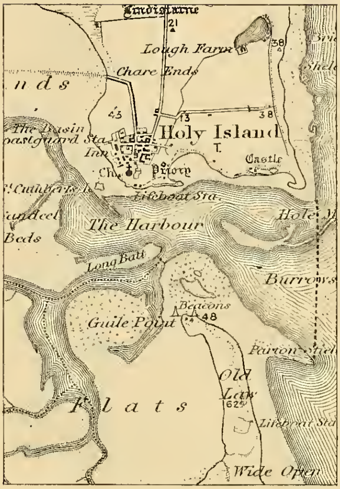
The characteristic sheet of the French 1/50,000 map distinguishes between important rivers, shown double; streams, shown by single lines; and canalised rivers, margined by thick blue lines, with signs for locks. Bridges of stone, steel, and wood; suspension and swing bridges; ferries, and wiers, are all given conventional signs.

The International Map has a quite different set of signs, suitable to its smaller scale. Perennial rivers are shown by a solid blue line of varying width; non-perennial are heavily long-dotted. Unsurveyed rivers are lightly dotted; and navigable rivers are shown by a double line. Navigable canals have cross strokes similar to those often used for railways, and non-navigable are distinguished from natural streams by their uniformity. There are signs for rapids and falls, and for the limit of navigation.

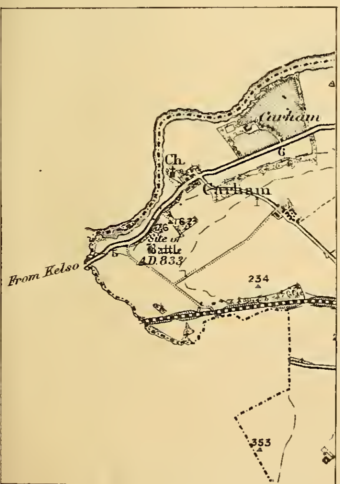
PLATE III

CONVENTIONAL SIGNS

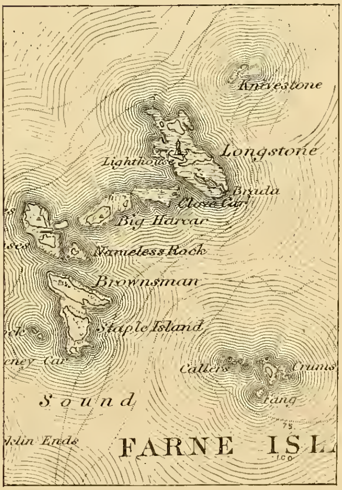
Marsh



Sands



National Boundary



Rock and Water Lines

Ordnance Survey, Southampton 1913

Woods and forests.

In black engraved maps these are shown by small tree signs, sometimes, as in the Ordnance Survey one inch map, of two varieties to distinguish between deciduous trees and conifers which are mostly evergreen. (See Plate II.) The effect is heavy, obscuring details, and rendering names almost illegible. On the British coloured maps the woods are overprinted with a tint of bright pale green. (See Plate IV.) This brings them out, perhaps somewhat too conspicuously, but leaves the underlying detail of roads and names more illegible than ever. The smaller scale half inch and quarter inch maps have the same system.

It seems to be decidedly better to leave out the tree signs, and to show woods by a uniform tint of green, except on layer-tinted maps, where the woods shown thus become confused with the tints representing height. In the latter case the woods may be shown by tree signs printed in green, as in the International Map, though this is hardly clear enough on the green layers.

The French 1/50,000 map shows woods in green tint, without tree signs; and has special signs for nurseries, gardens, and vineyards. Where tree signs are used trees in rows denote orchards, while trees irregularly disposed denote woods. The International Map, on the small scale of 1/1,000,000, has no sign for orchards and vineyards, which are seldom so extensive that they need be shown on this scale. It remains to be seen how they will be shown on those sheets of France, Germany, and California where the vineyards and orchards are of great extent, and might be shown.

Sheet margins.

It is important that all margins of sheets should be divided in latitude and longitude, and that the origin of the system of longitudes should be stated clearly.

It is also desirable that the margins should be divided into sections of some convenient unit of length, and that each section should bear a letter or a number, to provide a ready means of referring to a particular region of the map.

It is further desirable that the margins of contiguous sheets should overlap to some extent, so that it should never be necessary to refer to two sheets for the detail of a small district. The inconvenience of having a town or village on the extreme edge of the sheet is sufficiently obvious; yet no general attempt has been made to provide overlaps in the sheets of any topographical series. Some of the sheets of the large sheet series of the half inch map of England overlap north and south, but not east and west; and on the one inch map there are sheets which overlap irregularly rather than show a large extent of empty sea.

On the French 1/50,000 map there is a partial attempt to mitigate the inconvenience of having important detail cut in two by the sheet margin. East and west, and to a very slight extent north and south, there is room to show important detail beyond the strict limits of the sheet; but the principle upon which the irregular boundary is drawn is not clear; and there does not seem to be any advantage over the plan of making all the sheets overlap by a definite amount.

It is highly convenient to have the sheet divided up by lines drawn right across it; and in general it would seem that these lines should be the meridians and the parallels of latitude. The map is thus divided into trapeziums, and there is no reason why they should not be distinguished by letters and numbers to facilitate reference, as is very commonly done in atlases. There is, however, a certain advantage in dividing the map into squares rather than into trapeziums; it much facilitates the enlargement of small pieces of the map by the method of squares. For this reason all the recent half inch maps of Great Britain are divided into squares of two inches to the side, while the meridians and parallels are not carried across the sheet. This system is especially appropriate to the British sheets, which are rectangular, and not bounded by meridians and parallels, as more modern sheets are. There seems to be no reason why both systems should not be used, provided that the two sets of lines were printed in different colours. (See Plate V.)

In the use of the British squared maps it is most important to avoid the very common mistake of supposing that the vertical sides of the squares are meridians; they may be as much as four degrees out of the meridian. Yet it is common to find such statements as that for "practical purposes" the edges of an Ordnance Survey sheet may be considered north and south.

The sheets of the Ordnance Survey, unlike most, have on their margins a diagram showing the true meridian and the magnetic meridian of a given date, with a statement of the amount of the variation of the magnetic meridian annually. It is, however, not safe to use this diagram for the purpose of laying off either true or magnetic meridians. The lines shown are too short, and they are too close to the edge of the sheet for convenient use. Moreover on some at least of the sheets they are not accurate, having become a kind of conventional sign, in which the angle as engraved does not correspond with its numerical value as stated, while there is no means of knowing which if either of the meridian lines is engraved at its proper inclination to the margin of the sheet. This is particularly embarrassing in the use of the large sheet series of the one inch map, from which the division of the meridians and parallels has most unfortunately been omitted.

The representation of hill features.

The real difficulty in mapmaking is to represent the relief of the ground. This is naturally so, for we are trying to find a method of representing a solid figure by drawing on a flat sheet, or to represent three dimensions in two. Moreover, we have not a free hand to do the best we can with this particular problem, but are limited by the condition that we must not obscure the other details on the map.

Until the last few years little progress was made in the solution of this problem. So long as the map was printed in a single colour, almost necessarily black, very little could be done. Recent improvements in the processes of colour printing have made it possible to produce maps in colour, sometimes with twelve or fifteen separate printings. This has altered completely the conditions of the problem, and, while great progress has been made already, it seems probable that much more may be done. We shall therefore discuss this part of our subject as fully as possible.

The relief of the ground may be shown in a number of different ways: by hachures or hill-shading; by contours; by spot heights; by hypsometric tints, generally called in England "the layer system." And these methods may be, and usually are, combined so that three or four are in use on the same map. We shall begin by considering them separately, and then discuss how they may be used in combination.

Hachures.

Hachures are lines drawn down the directions of steepest slope. On slight inclines they may be delicate and not too close together. As the slope gets steeper they may be drawn heavier, and be closer together. If they are drawn faithfully they are very expressive, and give a good idea of the shape of the ground. But the system of hachuring has the following defects:

Its range is small; that is to say, it is impossible to show many different degrees of slope. Slight folds in the ground, if they are shown at all, are exaggerated; really steep slopes cannot be shown proportionately heavy without obscuring all other detail. Moreover, it is impossible to preserve uniformity of treatment on the different sheets of one and the same map. The steepest slope on a sheet of nearly flat country may be actually less steep than a relatively moderate slope on a mountainous sheet; and slopes which are important in the former may be insignificant in the latter. Hence hachures can be used to indicate that there is a slope, but they cannot give much information as to the absolute degree of the slope.

It is difficult to draw hachures properly in the field; and when the field sheets come into the hands of the engraver it is certain that they will be improved in appearance, and generalised, so that they become untrustworthy in detail.

Hachures, then, belong to the days of delicate and expensive engraving upon copper, and with the changing conditions of map reproduction they are rapidly becoming obsolete. Excellent examples of the system are to be seen in the old engraved sheets of the one inch Ordnance Survey maps of the United Kingdom (see Plate II), and in the older maps of Switzerland; and it survives on the modern colour printed maps that have as their basis transfers from the engraved plates. (See Plate IV.) But it is not probable that hachures would be used nowadays on any entirely new series of maps.

The term hachure has the definite meaning assigned to it here, and should not be confused with hill-shading, described in the following paragraph. It is regrettable that in the 1912 edition of the *Manual of Map Reading* the distinction between hachures and hill-shading is not maintained.

Hill-shading.

Hill-shading aims at producing very much the same effect as hachures in an easier and cheaper way. The draughtsman colours the slopes in rough proportion to their intensity, with brush or stump. The drawing is then photographed and a hill-shading plate produced in "half-tone," by a process similar to that by which photographic illustrations are produced in books and newspapers. Thus hill-shading consists of series of dots, whereas hachuring consists of series of lines; and the two are very easily distinguished. (Compare Plates IV and V.)

It is difficult to do hill-shading effectively in the field, and it is generally added by the draughtsman in the office; but since it is in its nature more generalised than hachuring, and is quite unsuitable for showing detail, this is of small consequence.

Both hill-shading and hachuring suffer from the defect that they do not readily show which direction is uphill and which is downhill. By themselves, in fact, they cannot give any indication at all on this important point. A ridge and a valley, each with shaded sides, cannot be distinguished one from the other simply by the shading, and one must rely on other details, such as rivers in the valley bottoms, or heights marked at various places, to indicate the interpretation of the shading. A sheet with hill-shading and nothing else might be interpreted equally well in opposite ways.

We are speaking now of shade which depends only on the degree of slope, without any convention as to the way in which the shade is cast; without, indeed, any possibility of imagining it as a shade produced by contrast with light from a definite source. It is sometimes spoken of as vertical shade—an expression which can have none but a conventional meaning; in other places it is called the shade cast by a vertical light, which is meaningless. These expressions serve, however, to distinguish it from the other form of hill-shading, which represents the shadow which would be cast on the ground by oblique light from a low source, such as the sun near setting. For some reason which is not clear the source of light is generally imagined in the north-west. Oblique hill-shading is very much used in European maps, and it produces a strong effect of relief. But it has the disadvantage that it makes the slope in the shadow look steeper than the slope in the light, left unshaded. In fact it is only by induction that one gets any suggestion at all of the slopes towards the light.

We may compare thus the effects of the vertical and the oblique systems of shading. Imagine a ridge and a valley, each running north-east, with the slopes on each side the same. Under the vertical shade they would be indistinguishable. Under the oblique shade they would be readily distinguished one from the other; but the ridge would appear steeper on its south-east side, the valley on its north-west side.

To avoid this difficulty an ingenious system has been devised for the new map of France on the scale of 1/50,000. The map is hill-shaded on both systems, printed in different colours. There is a vertical shade in bistre, and overprinted is an oblique shade in purple grey. On moderately undulating ground the effect is excellent; in mountainous country the colour becomes too heavy. And the system is of course expensive.

It is clear that no system of hill-shading can give any information as to the actual height of the ground above sea level. Hill-shading should therefore be considered as a means of bringing up the relief of the country graphically, to supplement the more precise information which can be given in other ways. This being so, it is important to notice that the hill-shading should be kept very light. The least tint that will serve to show the difference between one side of a hill and the other is enough, since the degree of slope should always be denoted by the closeness of the contours. Hill-shading often suffers from being too heavy, as in the half inch O.S. map. (See Plate V.) A pale transparent grey, as in the 1/250,000 Bavarian Staff map, is probably the best colour.

Spot heights.

Spot heights are the heights above sea level marked at various points on the map. They are sometimes called spot levels; but the misuse of the word level in this connection is to be condemned.

On cadastral maps the height of each bench mark is usually given; these are not strictly speaking spot heights, since they refer to the height of the bench mark, not of the ground. The heights which, on the British cadastral maps, are given along the crown of the road are spot heights, and a selection of them is given on the smaller scale topographical maps. There is a strong tendency to give spot heights for summits, and not for the bottoms of depressions.

Spot heights are very useful as exact points of reference, but they cannot by themselves give any idea of the form of the country.

Contours and form lines.

A contour is a line joining a series of points which are all at the same height above mean sea level. If the sea suddenly rose a hundred feet the new coast line would follow the hundred foot contour.

A form line is an approximate contour, not accurately surveyed, but sketched upon the ground.

There is some difference of practice in the use of the two expressions, but for our present purpose it is not material to define the precise difference in degree of accuracy which divides contours from form lines. It will be sufficient to keep the term contour for the product of instrumental methods, even if rough, and to call the much less accurate contours which are merely sketched, form lines.

Thus, the Ordnance Survey maps (Plates IV and V) have contours; the Basutoland map (Plate VI) has form lines.

Contours give a maximum of precise information with a minimum of obstruction to the map. They may be considered the standard method of showing relief, to which all others are subsidiary. But to be effective they must be drawn on carefully considered principles.

Contours should be drawn at uniform intervals of height; any departure from this rule is certain to lead to inconvenience. (See Plate II.) The interval chosen will naturally be a simple multiple of the unit of length employed: 50 or 100 feet; 10 or 20 metres.

The contours must be numbered; and when possible they should be numbered according to the rule adopted in the British one inch map:

The figures stand on the contours on the upper side. (See Plates II and IV.)

It is somewhat strange that this excellent rule is not followed in the later maps of the Ordnance Survey, for it affords a ready means of distinguishing between uphill and downhill. To do so it is not necessary that the map should be examined so closely that the figures of the height may be read. So long as one can see the places in which the figures are, one can see at once which way is uphill, for the figures stand on the contours on their upper sides.

The annexed figure shows the one way which is right and the three ways which are wrong, according to this principle of figuring the contours. A comparison of the British one inch map with any other map will show the undoubted advantage of this method. It fails only when the contours come so close together that there is not space to draw the figures between them. In such cases, and in no other, the number must be inserted in the line of the contour. A close scrutiny is then needed to discover in which direction the numbers increase, and the map is much more difficult to read.

When the country is steep the contours come close together, and it is difficult for the eye to follow them, even on close

ORDNANCE SURVEY OF ENGLAND

One Inch Scale $\frac{1}{63,360}$

In Outline, without Hills

In Colour

Ordnance Survey, Southampton 1915

examination ; while if one tries to obtain a general view of the map, the contours merge into one another, and become a mere shade. Many of the Swiss maps suffer from this defect.

In such cases it is necessary to guide the eye by accentuating every tenth or every fifth contour. If, for example, the map is contoured at ten metres interval, every tenth contour, that is to say, the hundred metre contours, should be drawn heavily. This

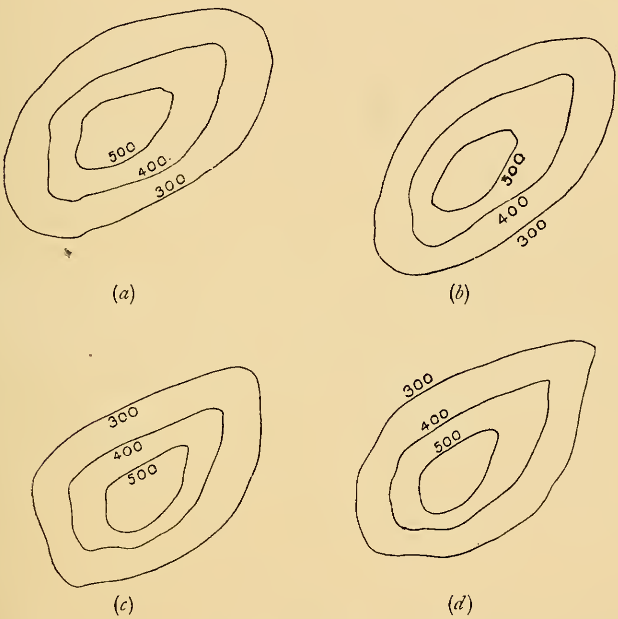


Fig. 3. Methods of figuring contours.
(*a*) right; (*b*), (*c*) and (*d*) wrong.

enables the eye to follow the run of the contours, and is a great help in reading the form of the ground. It tends to give the map a stepped appearance, and isolated hills seem to be ridged like oyster shells, as may be seen especially in the 1/62,500 maps of the United States. But this is a small matter in comparison with the real advantage of being able to follow the contours readily.

The worst way of accentuating each tenth contour is to chain-dot it, as in the Swiss maps on the scale of 1/50,000. These dotted contours, which are the only ones figured, disappear except under close attention, and the whole system becomes nearly unreadable. It is instructive to take one of these maps and to ink in the dotted contours, thus rendering them heavier than the rest. Immediately the map becomes readable.

We have said that the contour interval must be equal throughout, and that any departure from this rule is very inconvenient. There are certain cases in which it may be legitimate, indeed necessary, to interpolate intermediate contours. For example, in flat country nearly at sea level, such as the fen country in the East of England, there may be a large area which is all comprised within a single contour interval, and in such cases an elevation of a few feet may be more important than a rise of several hundred feet in more elevated regions. Intermediate contours at close intervals are then very useful; but it is evident that they should be readily distinguishable from the contours of the normal series. They may be chain-dotted, or distinguished in some other way. But they should not be drawn exactly like the others, as is done in the British one inch maps, which show the 50 foot contour, and above that only the 100 foot contours up to 1000 feet.

A more serious defect of the British map is that above 1000 feet the contour interval becomes 250 feet, and higher up the interval becomes wider still. This is destructive of all facility in reading the map, as may be seen at once in the example appended. (Plate II.) At 1000 feet all the slopes suddenly seem to become less steep, and it is very hard to train oneself to ignore this misleading appearance. If the objection is made that in every steep country contours at uniform intervals come so close together that they can leave no room for any other detail, one may reply that in country so steep as this there is little detail to show, except the contours; and that the closeness of the contours gives the effect of hachuring or hill-shading, with far greater precision than the latter is capable of.

It is desirable to have some guide to the choice of the contour interval. An examination of the best examples of British and foreign maps shows that the rule

Contour interval = 50 *feet divided by the number of inches to the mile*

represents pretty well the result of experience. It should be understood, of course, that this rule is entirely empirical, derived simply from a number of maps treated as experiments.

Layer colouring, or hypsometric tints.

The layer system, as it is generally called in English, is a comparatively new system which improvements in colour printing have rendered possible. Its aim is to give to the map the general effect of relief which the contours alone cannot give, because they can be read over only a small piece of the map at one time. A scale of gently graded colour tints is chosen, and all the ground which lies between two certain contours is coloured a certain tint, while that included between the next pair of contours is coloured to the next tint on the scale.

An early example of the use of the layer system is found in the well-known half inch maps of the United Kingdom produced by Mr Bartholomew. More recent examples are the Ordnance Survey half inch map (Plate V); several Continental maps, notably the Bavarian General Staff map; and lastly, the new International one in a million map of the World. (Plates VIII and IX.)

The layer system is exceedingly effective in country which is suited to its use; and it is very often exceedingly unsuccessful in general use. We will examine it in some detail.

It is successful in country which does not require more than seven or eight contour intervals. The colour scale can then be formed of eight tints of one colour, and progress from light to dark or from dark to light will denote progressive increase in height, while even the heaviest tint will not seriously obscure the underlying detail of the map. Where more than eight tints are necessary it is difficult to ensure that the heavier tints shall be transparent enough to leave the detail legible; and it becomes necessary to pass from one colour to another. At this point difficulties begin.

It is not possible to work up in tints of one colour to the point of change, from light to dark, and begin the new colour with the lightest tint, for the contrast is then too violent; the scale must be inverted at the change of colour, and if the first series ran from light to dark, the next must run from dark to light. This inversion of the colour scale introduces difficulties in reading the map, which it seems to be impossible to avoid. They can, however, be diminished by care in choosing the colours of which the scale is composed. It is asserted, and apparently rightly, that the change from one colour to another is least disagreeable when the colours run in their spectrum order. A colour scale which runs from green through yellow to orange and red is more agreeable than one which passes from green to orange without the intervening yellow. How far this principle rests on physiological foundations is not at all clear; but it seems to be true in effect. Undoubtedly the most successful layer system maps are those which follow this rule in the selection of the colours for the scale of tints.

A more serious difficulty is that even when this system of choosing colours is pushed as far as possible, it is still impossible to provide enough tints to serve for a great range of layers at a uniform contour interval. And were it possible to select the tints, the number of printings required would be prohibitive. It is necessary, therefore, in the higher ground, to widen the interval which is represented by one tint (Plate VII, Afghanistan); and this produces the same inconveniences as the wider spacing of the contour interval produces in contoured maps without the layers. This difficulty is felt especially when the country to be represented is a high plateau, such, for example, as the Transvaal. In such a case differences of a hundred feet are as important as they are at sea level; yet if a uniform scheme were applied throughout they would be shown by differences of colour in the latter case and not in the former. It is not easy to see how to overcome this difficulty.

A good deal may be done, however, by drawing in the contours at uniform vertical intervals (as in the Kenhardt sheet,

ORDNANCE SURVEY OF IRELAND

PLATE V

Half-inch Scale $\frac{1}{126,720}$

With Hill Shading

Layer System

Ordnance Survey, Southampton, 1913

Plate IX), even if it is not possible to assign a separate tint to each interval. The advantage of this may be seen on comparing the Bavarian Staff map with, let us say, the layer map of Scotland. In the former several contours are included in the limits of a single tint, on the higher ground; in the latter this is not done. There can be no doubt that the former is the more effective.

Combined systems of showing relief.

We have discussed separately the merits of spot heights, hachures and hill-shading, contours, and colour layers. In practice several of these systems are generally used on one map.

Contours and hill-shading make an effective combination, and if the contours are drawn strongly they make it possible to use oblique shading without much danger of the slope in the shade looking steeper than the slope in the light. (See Plate V.)

Hill-shading combined with layers demands great skill in its application, or the shade changes the tint of the layers, and gives a misleading effect. On the other hand, a layer map without hill-shading is very liable to look flat in the higher regions, where the layer interval is large. (See Plate IX.)

The merits of any combination cannot be discussed with profit, except by reference to particular maps. We will therefore defer criticism until we discuss in some detail the best existing examples of topographical maps of all countries.

Other conventional signs.

It is hardly possible within the limits of this book to give a complete account of the many other conventional signs adopted in different series of maps. A study of the conventional sign sheets of the different survey departments will show how varied are the ideas of what is desirable. Some of the signs for the Ordnance Survey are shown in Plate III.

The tendency of modern map-makers is to elaborate the conventional signs. The new French map on the scale 1/50,000 is an example, and the special maps for the use of aviators go much further. We shall discuss the difficult question of aero maps in a separate section.

Until recently it was the rule in British maps that no military or naval works were to be shown, and that no contours were to be shown within 5000 yards of any fortification. The result of this rule was that the public maps of garrison and dockyard towns were meaningless, which probably caused as much trouble to the Services as to the public, though of course there were complete confidential editions. As a precaution against knowing the position of a fortification the rule by its strictness defeated its own object, since it was easy to mark the points where the contours were suddenly discontinued, to draw the circle through those points, and to conclude that a fort was at the centre. The newly published smaller scale maps now show the positions of the forts, and the contours have been completed.

Map reading.

Facility in reading from a map all the information that is implied in its conventional representation of the ground is an accomplishment only to be attained by constant practice in the field, and it is useless to attempt to lay down many rules for it. Much excellent advice on the methods of learning the art is given in the *Manual of Map Reading and Field Sketching*; and we will not attempt to cover again the ground which is thoroughly gone over in that book. But we will try to supplement what is said there by a few additional notes.

Sections and profiles.

In the solution of many practical problems it is required to draw a section across the country, from the information which is given on the topographical map. Suppose a line drawn across the map along the line of the proposed section: it will cut the contours at a number of points, and these points will furnish the principal material for the construction of the section. Lay a strip of paper along the line, and mark on it the points where the line cuts each contour. Draw perpendiculars from the edge proportional in length to the heights of the contours above sea level: this will be facilitated if the paper is furnished with equally spaced lines parallel to the edge, and distant from one another by the contour interval on the adopted vertical scale of the section.

A broken line joining the summits of these perpendiculars is a rough approximation to the section, which can be much improved by studying the other indications of height upon the map. Thus, it is improbable that a spot height will fall exactly on the line of the section, but a good deal may be learned from those that fall near. Hill-shading is useful in suggesting the probable shape of the country between the contours, and care should be taken to utilise the information which is given by streams. By taking advantage of these subsidiary sources of information it is possible to construct a fairly good section from a topographical map; and of course the closer the contour interval the more accurate the result.

It is however inevitable that a section drawn in this way should be conjectural in its details, and if accuracy is required it is necessary to run a line of levels across the country along the line of the section. For this process we refer to the chapter on Levelling (page 95).

A profile of a road is a section run along the course of the road, instead of straight across country. It is constructed in the same way as a section, by laying a strip of paper along successive lengths of the road and marking off the points where the contours are crossed. In addition there are generally a number of spot heights marked along the road, and these are especially useful because they give summits. When a road rises above a contour and falls below it again there will usually be found an intervening spot height, which will mark the summit.

It is often useful to have the profile of a road along which it is necessary to send traffic, and profiles of the main roads of the country are being published for the use of motorists. Unfortunately the makers of these books have adopted the wrong name "contour road book," instead of "profile road book." This bad mistake should be avoided.

Problems of intervisibility.

Questions on the use of maps very often demand the solution of the problem, whether one point is visible from another. It is evident that this can be solved, in some degree, by drawing a section from one point to the other, and seeing if any intervening point on the section rises above the ray joining the given points. Since the section can be only approximate it is clear that caution must be used when the ray clears the intervening ground by only a little.

In most cases it is not necessary to draw more than a part, if any, of the section, for it is easy to see where are the critical points.

It should never be forgotten that in undulating wooded country the trees are the principal obstacles to mutual visibility of points, and it is not possible to estimate from the map the effect of the trees. Hedgerow trees, which are not marked on the map as woods, since they offer little obstacle to the passage of men, are often a complete obstruction to the sight. Consequently problems of mutual visibility of points are more useful in testing the understanding of the map than in deciding whether it is actually possible to see from one point to the other.

Reconstruction of the view from a given point.

It is an excellent exercise in map reading to try to reconstruct from the map the view of the country from a point of vantage, and to draw it as a panorama. From the chosen point of view radiating sections are run across the country, and it is usually not hard to discover what heights form the sky line in different directions, and what features are prominent in the middle distance. When these are determined, a study of the contours gives a general idea of the shape which these features will present, and then by the exercise of some ingenuity it is possible to construct a panoramic sketch which reproduces the broad features of the view. A few exercises of this kind are very useful in teaching facility in reading relief, especially in town schools where it is difficult to reach actual ground on which to practise.

Identification of distant objects.

It will often happen that a wide view, say in the Lake District, or on Dartmoor, presents a confused panorama of peaks which cannot be identified by their relations to one another as shown on the map. To identify such a distant object it is necessary to take its bearing by compass, subtract the westerly deviation, as given on the margin of the Ordnance Survey map, and with the protractor to lay off a line on the resulting true bearing from the point of observation. For the instrumental process reference may be made to page 105. The distant object will then lie on this line drawn upon the map; and of the several objects at varying distances which may chance to lie on it, it will not in general be difficult to select the right one.

The reverse problem sometimes arises. It is desired to identify on the ground, or at least to discover in what direction it lies, an object which is marked on the map, but which is not apparent to the sight. In such a case draw on the map a line from the point of view to the object in question, measure with the protractor the true bearing of this line, and add the compass deviation west. Then with the compass to the eye turn slowly round until some object is found which has the given compass bearing. The object sought will lie in the same straight line from the observer, and with this indication it is often possible to discover it, or at any rate to find exactly where it lies.

Measurement of areas.

The first consideration which arises in this problem is: are the areas correctly represented on the map; or is the projection on which the map is constructed an equal area projection.

Topographical maps are not usually constructed on a projection which is theoretically an equal area projection; but the misrepresentation of areas will always be much less than the uncertainty which is introduced by the expansion and contraction of the paper with damp.

Atlas maps will very often be on projections which misrepresent areas grossly; but for a consideration of this question reference must be made to a treatise on the somewhat intricate subject of Map Projections.

An easy way of measuring areas on a map is by superposing a sheet of tracing paper regularly ruled in small squares. First count the number of whole squares embraced by the area, and then estimate how many whole squares more are equivalent to the array of partially included squares along the boundary of the area. From the scale of the map calculate the area represented by one square of the tracing paper, and thence derive the whole area of the figure in question.

More elaborate methods involve the use of special instruments such as the planimeter.

The "Amsler" planimeter is a beautiful instrument whose use is simple, but whose theory defies explanation in an elementary book. It consists essentially of an arm carrying a pointer which is moved round the boundary of the area to be measured, and a wheel which rolls on the surface of the paper. A second arm is pivoted to the first between the pointer and the wheel, and its other end is free to turn about a fixed point. As the pointer moves round the boundary the wheel revolves, sometimes forwards, and sometimes backwards. The nett amount of rotation forwards is measured by a revolution counter and by divisions on the drum attached to the wheel. The nett rotation, multiplied by a suitable constant, gives the area. (See Plate X.)

The precise computation of areas is an important part of the work of a cadastral survey, but its methods are beyond the scope of this book.

Measurement of distances on a map.

As in the measurement of areas, it is first necessary to know if the distances are correctly represented on the projection which is employed. And a treatment of this matter is beyond the scope of the present book. On all topographical maps the distances are shown so nearly true that they may be measured to within the error caused by paper shrinkage. For the methods of construction of scales see page 13.

Map Reproduction.

It would be impossible within the scope of this book to describe in detail the many processes which are employed in the engraving and printing of maps. But a very slight sketch of the principal methods may be of interest.

The best of the old maps, in black only, were engraved on copper, and from the copper a steel-faced electrotype was made. The whole plate was covered with ink, and the surface wiped, leaving the engraved lines charged as in the ordinary process of printing from steel engraving. The print was made in a heavy press, which forced the paper into the engraved lines, from which they took up the ink. Maps printed from engraved plates can be distinguished by the relief of the lines. This process gives the best results, but it is slow and expensive, and does not lend itself to printing in many colours, which is now a necessity. In the production of modern maps, therefore, the various processes of photolithography on stone or zinc have displaced printing from engraved plates.

Where, however, the expense of engraving on copper can be afforded, an engraved plate still forms the basis of the process. From the engraved plate a print in light blue is taken, and the draughtsman inks in on this the portions which it is desired to print in any one colour. When this drawing is photographed the light blue disappears, and only the inked-in portion is transferred to the stone or zinc from which the coloured impression is made. Thus it is possible to prepare from the basis of an engraved original as many colour plates as may be required.

Recent improvements in colour printing presses have greatly increased both the speed and the accuracy of register of the impressions, so that it is possible to produce at a reasonable cost maps with a dozen or more impressions. The success of modern topographical maps is due largely to the greatly extended possibilities afforded by these processes.

Engraving on copper is costly, and many attempts have been made to find a substitute for it; the engraving of the names, in particular, seems at first sight to be very wasteful.

But no method of stamping the names from steel dies has proved satisfactory. Some excellent results have been obtained, however, by drawing with a graver on glass coated with a white pigment which can be blackened chemically, and from which the printing plates can be made by photography. Another process which has given good results involves drawing on an enlarged scale on tracing paper, and photo-etching on copper from the drawing. But in each case the names have to be drawn—a tedious process.

All these are for maps of the highest class. For cheaper work there is a variety of processes of photozincography, and of preparing zinc plates by contact printing from a tracing. For rapid work in the field on active service, field lithographic presses have been designed, and a Printing Company, R.E., accompanies the Intelligence Division on service, ready to reproduce in short time any plans, enlargements, or sketches that may be required. For an interesting account of the equipment and organisation of such a company, reference may be made to the *Textbook of Topographical Surveying*.

For a complete technical treatise on the methods of engraving and printing, reference may be made to *Methods and Processes adopted for Production of the Maps of the Ordnance Survey*, Second Edition, 1902.

CHAPTER II

MAP ANALYSIS

Ordnance Survey Maps.

Until within comparatively recent years the Ordnance Survey produced excellent maps but appeared to have little interest in the question whether they sold or not. The maps were published in the form of flat sheets only, and before they could be used out of doors it was necessary to spend at least as much as the price of the map in having it mounted on linen and put into covers. The means of distribution and sale of the maps were also very inadequate.

About fifteen years ago maps mounted on linen and folded in covers were put on sale, and more recently the method of mounting in book form was introduced. This last simple expedient has done more than anything else to increase the convenience of using the map, yet strangely enough it has not been imitated, and it is still difficult to get an unofficial map-mounter to understand how to do it. A map so mounted can be opened at any desired section with one hand, while the other hand remains free for driving or bicycling. The map does not catch the wind, nor does it offer much surface to the rain, and it can be consulted without attracting attention.

It is a mistake to buy for field use any maps but those so mounted on linen, and folded without dissection. The dissected map is more flexible and lasts longer; but it is impossible to make measurements upon a dissected map, and this should be sufficient to condemn it.

Ordnance Survey maps can be bought at the local agents, and at the principal booksellers and railway bookstalls. It is not so well known that they can be obtained also by return of post from the Ordnance Survey Office at Southampton; and this is very useful when a map is suddenly required while on a holiday.

The large scale cadastral maps on the scales of 1/2500 and 1/10,560 and the town plans of five and ten feet to the mile hardly concern us here.

The topographical maps are

the 1/63,360, or one inch to the mile, which is the standard topographical map of the country, and in its recent form on large sheets is the most valuable for local use[1].

the 1/126,720, or half inch map, which is the standard military map for war and manœuvres, and is also the most generally useful for motoring and bicycling.

the 1/253,440, or quarter inch map, which is the most useful for planning long distance journeys, and for intelligent railway travelling.

The smaller scale maps, ten miles to the inch, and the one in a million map, are for strategical and general purposes.

The student should make a point of analysing examples of the different series, since in no other way is it possible to obtain an idea of the possibilities of the different scales, or of the difficulty of finding a uniform system of mapping that shall be satisfactory in all varieties of country. The following notes on selected sheets are given merely as illustrations of some of the more obvious points of interest.

Ordnance Survey of England and Wales. 1/63,360.
Sheet 42. (Large sheet series.) Third Edition. Llandudno.

Printed in colour at the Ordnance Survey Office, Southampton. Dated 1909.

Relief by contours and hachures. Contours at 50, 100, and each 100 to 1000, then at 250 feet interval to 3000. Printed in red, figured in black. The break in the contour interval at 1000 feet has particularly noticeable results on this sheet.

Vertical hachures in brown; cliff drawing in black, very conspicuous. Spot heights frequent.

[1] This map can be obtained in the coloured edition, which is far the best (see Plate IV), and in the outline edition in black. The editions with hills in black and in brown have now been withdrawn.

Contours in the sea bed 25 and 50 *feet* below mean sea level, not *fathoms* as on the half inch map.

Metalled roads: first and second grades, black filled yellow; third grade, thin double black. Unmetalled roads same, but narrower. Footpaths long-dotted, and very likely to be confused with parish boundaries.

Woods, tree signs in black, over printed heavy green with boundaries.

Margin divided into two-inch divisions, not carried across sheet, but lettered and numbered. No indication whatever of latitudes and longitudes, a grave omission.

Small characteristic sheet attached.

This sheet is a very good example of the present one inch map of Great Britain.

Ordnance Survey of England and Wales. 1/126,720.
Sheet 39. (Large sheet series.) Brighton.

Printed in colour at the Ordnance Survey Office, Southampton. Dated 1908.

Relief by contours, hill shading, and layers. Contours at 50, 100, 200,... and by 100 feet interval to 1000; printed in brown, very lightly, and figured. Spot heights. Layer colours change at each contour, green passing through light brown to very heavy brownish green. Vertical hill-shading. The relief of the country is well shown, but underlying detail is obscured by the heavier colours, and the contours are confused by the hill-shade and the tree signs.

Roads: black filled yellow, two grades, and inferior roads double black only. No tracks or hill paths. Water blue. No contours in sea. Woods green tree signs, no boundaries[1].

Scale of miles. Latitude and longitude in margin, not carried across. Magnetic meridian and annual variation.

Names black, stamped and ugly.

Small characteristic sheet.

The same: new edition. 1911.

New scale of layer colours, changing at 100, 200,...700, 800, 1000, green, through yellow, to pale brown. No hill-shading. The map is much more legible, but the strong effect of relief is lost.

Contours in sea bottom: low tide, 5 and 10 fathoms. Layer tints of blue.

Ordnance Survey of England and Wales. 1/126,720.
Sheet 5. (Large sheet series.) The Lake District.

Printed in colour at the Ordnance Survey Office, Southampton. Dated 1908.

Relief by contours, layers, and some hill-shading.

[1] NOTE: On some sheets of this edition the woods are shown by plain green tint without tree signs, e.g. Sheet 24, Huntingdon.

Contours 50, 100, 200,...1000, 1250, 1500, 1750, 2000, 2500, 3000, lightly printed in brown and figured. Layer colours change at each contour, green into pale brown, ascending to brownish grey, descending to bluish grey, ascending to dark slate colour. An exceedingly ugly map, showing the layer system at its worst.

Other details as in Sheet 39 above.

Ordnance Survey of Scotland. 1/126,720.
Sheet 32. The Border Country.

Printed in colour at the Ordnance Survey Office, Southampton. Dated 1910.

Relief by contours and layers. Contours 50, 100, 200, and at 100 feet interval right up, printed in brown, and figured. Spot heights frequent. Layer colours change at 100, 200, 300,...800, 1000, 1500, 2000, 3000, green, yellow, leading to brown, and finally to an ugly shade of magenta (on the map), not conforming with colour scale in margin. No hill-shading. This colour scale adopted after the breakdown of the English scale on high ground. Result on this sheet unsatisfactory: colour uniformly heavy, obscuring contours.

Roads: double black filled with yellow (two grades), and inferior roads double black only. Tracks and hill paths not shown. Water blue. Woods: green tree signs, no boundaries.

Scale of miles. Latitude and longitude on margin, not carried across. Magnetic meridian and annual variation.

Trans-border country shown fully (a welcome improvement in British practice).

Names black: stamped and ugly.

Small characteristic sheet.

Ordnance Survey of Ireland. 1/126,720.
Sheet 3. Donegal.

Printed at the Ordnance Survey Office, Southampton. Dated 1911.

Relief by contours and hill-shading. Contours uniformly at 100 feet interval throughout, printed lightly in red, and figured in brown. Hill-shading vertical. Spot heights. 5 and 10 fathom contours in sea, and blue layers. Woods green, with black tree signs and boundaries.

Sheet divided into two inch squares, with reference letters and numbers in margin.

Other characteristics as on the British sheets of this scale.

The same, with layer colouring instead of hill-shading: see Plate V for small example.

The new scale of tints is very successful. The series begins with two descending shades of pale green; from 200 to 400 is left almost white, which is a new idea in layer colouring; above 400 the successively increasing clear brown tints change at every 200 feet. This is by far the best layer map yet produced by the Ordnance Survey.

Ordnance Survey of England and Wales. 1/253,440.
Sheets 19 and 23 combined. Second Edition. Berks, Wilts, Hants, etc.

Printed in colour at the Ordnance Survey Office, Southampton. Dated 1911.

Relief by hill-shading in brown. Spot heights. No contours.

Roads: first class, black filled yellow; second class, double black; third class, single black line.

Woods: tree signs in black, over printed pale green with boundaries.

Margin divided in latitude and longitude, and meridians at 20′ interval, parallels at 30′ interval carried across the sheet. Notice the obliquity to the meridian of the sheet edges.

The second edition differs from the original edition in the following points: The names are re-engraved and much improved; the woods have tree signs added, and the colour is much paler; the sign for railway station is much improved.

Maps of the Geographical Section, General Staff.

The Geographical Section of the General Staff, War Office, publishes a very large and varied selection of maps of British territories, and of other parts of the world in which Great Britain has special interests, or for which it is not likely that maps will be made by the local governments.

Some of these maps represent the work of the Colonial Survey Section; others are compilations from route traverses and miscellaneous work, and are of a provisional character; others, again, as the map of Canada now in progress, are published by arrangement with the Dominion authorities. The series of maps of Turkey in Europe, and of China, cover regions which have not been mapped by the local authorities, while the maps of Arabia, Mesopotamia, and Persia provide material for the consideration of strategic and political interests.

The style of production of these sheets is varied, and many of them, being provisional, are comparatively rough. Of recent years, and especially since the building of the new War Office gave the Geographical Section adequate accommodation, great improvements have been made in the execution of the maps, and the latest productions, particularly the Canadian map, and the first sheets of the International Map, are of the highest class.

The following notes are intended only to call attention to the importance of a study of these maps for all students of geography.

Orange River Colony. 1/125,000.
Sheet 125. V. iv. Odendaal's Rust.

Lithographed at the War Office, 1906.

Relief by contours, in brown, at 100 feet vertical interval, and occasional hill-shading. Spot heights plentiful.

Roads shown in three grades, principal roads filled yellow. Water blue. Bush shown by green tree signs.

Margins show latitude and longitude, and index numbers and letters. Magnetic meridian and variation.

Full characteristic sheet, and index to character of the river drifts, and of the water, grazing, and fuel at various halting places.

There is little detail to be shown on the sheet, leaving room for notes on roads and character of country.

Basutoland. 1/250,000.
N.E. Sheet. (See Plate VI.)

Printed and published by Geographical Section, General Staff. June, 1911.

Relief by approximate contours, at 100 feet vertical interval, printed in brown. Cliff drawing brown. The contours are figured occasionally, but generally they are too close for figuring.

Roads practically none. Bridle paths dotted black. Water blue.

A very interesting example of the ability of contours to show the relief of a mountainous and difficult country where there are few names and no roads or other detail to break up the run of the contour lines.

Uganda. 1/250,000.
Sheet $\frac{\text{North A. 36}}{\text{T}}$ (reference number on the new International Map system).

Printed in colour and published by the Geographical Section, General Staff. 1911.

Relief shown by approximate contours at 200 feet vertical interval, with interpolated contours at 100 feet interval long-dotted. Contours drawn exceedingly fine and printed in pale brown. Spot heights very numerous, brown.

Main roads coloured brown. Water blue. Forest by green tree signs. Cultivation yellow. Names very numerous, in black.

Full characteristic sheet. Magnetic meridian.

An unsatisfactory map, the relief of the ground quite illegible, owing to the confusion of the very faint contours with other detail. It should be compared with the map of Basutoland produced in the same year in the same office.

Plate VI.

Geographical Section, General Staff. War Office, 1913

PART OF N.E. SHEET

BASUTOLAND

Scale – $\frac{1}{250,000}$

FORM LINES AT APPROXIMATE 100 FT. V.I.

Plate VII.

Geographical Section, General Staff

War Office, 1913.

PART OF SHEET

PERSIA AND AFGHANISTAN

Scale – $\frac{1}{4{,}055{,}040}$

NEW EDITION 1913.

Persia and Afghanistan. 1/4,055,040.

Published by the Geographical Section, General Staff, War Office. 1906.

Relief by contours and layer system. Contours at 500, 1000, 2000, 4000, 6000, 8000, 10000, 15000, and 20000 feet, printed in brown, not figured. Layer colours in increasing shades of brown, changing at the above contours. No spot heights.

Railways in red, with distinction of gauge.

Roads in red. Water in blue.

Meridians and parallels at 5° interval carried across the sheet.

International boundaries green.

An interesting example of the difficulty of representing the tremendous mountain region of the Indian N.W. Frontier. Even with the great vertical interval of 5000 feet the contours in many places are too close for a clear appreciation of the layer tints.

A new edition of this map is in preparation, which is a great improvement on the old, and has many features of interest. The system of layer tints, green through orange (of a brownish shade) to clear red, is light and clean. There is some hill-shading in greenish ray, and contours are in grey.

We are much indebted to the Chief of the Geographical Section, General Staff, for placing at our disposal the specimen of the new edition given on Plate VII.

Foreign Maps.

Nearly all the countries of Europe are now more or less completely mapped, and the publications of the respective Survey Departments exhibit every variety of style, and of success or comparative failure. In other continents the work of survey is naturally less advanced; but there are now few civilised states which have not realised the importance of an accurate survey of their territories.

Within the limits of this small book it is impossible to do more than make notes on some of the interesting characteristics of a selection of foreign topographical maps. It is hoped that the selection is fairly representative, but it is far from complete, and the specimens chosen for annotation are doubtless not always the best. The author is, however, so convinced of the importance of a study of these foreign maps that he has thought it best to give in all cases the number of the sheet to which these brief notes refer, in order that students may have some guide in purchasing examples of the work of the principal foreign surveys.

Since the object of this study of various examples is to compare the respective merits of different systems, it is inevitable that the question will arise, How do the British maps compare with those of other European countries? The answer appears to be that there are isolated examples of topographical maps, new series of which only a few sheets have appeared, which are in some respects better than British maps: notably the 1/50,000 map of France, and the 1/250,000 map of Bavaria. But on the other hand there is no country which has maps of greater variety and completeness, and of more uniform excellence.

France. 1/50,000.
Sheet XXII. 14. Versailles.

Not dated. Printed in colours by the *Service Géographique de l'Armée.*

Relief: contours and double system of hill-shading. Contours in brown at 10 m. vertical interval, but not figured. Spot heights frequent. Vertical hill-shade in bistre; oblique shade from north-west in purplish grey.

Roads in black, four grades; tracks in black, two grades.

Buildings in red, so that where a road approaches a town and becomes bordered with houses it loses its black outline and becomes less conspicuous. Water blue.

Scale of kilometres. Latitudes and longitudes shown on margin in the ordinary and the centesimal division. Origin of longitudes Paris. Meridians and parallels not carried across the sheet.

Woods, meadows, and gardens in different shades of green; orchards and vineyards in purple, which becomes confused with the grey hill-shading and sometimes destroys its effect.

Population of each village shown in red, but the date of census not shown.

An excellent feature is that the margins are left open, and the principal roads, railways, etc. are continued off the sheet, together with anything which would suffer from being cut across by the sheet margin.

Railways, three grades, narrow gauge, and tramways, all in black.

Writing very plain. Names of water in blue.

Elaborate characteristic sheet, including separate signs for factories operated by steam, water power, and electricity respectively.

The most elaborate topographical map yet produced.

France. 1/200,000.
Sheet 8. Abbeville.

Printed in colour and published by the *Service Géographique de l'Armée.* No date.

Relief shown by contours and vertical hill-shading. Contours at 20 metres vertical interval, very finely drawn, printed in pale brown, and not figured. Hill-shading brown.

Roads and tracks, six grades, in red. Railways in black. Water in blue. Woods in green ; tree signs.

Meridians and parallels carried across map, inclined to margins, figured in centesimal division of the quadrant. Margin divided also in kilometres.

Full characteristic sheet.

The contours drawn so lightly and so much overlaid with names and detail that the relief is illegible.

Bavaria. 1/100,000.
Sheet 637. Landsberg.

Published by the Bavarian General Staff. 1904.

Relief by contours and hachures. Contours at 50 metres vertical interval, printed and figured in brown. Vertical hachures in brown.

Roads in three grades, double and single black.

Water blue. Woods by tree signs in black.

Names of water sloped to left.

Margin shows latitude and longitude (East of Ferro).

Scale of kilometres and "geographical miles": one mile = 7420·44 metres.

The contours drawn so lightly and so much overlaid with detail that relief illegible.

Bavaria. 1/250,000.
Sheet 8. Munich to southern frontier.

Dated 1906. Printed in colours. K. Topograph. Bureau.

Relief by contours, hill-shading, and layers. Contours at 100 m. interval throughout ; contours at boundaries of layer tints strengthened ; all printed in brown ; some intermediate contours in brown long-dotted. Contours not figured, and spot heights infrequent. Hill-shading light grey, oblique, north-west light. Layer colours in spectrum order, leading to very clear red for high mountains. Colours change at 300, 400, 500, 600, 800, 1000, 1200, 1500, 2000, and 2500 m.

Roads in black. Water in blue. Woods not shown.

Scale of kilometres. Latitudes and longitudes on margin. Origin of longitudes not stated ; evidently Ferro. Meridians not carried across sheet.

Trans-frontier country left nearly blank.

Writing : place names italic ; mountain names block ; water names in blue, sloped to left.

No characteristic sheet attached.

The general effect of this map is exceedingly good ; it is perhaps the best example of its kind.

Saxony. 1/25,000.
Sheet 15. Wellerswalde.

Engraved, lithographed, and printed at Leipzig for the Saxon General Staff. 1906.

Relief by contours, in brown, at 5 metre intervals, the intermediate 5's broken, and the 20's strengthened. Also subsidiary dotted contours when required, at variable intervals down to 1 m. Contours not figured, except in the margin, but spot heights numerous, and the contours easy to read on this sheet.

Railways and roads black. Water blue. Woods by tree signs, black.

Elaborate characteristic signs, but no explanation attached.

Margin shows latitudes and longitudes (East of Ferro).

A very well-engraved and clear sheet.

Switzerland. 1/25,000.
Sheet 376. Pilatus.

Dated 1894. Revised to 1906. Printed in colour by the Eidg. Topograph. Bureau.

Relief by contours in brown, at 10 m. vertical interval; every tenth contour long-dotted and figured. The contours are so close that they are very hard to follow. Cliff drawing in black.

Roads in black, of two grades. Tracks in black, long-dotted.

Scale of kilometres, and map divided into squares of approximately 6 cm.

Latitudes and longitudes shown on margin. Origin of longitudes not stated, apparently Paris.

Meridians and parallels not carried across the sheet.

Woods shown by very minute tree signs in black, making the pale brown contours still more difficult to read. Water blue.

Writing in italic; no distinction between physical features and village names.

No characteristic sheet attached.

Switzerland. 1/100,000.
Sheet XVIII. Rhone Valley and Simplon.

Dated 1854, revised to 1907. Engraved, and printed in black.

Relief shown by hachures, darkened on the side away from a north-west oblique light. Good cliff drawing. Glaciers only contoured. Spot heights in metres, small and rather illegible.

Trans-frontier country shown in full.

Roads double black lines, white between, showing up well on the dark hachures.

Tracks long-dotted, not very distinct.

Scale of kilometres and hours. (One hour equals 4·8 km.)

Latitudes and longitudes shown on margin in the ordinary and also in the centesimal system. Origin of longitudes not stated. Meridians not carried across the sheet.

No characteristic sheet attached.

Switzerland. 1/250,000.
Special railway map.

Published by the Swiss Topographical Bureau, Bern. 1908.

The ordinary engraved and hachured map is printed in brown. Railways with names of stations are heavily overprinted in black.

An excellent example of the map for special purposes.

Italy. 1/100,000.
Sheet 32. Como.

Dated 1907. Printed in colour at the *Istituto Geografica Militare.*

Relief: contours and hill-shading. Contours in light brown, at 50 m. vertical interval. Hill-shade oblique, north-west light, brown. Frequent spot heights. Roads in black. Three grades metalled, two grades unmetalled, and various kinds of tracks distinguished. Railways, double and single, tramways narrow gauge and tramways distinguished. Water blue. Houses black. Woods not shown.

Scale of kilometres.

Latitudes and longitudes on margin. Origin of longitudes: Rome, Monte Mario.

Meridians and parallels not carried across the sheet.

Mountain names in engrossing. Water names in black.

Good characteristic sheet attached.

Italy. 1/200,000.
Sheet 11. Brescia.

Dated 1908. Printed in colour, by the *Istituto Geografica Militare.*

Relief by contours and hill-shading. Contours at 100 m. vertical interval. Hill-shade in grey brown, oblique.

First and second grade roads in red; third grade, black in the plains and red on the mountains. Minor roads made and unmade, muletracks, footpaths easy and difficult, and mountain passes all distinguished by characteristic signs. Railways black. Water blue. Towns by signs to indicate degree of importance. Double, single, narrow gauge, and tramways of various kinds, all distinguished by signs. Woods pale green.

Scale of kilometres.

Latitudes and longitudes shown on margin. Origin of longitude: Rome, Monte Mario. Meridians and parallels not carried across sheet.

International frontier with broad band of colour. Trans-frontier country in full detail.

Mountain names in engrossing, difficult to read.

Good characteristic sheet attached.

Central Europe. Austrian General Staff Map. 1/200,000.
Sheet 41° 41°. Saloniki.

Dated 1903, revised to 1909. Printed in colour.

Relief by hill-shading and contours. Hill-shade vertical, pale brown. Contours darker brown, at 100 m. interval.

Roads in black, two grades; and tracks long-dotted. Railways black. Water blue, but not the names of water. Woods shown by pale wash of green.

Latitudes and longitudes on margin. Origin of longitudes: Ferro. Meridians and parallels not carried across sheet. Sheet not bounded by meridians and parallels.

Scale of kilometres and schritte. (1000 schritte = 0·75 km.)

Mountain names in engrossing.

No adequate characteristic sheet attached.

A very ugly map.

Central Europe. Austrian General Staff Map. 1/750,000.
Sheet 8. Skoplje.

Dated 1900. Printed in colours.

Relief by contours and layers. No hachures or hill-shading. Contours at 150, 300, 500, 700 and thence at 300 m. intervals; layer tints in ascending shades of brown, rather heavy. Contours in darker brown are the boundaries of the layers; no intermediate contours. "Thalsohlen und Thalebenen," apparently plains in the bottoms of valleys, in two shades of greenish blue.

Roads of two principal grades in red; third grade in black; tracks in black, long-dotted. Railways in black. Water, including names of water, in blue.

Scale of kilometres.

Latitudes and longitudes on margin. Origin of longitudes: Ferro. Meridians and parallels drawn across sheet.

Woods not shown. Mountain names in engrossing.

No characteristic sheet.

Austria-Hungary. School district maps. 1/100,000.
Sheet Deutsch-Lansberg.

Dated 1910. Printed in colours by Freytag and Berndt, Vienna.

Relief by contours, oblique hill-shading, and layers. Contours in brown at 50 m. vertical interval. Hill-shading in grey, by north-west light. Layer tints in pale green, yellow, orange, and red. Contours at 1000 and 2000 m. long-dotted. Colour changes at 400, 500, 700, and 1500 metres. Difference of tints so slight, and so much obscured by hill-shading, that practically only the change at 500 from green to yellow is of much account.

Roads in black, two grades; no tracks shown. Railways in black. Water blue.

Scale of kilometres. Section across the country.

Woods not shown.

Latitudes and longitudes on margin. Origin of longitudes: Greenwich. Meridians and parallels not carried across the sheet.

Writing: no distinction between place-names and physical features.

Characteristic sheet attached.

Price 50 heller (about 5*d.*). Very good maps for the price.

Greece. 1/75,000.
Sheet 40° 1° E. ΡΑΨΑΝΗ-ΤΕΜΠΗ.

Dated 1909. Printed in colours by the K. K. Geog. Inst., Vienna.

Relief by vertical grey shading. Contours at 20 m. darker grey; 100 m. contours strengthened; occasional intermediate 10 m. contours long-dotted. Sea bottom contoured, at 2, 5, 10, and by tens to 60 m. Cliff drawing brown.

Principal features across frontier shown, with 100 m. contours and hill-shade.

Roads red, in three or more grades. Tracks in red. Water blue. Woods black, with tree signs.

Scale of kilometres and Bemata (paces). Scales of slopes corresponding to contour intervals (this an unusual feature).

Latitudes and longitudes on margin. Origin of longitudes: Athens, with reduction to Greenwich. Meridians not carried across sheet.

Writing in modern Greek character. Mountain names engrossing.

Complete and elaborate characteristic sheet attached.

Sweden. 1/200,000.
Sheet 58. Kolasen.

Date 1905. Printed in black and slight colour.

Relief by hachures below about 550 metres and contours above; both black. Hachures vertical; contours shaded to bring up relief, apparently arbitrarily. Contours not figured, and spot heights insufficient to show contour interval. Combination of hachures and contours in this way unusual.

Principal roads double black line, yellow between. Lakes blue. Rivers black.

Scale of kilometres.

Latitudes and longitudes on margin. Origin of longitudes: Stockholm, with reduction to Greenwich. Meridians but not parallels carried across sheet.

Woods not shown very clearly; small black tree signs on the hachures hardly distinguishable.

Trans-frontier country left entirely blank.

Writing: no distinction between hill names and villages; names of lakes sloped to the left.

No characteristic sheet attached.

Sweden. 1/500,000.
Sheet 11.

Date 1896. Printed in colour by the Swedish General Staff.

Relief by contours and layers. Contours at 100 metres vertical interval, in brown, with intermediate contours at 33 and 66 metres up to 500 metres. Layers changing tint at each 100 metres, in shades of yellow, brown, bluish grey, to white. Colour scale ascending, then descending. No hachures or hill-shading.

Latitudes and longitudes shown on the margin. Origin of longitudes: Stockholm. Meridians and parallels carried across the sheet. Edges of sheet not meridians but much inclined.

Lakes blue; rivers black. No roads on this sheet. Woods not shown.

Trans-frontier country left entirely blank.

Writing all in black. River and lake names in character sloping to left.

Mountains in separate character, but not engrossing.

Scale of kilometres. No characteristic sheet attached.

United States. 1/62,500.
Glens Falls Sheet.

Published by the United States Geological Survey. 1906.

Relief by contours, printed in brown at vertical interval 20 feet; every fifth strengthened, and every fifth or tenth figured. Occasional spot heights in brown.

Roads and railways black. Water blue.

Meridians and parallels carried across sheet. Longitudes from Greenwich.

The representation of the relief by contours very successful, depending largely on absence of names and other detail.

Full explanation and conventional signs on back of sheet.

The International Map on the scale of 1/1,000,000.

At the international Geographical Congress which assembled at Berne in 1891 it was proposed by Professor Penck, then of Vienna, and now of Berlin, that steps should be taken to urge the publication of a map of the whole World on the scale of one in a million, with sheets uniform in size and shape, systematically arranged, and drawn in uniform style. Such a series of maps would clearly help the comparative study of different regions of the World.

At the next meeting of the Congress, held in London in 1895, the proposal was discussed in detail, a number of resolutions were voted, and schemes for the division of the sheets and the methods of construction were adopted. Two preliminary difficulties had to be overcome. The choice of the initial meridian had to be made; and some means had to be found of reconciling the differences between metric and non-metric countries.

As to the former, there could be little real difference of opinion, for the maps and charts whose longitudes are referred to the Greenwich meridian were greater in number than those referred to all other meridians together. The question of a unit of length was nearly unessential, because it would be easy to draw on the margin of the map scales expressed in as many units of length as might be desired. But the question whether heights should be expressed uniformly in metres was difficult, because the British delegates at that time refused to have anything to do with the metric system on British sheets. Eventually it was agreed to adopt the meridian of Greenwich as the prime meridian, and the other question was left undecided.

For thirteen years little was heard of the scheme. The resolutions of the Congress bound no one; and though several countries undertook the publication of maps on that scale, they did so independently and in different styles. This delay was useful in that it allowed the accumulation of experience in the use of this scale, which is intermediate between the scales ordinarily used for topographical maps and for atlas maps. And systems which give excellent results on one scale very often fail altogether on another.

At last the question of the International Map was revived at the Congress held in 1908 at Geneva. More resolutions were voted, and there seemed every likelihood that they would remain as inoperative as those that had gone before, for the Congress that voted them was not in the position to undertake itself the construction of the map, and in default of an official agreement between the Governments interested, very little could be expected. At this point the British Government resolved to take the steps necessary to put the project on an official basis, and issued invitations to the principal Governments of the World, to send delegates to a committee, which should discuss the question and make definite recommendations. This committee met in London on November 19, 1909, and speedily arrived unanimously at an agreement which was ratified by all the Governments concerned. The official report of the proceedings was published in February, 1910; the following is a short summary of the decisions.

1. A uniform set of symbols and conventional signs was adopted, and a characteristic sheet prepared.

2. Each sheet covers an area 4 degrees in latitude by 6 degrees in longitude; but nearer the poles than latitude 60°, two or more sheets of the same zone may be joined. The limiting meridians are reckoned from Greenwich, and the limiting parallels from the equator.

3. The sheets are numbered according to a diagram attached to the Report on a plan which is somewhat complicated. Each sheet has a number, such as

North K. 35.

The letter K signifies the zone of latitude 40° to 44°, the eleventh zone from the equator, as K is the eleventh letter of the alphabet. The number 35 signifies the 35th lune of longitude, each of six degrees, reckoned eastward from the meridian opposite that of Greenwich. Thus a short calculation leads to the result that sheet North K. 35 is the sheet covering Latitude N. 40° to 44° and Longitude E. 24° to 30°. The merits of this system of numbering are not obvious.

Each sheet must also bear the geographical coordinates, that is to say, the latitude and longitude of its central point; and there seems to be no reason why these numbers should not have been used as the sheet numbers.

4. The projection is a slightly modified form of the polyconic projection proposed by one of the French delegates, M. Lallemand. It has all the properties necessary for such a map; that neighbouring sheets shall fit along their edges; that the representation of distances and bearings within the sheet shall be sensibly perfect; and that it shall be constructed with ease.

The upper and lower parallels are constructed as in the ordinary polyconic projection, but they are brought slightly closer together, so that the meridians 2° from the centre are their true lengths, instead of the central meridian; and the meridians are drawn as straight lines instead of being slightly curved. These refinements on the ordinary polyconic projection are practically not detectable on the printed sheet, but are theoretically elegant. The tables necessary for the construction of the sheets are given in the Report; they occupy only two pages.

5. Contours are drawn at vertical intervals of 100 metres, "but in very hilly districts the contours may be at larger vertical intervals, provided that they are spaced at 200, 500, or 1000 metre intervals." The map is coloured on the layer system, according to a scheme attached to the Report, following the spectrum order of colours, except that an ugly shade of magenta is used instead of red.

The tints are changed at the contours given in the following scheme:

From sea level at every 100 metres to 600;
thence at intervals of 200 metres to 1200;
thence by two steps of 400 metres to 2000;
thence by two steps of 500 metres to 3000;
thence by steps of 1000 metres to 7000.

It is not made clear whether the contours should be shown uniformly at intervals of 100 metres, irrespective of the changes of tint; but it may be noticed that steps of 400 metres are specified in the colour scheme, whereas they are excluded in the specification for the contours which immediately precedes.

6. Minor features of importance, which would not be shown by the contouring, may be represented by shading, but not by hachuring; and the method of lighting which is most effective for the district may be selected.

Thus there is liberty in hill-shading, but not in contouring.

7. Precise rules are laid down for the spelling and transliteration of place-names. The basis of these rules is that the spelling of every place-name in an independent country or self-governing dominion shall be that adopted by the country or dominion. This is of great importance, since it abolishes the customary corruptions of place-names as used by foreigners in such countries as Turkey.

8. Water features and glaciers are in blue; contours in brown, for the land, and in blue for the sea bottom; roads are in red, and railways in black.

9. Heights above mean sea level are in metres, mean sea level being deduced in each country from tidal observations on its own coasts.

These are the principal resolutions in the Report of the International Map Committee. How far they can be put into practice uniformly cannot be predicted. The few sheets which have appeared at the time of writing have already shown some not unimportant deviations from the strict letter of the scheme, which are noted in the brief analyses which follow. Doubtless there are excellent reasons for each departure from the strict rule. Nevertheless it seems to the writer that it would have been better to make the first few sheets in strict conformity with the resolutions of the Committee, because it would then have been easier to see how far it is necessary to give greater latitude in the application of these rules.

The International Map was necessarily an experiment, because the Committee which drew up the Convention for its execution had not before it any example of a map on that scale elaborately printed in colour; none had been produced at that time. This being so, we are not bound to consider the existing scheme as fixed for better or worse, and it is legitimate to discuss what improvements are possible.

But let us first note any special points in the sheets already published.

International Map. 1/1,000,000.
Sheet North O. 30. Scotland. The Highlands.

Published by the Ordnance Survey. 1912.

The following variations from the Conventional signs sheet may be noticed.

Above 200 metres the contour interval is 200, instead of 100. This deranges the layer tints, whereby one tint of green and both of yellow are lost.

No hill paths are shown.

The coast line is drawn as a sea-contour (blue) instead of as a land-contour (brown). This gives a weak effect to the islands.

In spite of the increased vertical interval the contours in the mountains come so close together that the layer system loses effect.

International Map. 1/1,000,000.
Sheet North M. 31. Paris.

Published by the *Service Géographique de l'Armée.* 1911.

Although the country is generally of slight elevation, only the 100 metre contours are shown, and the representation of relief is therefore very inadequate.

The colours do not follow the adopted scale very closely, and in particular the blue is bad.

The compilation of the part of Holland shown has mistakes in spelling, and the main stream of the Rhine through Dordrecht and Rotterdam is not shown as navigable. Hook of Holland, Flushing, Queenborough, and Newhaven are not shown as ports with regular mail service.

International Map. 1/1,000,000.
Sheet North K. 35. Istambul. (See Plate VI.)

Printed and published by the Geographical Section, General Staff. 1912.

The following variations from the Conventional signs sheet may be noted:

The lower contours are at intervals of 200 metres.

This disarranges the layer tints. Green goes to 400 instead of 300, and there is only one tint of yellow.

The blue of the sea below the 200 metre contour is very intense, and this gives a weak appearance to the coast line, which might perhaps have been avoided if the coast line had been drawn in brown as a land contour.

The names—which are the real names of the places, and not the conventional Anglicized forms—make a very interesting study, and there is a valuable glossary of pronunciation of Bulgarian, Rumanian, and Turkish.

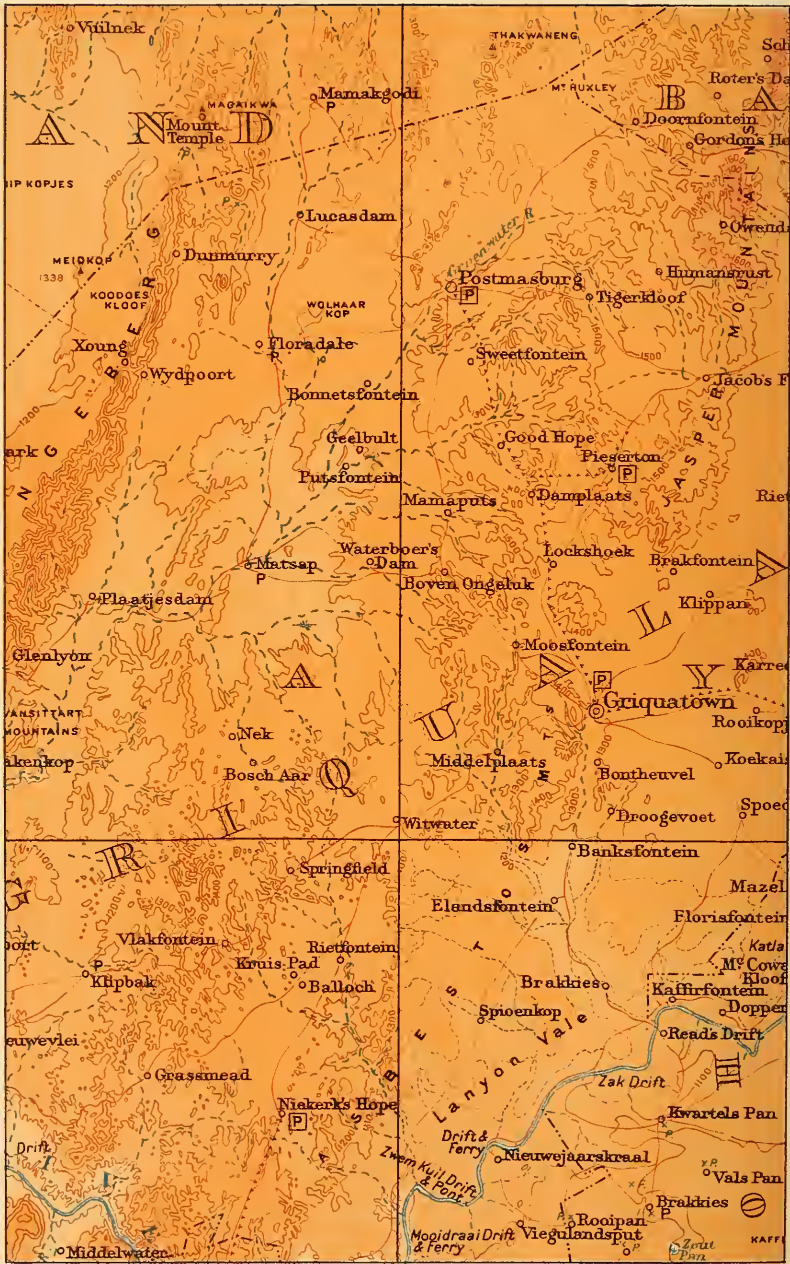
This sheet is a beautiful example of the merits of the style of lettering adopted for the International Map.

INTERNATIONAL MAP OF THE WORLD

Scale – $\frac{1}{1,000,000}$

PART OF SHEET "NORTH K 35 ISTAMBUL"

Plate IX.



INTERNATIONAL MAP OF THE WORLD

Scale – $\frac{1}{1,000,000}$

PART OF SHEET "SOUTH H 34 KENHARDT"

International Map. 1/1,000,000.
Sheet South H. 34. Kenhardt, Cape Colony. (See Plate VI.)

Printed and published by the Geographical Section, General Staff. 1911.

This sheet follows very closely the Conventional signs sheet of the International Committee.

Contours are shown at uniform intervals of 100 metres, but are not carried across the frontier into German South-West Africa.

The ground rises steeply from the sea to 1000 metres, and the greater part of the sheet is heavily coloured brown. A good example of the failure of the layer system on high plateaux.

The impression to be derived from a study of these first sheets is, that in most respects they are very successful, but that in the most important of all, the representation of relief, they are not entirely satisfactory.

The style of the lettering serves admirably to distinguish between features of different kinds by differences in the character of the letters. Physical features are perfectly distinguished from names of towns, and both are equally legible. The systematic transliteration of the place-names, and the glossaries of pronunciation of the Slavonic names, are features of great value. The indication of the population of a town by its characteristic sign is good, and so is the retention of the real name of the town in place of the name by which it is habitually known in other countries.

The hard and fast rules for the boundaries of the sheets work badly in Scotland, where the six degrees of longitude assigned as the width of the sheet are diminished by the convergence of the meridians so that the sheet is nearly half as tall again as it is broad. It would have been more convenient to extend the sheet westward to include the Hebrides, which by the rule must be shown on the eastern edge of a separate sheet. North of latitude 60° the sheets are doubled in width, so that the Shetlands will have to themselves a sheet nearly double the width of the Scotch and English sheets.

The result of the first application of the layer system to the scale of one in a million is not encouraging. The wide vertical interval of the contours on the lower ground—100 metres—is too coarse for the effective representation of the lower land; while the small horizontal distance between the contours in the more mountainous country, due to the small scale of the map, makes the interlacing of the layer tints too complex for a clean result. The mingling of very narrow strips of various tints produces only a quiet ineffectual colour, in the same way that brilliant coloured threads are blended into a tweed of the most unobtrusive kind. A strip of layer tint must be at least five millimetres broad if it is to have size enough to develop its effect; but this principle was not recognised when it was resolved to construct the International Map upon the layer system.

It is understood that the Ordnance Survey will publish an edition of the British 1/1,000,000 sheets without the layer colours. That will give an occasion to try whether there is not a simpler plan of achieving the desired effect. It appears to the author that on maps of the small scale of one in a million it would be possible to obtain all the effect of relief required in mountainous regions by printing the simple contours in colours chosen after the plan of the layer system of tints. But it must be confessed that no one in command of a map office, and in the position to make a trial of this notion, has ever shown much inclination to adopt it.

Aero maps.

The rapid advance of flying two years ago produced a sudden demand for maps of a new kind, in which some attempt should be made to depict the country as it appears from above, and especially to emphasize the objects which serve as leading marks to the pilot in charge of the aircraft. Experimental maps were produced by the General Staffs of Great Britain and of France, by the Aéro-Club de France, and by the promoters of the great flying "circuits" which had a brief success.

At the meeting of the British Association held at Portsmouth in 1911 there was an interesting discussion on aero maps, and strong divergences of opinion were manifested. The military flying men were not pleased with the special maps, and declared that the ordinary half inch or quarter inch maps, though not perfect, were better than any others. The civilians complained that they needed something more simple and easy to read than the Survey maps. But it was pointed out that the only competitor in the Circuit of Britain who never lost his way was the French naval officer who flew over ground with which he was quite unacquainted by the aid of the quarter inch map; and that all who relied upon the route maps specially prepared for them had come to grief.

The special maps prepared by the General Staffs showed the roads white, as it was imagined that they would look from above. But just at that time the main roads were extensively tarred, and thus they lost their whiteness, and became less conspicuous from above than the secondary roads. Moreover, it was found that the appearance of the ground below changed so greatly with the change of light that the attempt to imitate it to some extent is doomed to failure.

If special maps are to be made in the future, it seems likely that the most useful modification will be to accentuate the characteristic shapes of road junctions and crossings. On the ordinary maps these are generally masked by the exaggerated conventional width of the road. But it should not be difficult to exaggerate also the special shape of the crossing which is often perfectly characteristic, and thus to make use of the natural signs which much exceed in size and distinctness any that could be erected for the special purpose of acting as guides to flying.

The whole subject is hardly as yet in the experimental stage, however, and the information gathered in the manœuvres of 1912 is not at present available.

The following notes on the special maps issued in 1911 may be of interest.

England. Aero map of the 1911 Manœuvre Area. 1/253,440.
East Anglia.

Printed at the War Office. 1911. In colour.

General groundwork of the sheet greenish grey.

Coarse vertical hill-shading. Spot heights in feet.

Roads in white; two grades. Water blue. Towns red.

Woods in green. Parks in very pale green. Churches with spires (but not those with towers), windmills, and isolated trees in black.

Railways in very heavy double or single black.

It is believed that this map was not considered a success by the military aviators.

France. Carte Aéronautique. 1/200,000.
Sheet: Chalons.

Printed in colour and published by the *Service Géographique de l'Armée.* Paris. [1911.]

The ground of the map is grey. Relief is shown by vertical hill-shading in brown. Spot heights.

Woods in uniform tint of bright green. Water blue.

Roads are white between black lines. Villages in red.

Railways in black, three grades.

Ground dangerous for landing hatched in red.

Special characteristic signs for hangars, landing grounds, and hydrogen depots; cathedrals, chateaux, factory chimneys; high tension electric cables, etc.

An interesting example of special map, rather heavy and dull in colour.

Carte de l'Aéro-Club de France. 1/200,000.
Sheet 93. Laon.

Printed in colour and published by Ed. Blondel la Rougery. Paris. No date.

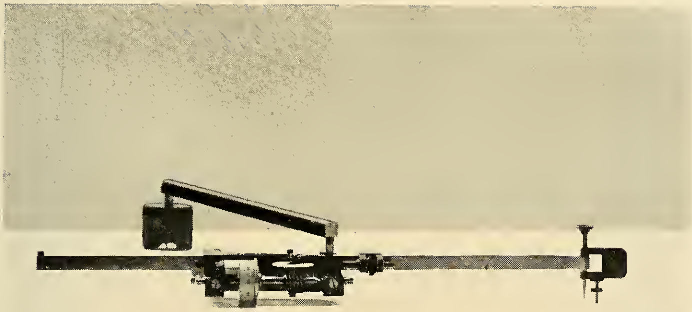
Relief by rough grey vertical hill-shading. Spot heights, summits distinguished.

Railways black, grades distinguished. Roads double black line, principal roads filled red.

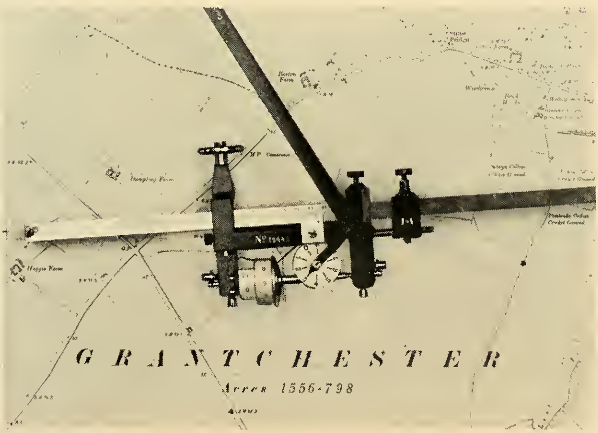
Water blue. Woods plain green tint.

A large variety of special characteristic signs, of importance to aviators: aerodromes, landing grounds, hangars, hydrogen factories, gas works, etc. Sketches of the principal buildings in the margin.

A crudely executed but interesting attempt to provide the special information required by aircraft.



1. The Amsler Planimeter.



2. Central parts of planimeter (from above).

CHAPTER III

ROUTE TRAVERSING

The Explorer's Route Map

The object of the Route Map.

The first care of a traveller who passes through an unknown, or but partially explored, country is to make a record of where he has been, and of the main features of the country along the route by which he has travelled. Often singlehanded, encumbered by transport, compelled to keep to the track, and unable to leave his party, he cannot hope to make anything in the nature of a map, in the ordinary sense of the term. But for his own guidance, to avoid getting lost, he is compelled to determine his position day by day in much the same way that the position of a ship is determined at sea, by observation of the Sun and the stars, so that he is able to say roughly in what latitude, and perhaps in what longitude his halting places were. Moreover, as he goes along he is able to make such observations of the shape and course of his path as to enable another man coming after him not only to arrive more or less at the same place, but to follow the same route. And finally, he can keep a sort of running record of the things that lie immediately to the side of his path. All this he does by the construction of a "route traverse" or "route map."

It is essentially the work of the pioneer, whose main business is to get through the country, and who can afford to give to mapping and survey only a small part of his attention, and no voice in the determination of his plans. Such is the first exploratory survey of a country. Route traverses were run across Africa by the explorers of last century, and the published accounts of their travels contain maps of vacancy traversed by thin red lines, the results of these route surveys. These travellers opened up the country, and they made determinations of the latitudes and longitudes of a great number of places, which got on to the maps, but which necessarily were often wrong. A great deal of trouble has been caused by these errors, owing to the ignorance on the part of diplomatists and officials generally of the unavoidable roughness of preliminary maps not based upon regular survey. It is essential that the sources of information should be stated on the margin of all maps pretending to show detail.

The astronomical observations.

These differ very little in kind from those used in much more elaborate work, and we may defer a detailed consideration of them, confining ourselves for the moment to an examination of the general principles, which are common to voyages on sea and on land.

Latitude, the distance north or south of the equator, is found by the observation of the altitude of a heavenly body as it crosses the meridian: the Sun about noon, or stars at their meridian passages during the night.

Longitude, the angle between the meridian of the observer and the standard meridian, generally that of Greenwich, is measured by the difference of times of the two meridians. The local time is determined by observation of a heavenly body as nearly due east or west as possible: the Sun in the early morning or late afternoon, or stars at the appropriate time of night. The Greenwich time is carried by chronometer or watch. (For simplicity we exclude for the moment the alternatives of finding the Greenwich time by observation, or of receiving it by telegraph cable or wireless.)

Azimuth, or true bearing, required for the correction of the compass, is determined with the local time.

At sea the ordinary mariner works almost entirely by the Sun, and the observation which is familiar to all passengers is the noon altitude of the Sun, which gives the latitude. It is a very common mistake to suppose that this observation gives the instant of noon. This is not so; the observation which gives local time is made somewhat early in the morning or late in the afternoon. Thus latitude and longitude are determined at different times. But meanwhile the ship is under way, and it is necessary to have some method of carrying forward the morning longitude to the latitude at noon, or of carrying forward the noon latitude to the afternoon longitude. This is done by keeping the "dead reckoning" of the ship's course. A continuous record of the course and of the speed of the vessel on that course is kept in the log (the journal of the voyage, not the instrument of the same name by which the speed is measured). The dead reckoning enables the navigator to make the required allowance for the run of the ship between the successive observations, and to carry on during cloudy weather.

The traveller on land works in very much the same way. There are obvious reasons why it may be necessary to avoid as far as possible observation of the stars by night: mosquitoes and the risk of fever are sufficient. In the ordinary course of things he will rely largely on observations of the Sun, though star work is more accurate. But the requisite observations of the Sun must be made, as we have seen, at widely different times of day, and the traveller cannot as a rule afford to wait for a great part of a day at every place whose position he wishes to fix. He is therefore compelled by the nature of the case to use some means of keeping account of what the sailor calls his "dead reckoning," that is to say, of keeping a current account of his position, carried on from one place to another by observation of the course he is steering and the rate at which he is travelling. He makes, in fact, what is called on land a "compass traverse."

In modern practice the navigator does not confine himself to the old routine of the noon altitude for latitude and the morning or evening sight for time and longitude, but in doubtful weather he gets an observation whenever he can. An altitude of sun or star, at a known standard time by chronometer, fixes a small circle of the sphere on which the observer must be at the moment of the observation; and a portion of the circle sufficient to cover the range of possible positions can be laid down as sensibly a straight line on the chart. A subsequent observation made on a different bearing defines another small circle, which intersects the first at the position of the observer. Intelligently used this method is of wide generality, and has the great merit of giving its full weight to any observation made at any time, while avoiding the often troublesome necessity of stopping to make the observations at closely defined instants. It does not appear that the method has been employed on land, but it is equally applicable there for at any rate the rougher determinations of position with a small theodolite or sextant. Within a few degrees of the pole the application of the method becomes of remarkable simplicity. See, for example, a paper by the author in the *Geographical Journal*, March 1910.

The compass traverse.

A traverse is defined as a connected series of straight lines on the Earth's surface, of which the lengths and the bearings are determined. In a compass traverse the bearings are determined with the prismatic compass, which differs from an ordinary pocket compass in two principal respects: it is fitted with sights which can be directed upon a distant object; and with a prism which brings into view at the same time the scale of degrees marked round the edge of the compass card. The bearings are invariably reckoned in degrees from 0° right round to 360°, from magnetic north through east. The complicated system of "points," now becoming obsolete at sea, is never to be used on land.

Selecting the most distant conspicuously recognisable point upon the line of march, the traveller observes and records its bearing, and proceeds to determine, as accurately as circumstances will allow, the distance he has travelled by the time he arrives at it, or the length of the "leg." Accurate measurement is of course inconsistent with rapid travel. A short distance can be paced, but it is not possible to count paces all day for days at a time. The legs of a traverse are therefore generally measured by cyclometer or "perambulator," or merely estimated by time.

Distances by cyclometer or perambulator.

The perambulator consists of a wheel of known circumference, frequently ten feet, mounted in a fork with a handle, very much like the common child's toy, and fitted with a counting mechanism to record the number of turns which the wheel has made. If a man can be spared from the caravan to trundle this instrument—an easy duty which fills the native carrier with pride—it is simple to record the length of each leg of the traverse in terms of the number of revolutions; but it is hard to tell how much to deduct for the windings of the path and the inequalities of the ground.

The sledge-meter used by Sir Ernest Shackleton and Captain Amundsen on their South Polar journeys was a "perambulator" wheel carried out on a light spar behind the sledge. Its indications were in general remarkably accurate.

The ordinary cyclometer registers only eighths or tenths of a mile, and is too coarse; a more refined instrument of the kind would sometimes be useful. But it is easy to calibrate any bicycle so as to know the value of a revolution of the front wheel.

Distances by time.

The apparent advantages of the perambulator method of measuring distances are in practice much discounted by the difficulty of knowing what allowances to make for the windings of the path. An experienced traveller will obtain results which are pretty well as good, without being obliged to spare a man for the work, by the simple process of timing each leg of the traverse, and estimating the rate of march. The average rate of a party on fairly level and unobstructed ground is found to vary very little. Practice will enable the traveller to make allowance for change of rate over rough or hilly country. The most common error is a persistent over estimation or under estimation of the rate; and we shall see later how it is possible to keep a check on systematic errors of this kind. The most serious difficulty is common to all methods of route traverse—that of keeping the average direction and estimating how fast one is really covering the ground, when marching along a winding track through thick bush.

Details on the flanks.

If the country through which the traveller is marching is fairly clear he can fix roughly the positions of its principal features as he goes along by the method of cross bearings. The compass bearings of prominent peaks and other easily recognisable objects are taken from different points, and the intersections of these lines of bearing, when plotted at the end of the march, give positions of the objects in question with a degree of accuracy comparable with the general accuracy of the traverse.

At the same time the bearings of all cross tracks and streams are taken at the points where they meet the line of march; the character of the ground is recorded at intervals, with any other information which can be obtained readily.

Check by cross bearings.

A similar process can be used for the opposite purpose, of checking the accuracy of the traverse by bearings of a distant object whose position is known. For example, in traversing round about Ruwenzori occasional bearings of the peak will serve as a check on the traverse, and lay down its position on the ground. A like method is much used at sea for fixing the position of the ship when a known object is in sight, such as the Peak of Teneriffe, visible sometimes at a distance of 100 miles.

The field book.

The method of recording a traverse is best shown by a page of the field book, which is kept by well recognised rules.

The essential is that it begins at the bottom of what would ordinarily be the last page of the book, and goes upwards and backwards to the beginning. The columns up the centre contain the time of each observation, the bearing of each leg, and the estimated rate of progress on that leg, or the number of turns made by the perambulator wheel. Detail to the right or left flank is recorded in the right or left margin, and it is important to note that the page becomes a kind of diagrammatic representation of the country traversed, of which the central columns represent a line, the line of march. Hence if a straight stream or track crosses the route obliquely, the portions represented on each flank must not be drawn as parts of one straight line, but in the manner shown in the example below. A similar convention will be found later in the methods of keeping field books for other kinds of survey.

Village W

	Time	Compass Bearing	Rate M.P.H.	
Peak A 127°	11.14			
			3	
	10.52	198		
			$2\frac{3}{4}$	
	10.41			
	10.34	220		Shallow stream 10 ft. wide
			3	
Halt at Z. Shade trees and good water	10.7	234		
	8.52			
			3	
	8.40	202		
			$2\frac{1}{2}$	
	8.22	219		Track to Y 308°
			$2\frac{3}{4}$	
	8.5	223		
			$2\frac{3}{4}$	
	7.57	246		
			3	
Snow peak A 146°	7.46	214		Cultivation

Leave Camp at Village X

Specimen field book.

The compass.

For instrumental details as to the care and use of the compass, see page 102. We shall deal here with the particular points which are special to compass traversing.

It is usually essential that the march of the party shall not be interrupted while the observations are made, and it is generally undesirable that the observer should have to run in order to catch up with the party after the observation. If he is on foot he will try to walk on ahead to the point of observation ; if he is mounted he can afford to spend more time, perhaps to dismount and set up the compass on a tripod, which much improves the accuracy of the observation. It is clearly impossible to prescribe any exact rule or programme. Two points are to be remembered: the rate of march which is recorded is that of the main party, which keeps on steadily, and it is therefore unnecessary for the observer to take account in his time records of the short intervals during which he himself is halted to make the observations. And secondly, the whole operation is a rough and ready affair; he must therefore be careful not to

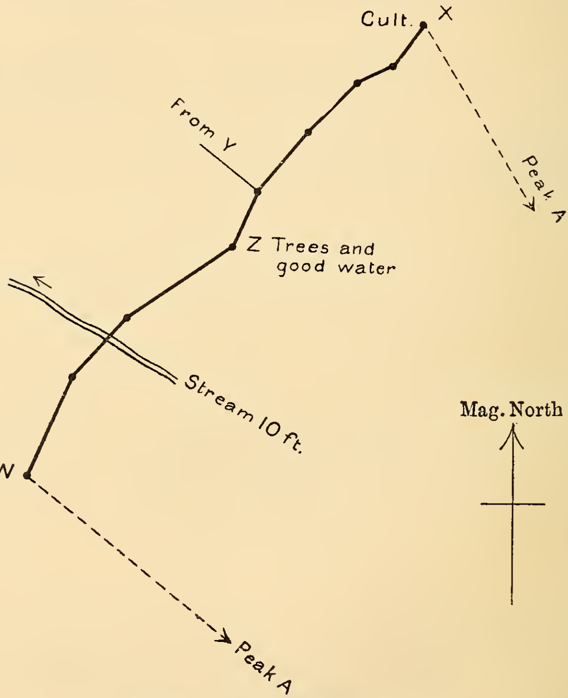


Fig. 4. Plot of compass traverse.

waste time in trying to record minute details which have no real importance; small deviations of the track will be ignored so long as the general direction is preserved, and it is not necessary to take a careful bearing of a cross track which disappears round a corner in a few yards.

In thick bush, where the direction of the path changes every few yards, or on the march in a hostile country, when it is impossible to leave the column of march even for a moment, it is possible to do a good deal simply by watching the average position of the compass card as it is held in the hand while marching, and recording the bearing every five minutes.

The check by astronomical observations.

Even under the most favourable circumstances the error in the recorded length of a route traverse will often be ten per cent.; and in a country where the rocks are magnetic, and the compass consequently unreliable, the bearings may be affected by large errors. It is therefore very important to lose no opportunity of checking the traverse by astronomical methods. Particularly on long journeys, extending over months, it would be folly to rely on the compass traverse only, just as it is dangerous to rely for many days on the dead reckoning at sea.

We may sum up the possibilities of astronomical determination as follows:

Latitude. Observation of latitude, either by the Sun or the stars, is easy, and there is no difficulty at all in getting latitude within a mile by sextant, or within a small fraction of a mile by micrometer theodolite.

Longitude. Observations to find local time are easy, though the calculations are a little long. But the longitude is the difference between local time and Greenwich time, and the practical impossibility of getting longitudes right within a number of miles while upon the march is due to the difficulty of carrying or obtaining Greenwich time. To carry Greenwich time means to carry such a number of chronometers, or better, of half chronometer watches, that the mean of their indications, corrected for their rates so far as known, is right within a small number of seconds. A difference of four seconds of time is equivalent at the Equator to a difference of one geographical mile.

The cost of the chronometers, the anxiety of their care and transport, and the little reliance that can be placed upon their rates when they are exposed to jolting and great changes of temperature, make their employment practically impossible.

Watches carried carefully in the pocket are a little more satisfactory, but cannot be trusted absolutely for long.

Greenwich time. Occultations.

To find Greenwich time by observation on some other meridian, as distinct from carrying it with one, requires the observation of the occultations of stars by the Moon. This involves, firstly, half an hour's drawing and computation, to predict approximately the circumstances of the occultation at the place; for without such a prediction it is impossible to make the observations successfully, or even to know whether there will be anything to observe. Secondly, there is the observation of the phenomenon with a fairly large telescope, of say three inches aperture and three feet long—a telescope which is rather large and cumbrous to carry. Third, if the observation is successful, there is a long computation afterwards, to deduce rigorously the Greenwich mean time of the occurrence. And finally, a comparison between the calculated time and the time recorded by the chronometer at the moment of the occultation, gives the quantity we seek, the error of the chronometer on Greenwich mean time. It will be believed readily that the comparative infrequence of occultations observable, the labour involved in the prediction and observation, and the length of the subsequent calculations, make this method of limited use to the traveller.

Under special circumstances, however, the method of occultations may still prove of value. Whenever a skilled and enthusiastic observer finds himself compelled to spend a considerable time in a place of which the longitude is badly known he will find it worth his while to predict and observe some occultations. Such cases might be, for example, the stay of a scientific expedition on an island; or a polar expedition in winter quarters; or a missionary or consul at some out of the way station in China. But wherever the telegraph or wireless is within reach the method of occultations is superseded.

Lunar distances.

An alternative method of finding Greenwich mean time is by the observation of lunar distances, in the way which used to be practised at sea before the vibration of fast steamships made accurate observation impossible. This method requires a sextant, whereas for every other observation the traveller will do better with a small theodolite; it can be practised whenever the Moon is visible with a bright star or planet, and to that extent is superior to the method of occultations; but the results are less accurate, and the calculations are long and troublesome.

We may conclude that the determination of longitude by astronomical observation is possible only to those travellers who are so fortunate as to have plenty of technical skill, plenty of time on the march, and unusual freedom from the ordinary anxieties of an expedition. Those who are not so happily situated can scarcely hope to keep their longitudes within a number of miles.

Azimuth.

The azimuth or true bearing of a ray, the angle between the ray and the meridian through the line of sight, is different from the compass bearing of the ray by the amount of the deviation of the compass. Were this deviation constant it would have the effect of slewing all compass work round in azimuth, but not of altering its shape. But the deviation of the compass varies not only from place to place, but also to some extent from month to month at the same place. Hence all compass work is incomplete unless it is accompanied by determinations of the compass deviation. Such observations consist in finding from the Sun or the stars the true azimuth of a given ray, and comparing it with the compass azimuth.

The determination of true azimuth is made in much the same way, and under the same circumstances, as the observation for local time, and if necessary can be combined with it. It is not a very laborious process, and should therefore be practised frequently.

At sea the observation for the deviation of the compass is more frequent than any other observation; on a well run ship an observation is taken every watch, if the weather allows, for an unknown error of even a quarter of a degree is by no means negligible in the day's course of a fast steamship.

On land, where the rate of progress is much slower, and the compass used is smaller and less accurate, such very frequent control is not necessary. But it is essential to control the general accuracy of a compass traverse by taking a true azimuth from time to time, and an example will illustrate the whole process.

Before starting in the morning the traveller may be informed by his guides that the day's march will take him near a distant well-marked point. He sets up his theodolite, sets it on the distant point, and reads the horizontal circle. Then he turns to the Sun and obtains simultaneous readings of the horizontal

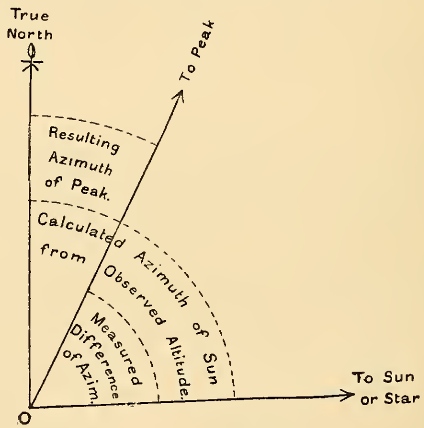


Fig. 5. Observation of Azimuth.

circle and the Sun's altitude. From the altitude, and an approximate knowledge of the latitude, the true azimuth of the Sun can be calculated. Apply to this the angle between the Sun and the distant point, as measured on the horizontal circle, and the azimuth of the distant point is found. Compare this with the compass bearing of the point, and the deviation of the compass is known.

Now when at the end of the day's march the route is plotted, and the position of the object observed to in the morning has been laid down with reference to the route by cross bearings aken from near at hand, the azimuth of this object from the starting point, as shown on the drawing, may be compared with its true azimuth as found from the morning observation. This will provide an excellent check on the general accuracy in azimuth of the whole day's traverse. It must not be forgotten that, except near the equator, the "convergence of the meridians" must be taken into account in plotting a long traverse, but the discussion of this refinement may be postponed.

Check on the length of the traverse.

We have seen that latitudes may be found very easily to within a fraction of a minute of arc, that is, of a geographical mile. A comparison between the latitudes taken at each end, and the distance made north or south, as shown by the traverse, will give an admirable check on the scale of the traverse in this direction.

But it should be noted carefully that before proceeding to resolve the traverse into its north-south or east-west components, all the bearings must be reduced from magnetic to true bearing. The resolved parts of each leg of the traverse may then be calculated directly, or they may be taken out from Traverse Tables, or from the tables which are called, in the curious terminology of the navigator, "Latitude and Departure Tables."

A similar check on the scale east and west cannot be obtained by observations for longitude, for the reasons given above; or at least, it is beyond the reach of the ordinary traveller. But if care is taken to check by differences of latitude whenever the route leads considerably north or south, there will be an excellent indirect control upon the lengths of the traverses running east and west.

Dead reckoning.

The observation for time or azimuth, morning or evening, requires a knowledge of the latitude, which is found from the Sun only near noon; while the observation for latitude requires a knowledge of the local time, except in rough sextant work, and of the approximate Greenwich time, which cannot be found near noon by any practicable field methods. Suppose the traveller has obtained an observation for time before setting out in the morning. By noon he will probably have moved into a different longitude, and his local time will have changed. But his route traverse will give him very nearly the change of longitude, and so he can apply the necessary correction to the error of his watch which he found in the morning, and thus he can obtain his true local time near noon. In the same way, he can bring forward the noon latitude to give him the approximate latitude required for the time or azimuth observation morning or evening.

It will be seen that this process of carrying forward the change of latitude or longitude between one observation and the next is very like the process practised continually at sea, of carrying on by dead reckoning.

The details of these astronomical processes need not be studied at the present stage. But it seems to be essential that the student should have a general idea of the nature of the control which field astronomy can exercise over traverses plotted by the compass, such as the pioneer traveller makes in his first journey through an unmapped country.

Thus, for example, in the *Geographical Journal* for January 1913, among the notes on new maps we find an account of a map of a part of the Sahara, published by the French *Ministère des Colonies*, 1912, "constructed from the itineraries and sketches of Captain Cortier, officers attached to his expedition, and others....It has been adjusted to 33 astronomical positions determined by Captain Cortier, a useful table of which is given in the lower right hand corner of the map."

Route traverses cannot make a map.

A route traverse carefully made is admirably adapted to illustrate the account of a journey, and to enable future travellers to follow the same route. But it is altogether wrong to suppose that anything in the nature of a satisfactory map can be made by combining a number of these traverses. Each individual traverse will serve very well by itself, until it comes to be fitted to other traverses. Then it is invariably found that the separate traverses will not fit accurately together. The reason for this is easily seen. Each traverse is a zigzag line, which may have been stretched by error in estimating distances, and distorted by errors in the mean bearings of tortuous tracks. A certain number of points will have been tied down, so far as displacements north and south are concerned, by the astronomical latitudes, and the general bearings of considerable lengths will have been controlled by the astronomical azimuths. But within these constraints there will always have been plenty of room for errors to accumulate.

Moreover, a number of traverses run across a country leave large areas unvisited, and a map cannot be considered worthy of the name which shows detail in one part, and leaves out more important detail of the same kind in another. Thus the compilation of traverses cannot make a map.

The impossibility of making a map by compiling traverses is one example of a general principle which underlies the whole of Survey: a map must be constructed on a rigid framework. And how can such a framework be obtained? The answer is the same in all branches of surveying. By building it up of triangles in which the angles are measured, not the lengths of the sides.

It must be understood, however, that when we speak of the impossibility of making a map by the compilation of route traverses, we mean that a final and accurate map cannot be made by such means. A study of the maps of Africa issued by the Geographical Section of the General Staff will show that many of these are compiled from such material; but such sheets always bear the legend "None of this country has been surveyed"; the compilation is provisional, a little better than nothing at all, and as soon as possible it is superseded by a regular survey.

We must make the reservation also that there are cases in which the final work of survey must be done by traversing: in dense forest regions, and in cities. But this is precise traverse, of an altogether different order of accuracy, which will be dealt with briefly in Chapter VI, page 162.

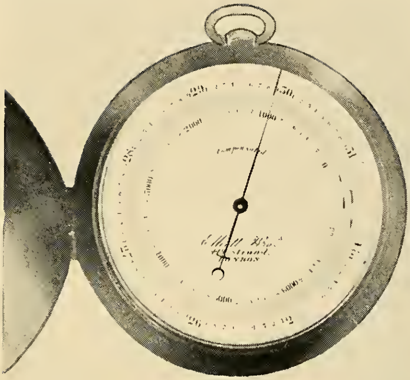
Heights by Aneroid Barometer.

The clinometer is good for determining relative differences of height over a small range of ground, but is useless for carrying forward such determinations over a long distance: the accumulation of error would be soon intolerable. The traveller therefore requires some instrument to give him rough determinations of absolute height at a point, and to measure considerable differences of elevation under such circumstances as the ascent of a mountain peak, where the clinometer is quite inapplicable.

The pressure of the atmosphere varies with the height above sea, and the reading of the barometer varies accordingly. Roughly, the barometer falls one inch for each thousand feet of ascent. But the pressure of the air and the height of the barometer are affected also by the disturbances moving in the atmosphere which affect the character of the weather; and they are also dependent upon the temperature of the air. Hence the reading of the barometer at any moment is dependent upon a complication of circumstances, and can give no precise determination of height above sea. One may say, however, that the barometer at sea level is rarely above 31 inches, and rarely below 29; so that if it is observed to stand at 24 inches, the presumption is that the observer is somewhere between 5000 and 7000 feet above sea.

To obtain a clear understanding of the way in which the barometer can be used to obtain more precision than this, consider the case of a recording barometer carried by train from Lancaster to Carlisle. At Lancaster it will draw a trace showing the variations in the pressure of the air associated with the passage of disturbances or the establishment of anti-cyclones. Between Lancaster and Carlisle the train climbs nearly 1000 feet over Shap Fell; the barometer will fall about an inch on the ascent, and will rise again as the train runs down the steep descent through Penrith. At rest at Carlisle the barometer will draw still a variable trace, depending again upon the passage of disturbances in the atmosphere. The question is therefore, how to disentangle the variations due to height from those due to weather, including changes of temperature.

Plate XI



1. Aneroid Barometer.

2. Boiling Point Apparatus or Hypsometer.

Determination of Heights.

It is not safe to assume that the sea level pressure is the same at two places fifty miles apart. Therefore if one wishes to disentangle the weather changes from the altitude changes, it is almost necessary to have a barometer stationary in altitude, as nearly as possible below the barometer which is being carried uphill. The weather changes of pressure are given by the former and applied to the latter; what is left of change may be ascribed to the variation in height of the travelling barometer.

In many cases it is not possible to leave a barometer at the base camp, to be read while the travelling barometer is away. One must then do the best possible by returning to the base camp as soon as possible after the ascent, and determining the change in the reading there which has taken place during the day. Thus, suppose that a climber reads his barometer at 4 a.m. before setting out, and records frequent readings during the ascent and descent. He reaches the top at noon, and is back in camp at 5 p.m. Comparison of the morning and evening records at the camp shows that the barometer has fallen half an inch during the time the expedition was away, and to compare with the noon reading at the summit one must interpolate between the morning and the evening readings below. If the barometer has been falling regularly throughout the day, this will give the correct noon reading at the lower station; but otherwise not; and the advantages of having a second observer remaining below are sufficiently clear.

Barometer heights in exploratory survey.

We have seen that accurate results can be obtained only when the barometer is used to obtain differences of height between two stations which are occupied as nearly as possible simultaneously. In general this is not practicable for an explorer, who has to push on through a country, and cannot retrace his steps, or leave another observer behind at a base camp. Such a man must do the best he can to obtain information as to the average pressure at sea level in the region where he is travelling, and must be careful to make allowances for the seasonal and daily variations of the pressure, which in tropical countries are often surprisingly regular, and quite worth taking into account.

In the survey of Southern Nigeria, for example, it is found that the diurnal changes of the barometer are so regular that it is possible to run fairly accurate contours in the thick forest, if care is taken to study and apply the corrections for the diurnal variation.

But with all care it is not possible for a traveller single-handed to obtain much accuracy with the aneroid barometer, and this explains why the heights of mountains and lakes in Africa are often found to be several hundred feet wrong, when the early barometer heights are at last compared with the results of precise surveys.

Instrumental precautions.

The aneroid is a delicate instrument, and must be treated with all care. It must be allowed some minutes to come to rest before a reading is taken after a rapid change of altitude; the process is hastened by gently drumming with the fingers on the case of the instrument; but hard tapping is bad for the instrument, and all shocks must be avoided.

An ordinary aneroid carried for a long time at a great height, say over nine thousand feet, is liable to become strained, and its readings inaccurate. Special types of instrument, called Mountain Aneroids, are made for use at great heights. But if it is necessary to use an instrument of the ordinary pattern, a simple device will preserve it in good order. A well-fitting tin has a bicycle valve soldered into it. The aneroid is placed inside, the joint sealed with surgeon's rubber paster, and the tin is pumped up with a bicycle pump until the pressure inside is near the normal sea level pressure. The aneroid will travel thus without strain, and can be taken out when required. This arrangement was found to work very well by a traveller in the Andes.

Temperature corrections.

The aneroid barometer is corrected for the effects of temperature upon the instrument itself; but it is necessary to take into account the temperature of the intervening air between the upper and the lower stations. This cannot be done accurately, and the method suffers in consequence. It is seldom possible to do more than to take the mean of the temperatures at the upper and the lower stations, and to treat this as the mean temperature of the intervening column of air. When there is no lower station for comparison, and some assumption has to be made as to the temperature below, the results become still more uncertain.

Heights by Barometer.

There are two sets of tables in common use, those calculated respectively by Loomis and by Baily. Both are given in *Auxiliary Tables of the Survey of India*; the former are given in *Hints to Travellers*, published by the Royal Geographical Society; and the latter in *Textbook of Topographical Surveying* (Close).

In none of these places is there an adequate account of the basis of construction of the tables, and it does not appear that any such account is readily available. A brief summary is therefore given here.

An investigation of the theory of the subject is to be found in Laplace, *Mécanique Céleste*, Vol. IV, p. 289 of the edition of 1805. With some modifications, this leads to the following formula*:

If H = height of barometer at lower station,
H' = „ „ „ „ upper „
T = temperature of *barometer* at lower station,
T' = „ „ „ „ upper „
t = „ „ air at lower station,
t' = „ „ „ „ upper „
λ = the latitude,
s = height of lower station above sea level,
x = difference of height of two stations,
μ = modulus of common system of logarithms,
θ = difference of expansion between mercury and the metal of which the barometer scale is made,
a = radius of the Earth.

Then $$x = P \times \{\log H - \log H' - \mu\theta(T - T')\}$$
$$\times \left\{1 + \frac{t + t' - 64}{900}\right\}$$ [when temperatures are on the Fahrenheit scale]
$$\times \{1 + 0{\cdot}00265 \cos 2\lambda\}$$
$$\times \left\{1 + \frac{2\mu P + x + 2s}{a}\right\}.$$

Taking heights in feet, the constant P is 60159, according to Loomis; $a = 20{\cdot}89 \times 10^6$ feet, and the constant multiplied by $\mu\theta$ is $2{\cdot}341$.

Hence

$$x = \{60159\,(\log H - \log H') - 2{\cdot}341\,(T - T')\}$$

$\times\left(1 + \dfrac{t + t' - 64}{900}\right)$ to allow for the mean temperature of the air and an average amount of aqueous vapour

$\times(1 + 0{\cdot}00265 \cos 2\lambda)$ to allow for the variation of gravity with the latitude

$\times\left(1 + \dfrac{x + 52251^{*} + 2s}{20{\cdot}89 \times 10^6}\right)$ to allow for the diminution of gravity with height.

Loomis' Table I gives the values of $60159 \log H - 27541$ for values of H from 11 to 31 inches. He gives no explanation of the reason for the choice of this constant 27541, and its significance is not obvious. He remarks merely that it does not change the difference of the two quantities taken from the table.

We enter Table I with the two quantities H and H', and take their difference. This gives a first approximation to x, the difference of height between the two stations.

Table II gives the values of $2{\cdot}341\,(T - T')$. It should be noted that this correction is required only when mercurial barometers are used, which is seldom. Aneroid barometers are mechanically compensated for their temperature, and no correction is then required on this account.

The resulting difference of height is then multiplied by the factor

$$\left(1 + \frac{t + t' - 64}{900}\right),$$

no table being provided for this process. The result is a close approximation to the final result.

Table III gives the value of $x \times 0{\cdot}00265 \cos 2\lambda$, by a table of double entry with arguments x and λ.

The correction for the variation of gravity with the height is split into two parts.

Table IV gives the correction equivalent to multiplication by the factor $1 + \dfrac{x + 52251}{20{\cdot}89 \times 10^6}$: the part involving the difference of heights. This is a table of single entry with argument x.

Table V gives the correction equivalent to the remainder of the factor $\dfrac{2s}{a}$. But since s is not necessarily known, though to the approximation required it may be deduced from the barometer reading at the lower station,

* $52251 = 60159 \times 2\mu$.

the correction is arranged in a table of double entry with arguments H and x. It may be noted that this table is unnecessarily extended. If x, the difference of heights, is 25000 feet, the barometer at the lower station can hardly be so low as 16 inches, corresponding to an elevation of about 16000 feet.

The above is the form of the tables as given by Loomis, and reproduced without comment in English books up to the present day. But it should be remarked that they are slightly erroneous in Table IV. The factor

$$1+\frac{x+52251}{20\cdot89\times10^6}$$

is required in the reduction of observations made with mercurial barometers. But the aneroid is equivalent to a spring balance, which in itself is independent of variations in the intensity of gravity. A reference to the theory shows that when aneroid barometers are used, the term 52251 should be omitted; and this is the greater part of the correction tabulated in Table IV. We shall avoid this error if we omit altogether the correction from Table IV; and enter Table V with the mean of the barometer heights at the two stations, instead of with the barometer height at the lower station.

We may note also that as Loomis' tables are commonly printed, the argument at the side of Tables IV and V in the column headed "height" is misleading. The column should be headed "difference of height of the two stations." The examples given in *Hints to Travellers* are wrong in this respect. The height of the upper station has been entered, instead of the difference of heights.

The tables in the form given by Baily are a modification of the above. Baily takes as an average case that s, the height of the lower station, is 4000 feet, and that x, the difference in height of the two stations, is about 3000 feet (though he does not say so in the latter case). With these assumptions, the tables are shortened; but they are arranged so that the computation must be done by logarithms, which is less convenient for the traveller. It does not appear, then, that the form given by Baily has any advantage over the form given by Loomis; and the results are not quite so accurate in theory, because of the assumptions indicated above.

Both Loomis and Baily neglect the variation in the amount of moisture in the air, and are content to arrange their constants to correspond to an average amount of moisture. The recent tables by M. Angot, as now published in the *Annuaire du Bureau des Longitudes*, give means of allowing directly for the moisture of the air, and are in this respect a great improvement on the older tables.

But it may very well be doubted if it is of much avail to take account of refinements such as the variations of gravity with height and latitude, and variations of the aqueous vapour present in the air, while the crude, though inevitable, assumption is made that the average temperature of the column of air between the two stations is the mean of the temperatures at those stations. This cannot be exact; and it will be seen that the error introduced by this assumption may very well be much greater than the small corrections due to the other causes.

The tables for the calculation of Barometer heights.

The following brief table is not sufficiently extended to be convenient in the actual calculation of observations. It is given here only that we may have an example of the style of the principal table, and of the magnitude of the quantities involved. For the reasons given above, we have not thought it necessary to give any table of the small corrections whose effect is trifling compared with the uncertainty of the principal temperature correction.

Bar. in inches	Feet	Diff. for 0·1 inch	Bar. in inches	Feet	Diff. for 0·1 inch
12·0	3670	217	22·0	19506	119
13·0	5761	201	23·0	20668	114
14·0	7698	187	24·0	21780	109
15·0	9500	174	25·0	22846	104
16·0	11186	164	26·0	23871	100
17·0	12770	154	27·0	24857	97
18·0	14264	145	28·0	25807	93
19·0	15676	137	29·0	26724	90
20·0	17016	130	30·0	27610	87
21·0	18291	124	31·0	28466	84

Take the difference of the heights corresponding in the above table to the barometer at the upper and lower stations.

To correct for temperature, multiply this difference by

$\frac{1}{900}$ (sum of air temperatures at the two stations $-64°$).

The boiling point thermometer.

The pressure of the air affects the temperature at which water boils, and a determination of the boiling point of water thus affords an independent determination of the pressure of the atmosphere, and gives the same kind of limited information as to height above sea as is given by the aneroid barometer. Since it is not possible in the field to carry thermometers which can be read to less than one-tenth of a degree Fahrenheit, and one-tenth of a degree in the boiling point corresponds to a difference of pressure which is in its turn equivalent to a difference in height of about fifty feet, it follows that the boiling point thermometer is less sensitive than the aneroid for determining differences of height. But on the other hand, it is less likely to become deranged, and it is therefore well to carry both instruments on a journey, and to use the boiling point apparatus to control the general accuracy of the barometer.

The following is an abbreviation of the usual table for the relation between the boiling point, the barometer, and the difference of height between stations.

Boiling Point	Equivalent Barometer	Height in feet above the point at which water boils at 212°
212° Fahr.	29·921	0
210	28·746	1046
208	27·613	2097
206	26·521	3151
204	25·466	4210
202	24·447	5278
200	23·461	6354
198	22·507	7439
196	21·584	8533
194	20·690	9638
192	19·828	10750
190	18·998	11867
188	18·199	12988
186	17·426	14124
184	16·681	15266
182	15·964	16412
180	15·275	17567
178	14·611	18725
176	13·970	19897

A second table is usually added, giving the factor by which the above differences should be multiplied to allow for the mean temperature of the intervening air. This is based on the assumption that the temperature at the upper station only is observed, and that the mean temperature may be derived from the approximate law that it decreases 1° F. for every 330 feet of ascent.

It appears that when the temperature at the lower station is observed, or can be estimated approximately, it is better to correct for temperature as in the calculation of barometer heights.

In a collection of survey tables it is usual to find the tables for the reduction of boiling point observations given in the above form; and no allowance is made for the small corrections due to change of gravity in different latitudes, or for different altitudes of the lower station. These are small compared with the uncertainties of the thermometer reading. But it is well to note that the most correct way of reducing the observations is to translate the boiling points to the corresponding barometer heights, by tables such as that given above, only more extended; and to complete the calculation as for aneroid readings.

Instrumental precautions.

The principal point to attend to is that the bulb of the thermometer must not be allowed to dip into the water which is being boiled, because any impurity present in the water alters the temperature at which it boils. The bulb should be suspended so that it is fully exposed to the steam which is coming off, but is just clear of the liquid itself. With this precaution it is possible to make the determination of boiling point a part of the ordinary cooking operations, as was done on the recent British Antarctic expeditions. The thermometers were inserted through the lid of the cooking pot and were read at each halt. This check upon the barometers was particularly valuable under the circumstances, because there was good reason to doubt the unconfirmed results of aneroid barometers working at elevations of over 10,000 feet, in intense cold.

It is of course essential that the errors of the thermometers employed should be verified at the National Physical Laboratory before the start of the expedition, and again on its return. The thermometer tends to lower its zero point for a long time after manufacture, at a gradually decreasing rate. Old thermometers, well standardised, are therefore more trustworthy than new ones.

CHAPTER IV

SIMPLE LAND SURVEY

The settler's land survey.

As soon as a country becomes settled townships are projected, mining areas are pegged out in claims, and the land is parcelled out into farms. These operations are usually simultaneous with, if they do not actually precede, the establishment of a settled government. Thus, for example, we read in the *Colonial Survey Report*, No. 1, page 23: East Africa Protectorate, 1903, "Since no survey existed, and it was imperatively necessary to settle the people on the land advertised as open for selection, every kind of makeshift had to be adopted to meet the situation. Much wasteful expenditure was incurred, and the settlers had legitimate grievances against the Government." On the average a settler was kept waiting 12·6 months for allotment.

The need of a map of the country is felt acutely from the first day of its opening up. But the production of a map is a long and costly business, and almost always has to wait. In the meanwhile some kind of plan of each township, mine, and farm is absolute necessity, both to the occupier and to the local administration. Land surveyors set to work to survey the properties as they are ready for allotment, or perhaps as they have been already occupied, and the result of their labours is a series of plans, which accumulate in the office of the Commissioner of Lands.

We must remember that these are not maps. A topographical map shows the natural features of the country, and in addition the principal features in the way of communications that have been added to it by man. But a map does not show the boundaries of property, and a map is not on a scale large enough to show details and areas sufficient for the purposes of property record or of local taxation. The cadastral, or property survey, on the other hand, is made on a scale sufficiently large to show all the details of boundaries, walls, fences, and ditches; and areas of each plot may be measured from it. But in general it shows nothing of the relief of the ground.

A topographical map is in the nature of a picture, a cadastral map is a mere diagram of the ground. For reasons which will appear in due course it is not possible to construct a map by piecing together a set of contiguous property surveys; and to a great extent the work put into the original surveys of property is wasted because it has to be done over again when the time comes for a regular survey of the country. The sooner that comes, the greater the eventual economy. But since it is not in practice possible to insist that a regular survey of the country should precede any of this detailed property survey, it will be convenient to consider here very briefly the principles upon which these preliminary land surveys are conducted. It will be understood that since this book is to deal with maps, and not with the minutiae of property and town survey, the treatment of this latter can be nothing more than a sketch.

The elements of property survey.

Suppose, in the first place, that the plot to be surveyed is small in extent, but that there is a great deal of detail in the nature of crooked boundaries, buildings, etc., that must be shown. The plan will be made by the simple process of land survey with chain or tape.

The principle of land survey is that every detail must be fixed by measuring its perpendicular distance from a straight line, and the position on that line of the foot of the perpendicular. Suppose, for simplicity, that a boundary is made up of a series of short straight lengths AB, BC, CD, DE, EF, ... Suppose a straight line KL is laid out as near as may be to the boundary, and that perpendiculars Aa, Bb, Cc, ... are drawn from A, B, C, ... to KL. Measure the lengths of the perpendiculars, and the distances *Ka*, *Kb*, ... *KL*. A plan of the boundary *AB* ... *F* ... may now be drawn as follows: Draw the line *KL* on any desired scale, and lay off the distances *Ka*, *Kb*, ... on it. Erect perpendiculars from *a*, *b*, ... and lay off on them to scale the measured distances *aA*, *bB*, ...; we have then transferred to the plan the relative positions of *A*, *B*, *C*, ... *F*. Join them up, and we have a plan of the boundary.

The measurements along the line *KL* are made with the surveyor's chain or with a steel tape; the perpendicular distances, called offsets, are measured with a graduated offset rod, if they are short, as they should be.

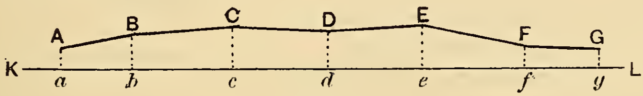


Fig. 6.

When offsets are not short they must be measured with the chain or tape; and it is then necessary to have some such instrument as the cross staff or the optical square, to set out the offsets perpendicular to the chain line. But long offsets are used only in rough work, and it is a cardinal principle of accurate land survey that offsets must not be long. A chain line must pass near every point that has to be fixed. The first thing to attend to, therefore, in making a land survey, is to lay out a suitable system of chain lines.

Suppose, for example, that the plot *ABCD* is to be surveyed. The elementary, often practised, but essentially bad method, would be to chain from *A* to *C*, and take offsets on each side of *AC* to the salient points of the boundary. This would be a bad, or at least untrustworthy method, (1) because the offsets are long, and the perpendiculars must be laid out with some elaboration; and (2) because there is no check upon the result except doing it all over again.

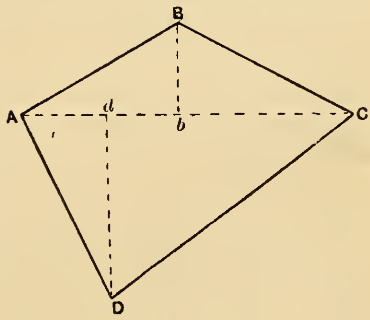


Fig. 7.

The proper method is to break up the ground into triangles. Chain from *a* to *b*, *b* to *c*, and *c* to *a*, taking offsets to the boundary along each chain line. The offsets are now short, and are easy to measure with sufficient accuracy. Do the same from *a* to *d*, and from *d* to *c*. But now note that the construction on our plan of the triangles *abc*, *adc*, depends on the accuracy of the measures of the lengths of our chain lines. An error in one would completely wreck the whole plan. Therefore they are to be checked by measuring the lines across the corners *kl*, *mn*. When the plan is drawn out these distances, as measured on the plan, must agree with the actual distances measured in the field. If they fulfil this condition, then we have a complete check on the main structure of the work. If they do not, the fact that there is an error somewhere is detected at once.

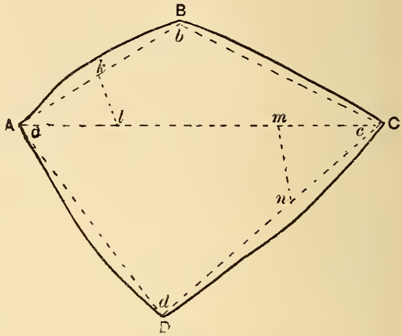


Fig. 8.

It has been mentioned already that a plan does not generally show the inequalities of the ground. It is one of the principal objects of a map to do so. But whether the inequalities are indicated or not, the plan or map must indicate the relative positions and distances of all objects as if they are projected by vertical lines on to a level surface. Distances must be measured and represented as horizontal distances, and the distinction is by no means insignificant in the case, for instance, of property on the side of a hill. In all land surveying by chain and offset rod, therefore, the chain and rod must always be held horizontal; and the horizontal equivalent of a distance down a slope will be measured in a series of steps. When a slope is steep this becomes difficult, and it is evident that the chain lines must be chosen so that they are as level as may be.

In theory land surveying is exceedingly simple, consisting only in measuring along the sides of the triangles, and taking offsets to all detail. The whole art of it in practice lies in selecting the system of chain lines so that they shall form as rigid a framework of triangles as can be made. If the three sides of the triangle are known with absolute precision the triangle can be constructed rigidly, within the limits of accuracy of the draughtsman. But errors will creep into the measurement of sides, and the draughtsman cannot draw with absolute accuracy, It is therefore necessary that the triangle shall be "well conditioned," as nearly equilateral as may be.

For consider the construction of a triangle with an acute angle *C* opposite the base *AB*. The point *C* is to be found by describing circles with centres *A* and *B*, and of radii equal to the measured lengths *AB*, *AC*. These circles will intersect at an angle equal to *C*, and it is evident that the more acute the angle, the greater will be the error in the position of *C* caused by an error in one of the measured lengths.

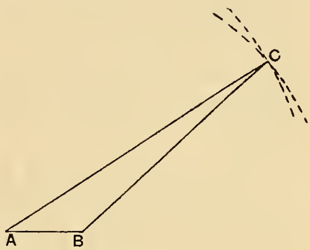


Fig. 9.

The same kind of argument applies in all branches of surveying that depend upon triangulation of any kind: that is to say, in all kinds of survey except the simple route traverse. There must be no unduly acute angles in the triangle.

The method of chain survey is well adapted to making plans of small detail. The plan of each triangle, and of the points fixed to it by offsets, has considerable accuracy in itself. But it will be understood easily that a large estate cannot be surveyed in this way, in a number of small triangles, because every triangle is inaccurate to a small degree, and the effects of these small errors rapidly accumulate when an attempt is made to fit a large number of the triangles together. In this, as in all branches of survey, it is impossible to make an accurate extensive map or plan by piecing together small portions surveyed independently, to build up a large map from small blocks. To take the exactly opposite way is the right course. Construct a simple framework covering the whole extent of land to be surveyed; get this framework so accurately made that it cannot be in error by an amount visible to the eye on the scale which is proposed for the map; and hang the detailed survey upon this framework. An accumulation of error is then impossible.

It follows from this principle that a property survey of whatever size must begin with a few big triangles covering the whole property, and work downwards from these to the smaller triangles in which the detail is surveyed. But lines a mile long cannot be measured conveniently with a chain, except in very flat and open country: some obstruction or other will be continually intervening to break the line and make a detour necessary. Hence in making the survey for a township, a large estate, or a mining concession, we must lay out the principal triangles with some more handy and convenient instrument than the chain. Such an instrument is the theodolite.

Our next section will therefore deal with the elements of triangulation with a theodolite.

Simple triangulation with the theodolite.

Considered in the simplest possible way, the theodolite, as used in triangulation, consists of a graduated circle fixed in a horizontal plane; a telescope which can be rotated about a vertical axis passing through the centre of this circle; and a pointer attached to the telescope, which can be read against the circle.

We shall postpone to Chapter VIII the consideration of all the instrumental details of the theodolite, and for the moment confine our attention to the outlines of the method.

Suppose that we have three points A, B, C marked on the ground in some visible way, and that the theodolite is set up over A. It is pointed on B, and the reading of the pointer on the circle is recorded; it is then pointed on C, and the circle is read again. The difference between the two circle readings will be the angle BAC. The theodolite is then moved to B, and the angle ABC is measured; then to C, and the angle ACB is observed. These three angles should of course add up to 180°, unless the triangle is so large that the curvature of the Earth must be taken into account; and this will be a check upon the accuracy of the observations.

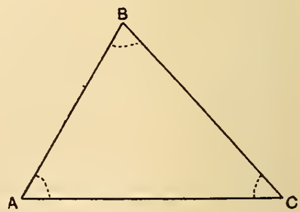


Fig. 10.

When the three angles are known the shape of the triangle is known, but not its size. To get its size we must measure the length of one of its sides; and then by a very simple piece of trigonometry we calculate the lengths of the other sides, from the known values of the angles.

In a triangulation, therefore, we must measure the length of one of the sides of one of the triangles. The lengths of all the other sides of the whole triangulation will be worked up by calculation from the observed angles and the length of the initial side, which we call the base.

Suppose, then, that we have selected six points on our ground, *A*, *B*, *C*, *D*, *E*, and *F*, disposed so as to form the triangles of our figure, of which, it will be observed, no one has a very acute angle. Each point must be visible from the other points of the triangles to which it belongs; but it is not at all necessary that all the points should be intervisible. For example, *C* must be visible from all five others; *B* from *A*, *C*, and *D*; but *E* need not be visible from *A* or *B*. These points are marked by pegs driven into the ground, and signals are erected over them.

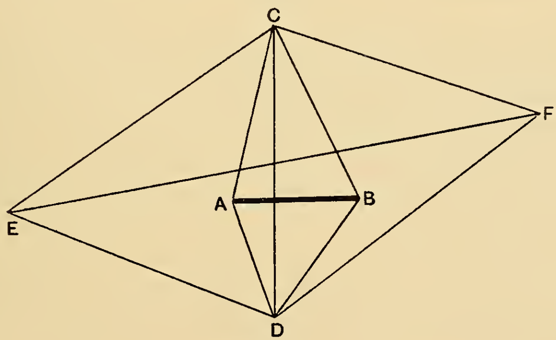


Fig. 11.

The theodolite is set up over each peg in turn, the signal being removed if necessary, and the angles in the triangles are measured. Each triangle is checked by the necessity that the sum of its angles should differ from 180° only by the small quantities which may be allowed as errors of observation.

It is important to notice that, though the points of the triangulation may be at different elevations, the angles that are measured are the angles of the projection of the figure upon a level surface. For suppose that in the triangle *ABC* the point *B* is higher than *A*, and *C* higher than *B*. If we wished to measure the true angles of the triangle *ABC* we should have at each station to tilt the theodolite so that the graduated circle lay in the plane of the triangle. If, on the other hand, we keep the circle horizontal, what we actually measure is not the angle BAC, but the angle between the vertical planes through AB and AC respectively; which is of course equivalent to the angle at A in the triangle ABC projected on the level. But this is what we want; we have already remarked that the plan or map must represent the projection upon a level surface, not the actual configuration upon the undulating surface of the ground.

When all the angles are observed we have the shape of the figure. One side must be measured, and any one of these will do. We shall naturally select the one that lies on the most level and unobstructed ground. We suppose it is AB which is measured with chain or tape. Then in the triangle ABC, knowing all the angles and one side, we can easily calculate the lengths of AC and BC.

One of the sides of ACD thus becomes known, and the others follow immediately, since all the angles are known, as before.

In this way, from one measured side of one triangle only, we arrive at the lengths of all the sides of all the triangles.

For an example of the calculation, see Chapter VI, page 156.

Choice of base, and connection with triangulation.

Having arrived at the principles of triangulation, we must now see how they can be put into practice conveniently.

The stations of the triangulation will naturally be for the most part on the summits of hills, from which an extensive view can be obtained. But it will generally not be convenient to measure from one of these stations to the next, because the intervening ground will not be open and level, and otherwise suitable for the purpose. In practice, therefore, one chooses a site for the base, and arranges a special piece of triangulation to connect it with the nearest side of the main system of triangles.

Suppose AB is the base, and EF the nearest side of the triangulation. Select two points C and D, lying on opposite sides of the base, so that the triangles ABC, ABD are well shaped or conditioned; and at the same time the triangles CDE, CDF are also well conditioned. Erect beacons at A, B, C, D, and, of course, also at the principal triangulation points. For the present we shall not examine the method of constructing beacons. For this see Chapter VI, page 139. Set up the theodolite successively at the six stations, and observe along the rays drawn in the figure. For example, at C observe to E, A, D, B, and F.

Now in the triangle CAB we have all the angles known, and one side AB; hence we can find the length of BC. Similarly in the triangle DAB

we find DB from AB. Then in the triangle BCD we know both sides BC, BD, and through either of them we find the length of CD. Then working through the triangles CED, CFD, we find CE or CF, and thence from the triangle CEF we find EF.

Our base AB has now been extended through a series of carefully planned triangles to EF, which is several times the length of AB, and is one of the sides of the principal triangulation.

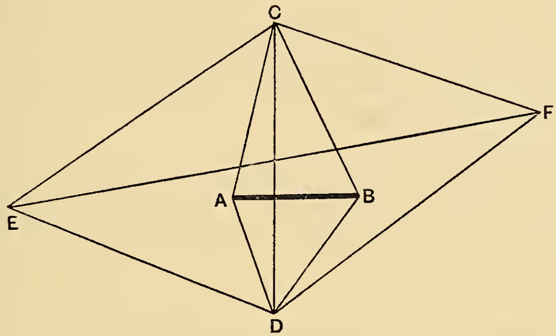


Fig. 11*a*.

It will be noticed that we might have arrived at the length of EF from AB by a number of different ways. For simplicity we have spoken as if there were only one way round, but at a later stage we shall see that the other ways must not be neglected in accurate work. If, however, we consider more than one way round, this difficulty will arise, that since all the measured angles are subject to errors of observation, the whole figure is slightly inconsistent in its various parts, and we should get slightly different results for the length of EF according as we derived it from AB by one route or the other. This would be intolerable in practice, and we must devise a way of getting over the difficulty before we come to deal with really accurate work. In small pieces of isolated survey the question hardly arises.

The main triangulation.

Having derived the length of the side EF, a side of one of our main triangles, from the measured base AB, we can complete the triangulation through G, H, K ... until the whole ground that we propose to survey has been cut up into a small number of relatively large triangles, of which all the angles have been observed with the theodolite, and the lengths of all the sides deduced from the measured base through EF.

The next step depends upon the size of our ground. If it is not more than say ten miles square we shall make no serious error if we neglect the curvature of the Earth, and treat it as plane. In that case the triangulation may be laid down upon the sheet of the plan simply by constructing the triangles in succession from the calculated lengths of their sides ; or more accurately by calculating the rectangular co-ordinates of the triangulation points with reference to one taken as origin. But in order to get the plan orientated we shall want to know the true bearing of one side, say *EF*. This may be obtained very roughly with the compass, or very quickly and accurately from an azimuth of the Sun.

If the ground is much larger than ten miles square we may not be able to afford to neglect the curvature of the Earth. But this case may be reserved for the chapter on Topographical Survey. See Chapter VI, page 152.

The advantages of triangulation.

Let us look again for a moment at the reasons for making this framework of a few big triangles covering the ground which we propose to survey in detail afterwards. Suppose that our base is only a few hundred feet long, and that the country is so rough that we cannot hope to find a place where we can measure a longer length on the ground with any accuracy. It is very easy, and does not require any special precautions, to measure this base with an accuracy of one in ten thousand. If our triangles were quite exact we should arrive at the lengths of our longest sides with the same proportional accuracy. This will not be achieved in practice, but the diminution in accuracy can be controlled by the amount of care that we are willing to give to the triangulation. Suppose that it is so done that the error in the side most remote from the base is increased to an uncertainty of one in three thousand. The principal points being related to one another with this degree of accuracy it is not possible for error to accumulate over any considerable part of the plan to a greater extent than this. In cutting up the bigger triangles into smaller, either with the theodolite or with the chain, local errors may be made, but their effects are not cumulative. They cannot extend outside the particular triangle in which they are made.

Again, if only we can find points for the principal triangles which are visible from one another, the accuracy with which they are fixed is independent of the character of the intervening ground, which may be of a kind to render any sort of linear measurement impossible.

Or, to put it another way: It is very hard to measure distances accurately with chain or tape except upon open and level ground; it is very easy, by means of the theodolite, to measure angles from one well-defined point to another. We shall expect, therefore, to do well with a method that gives us the triangles by measuring their angles, and requires that one side only shall be measured, for which a site can be chosen in the most favourable place.

Town and forest survey.

There are two cases in which the ordinary method of triangulation with the theodolite breaks down: in towns, where the walls and buildings make the triangulation impossible; and in dense forest such as the Gold Coast, where the hills are round topped and cannot be cleared, and where it is impossible to obtain a view of any importance.

In such cases it is necessary to traverse with the theodolite. For this method see Chapter VI, page 162.

The dangers of patchwork survey.

We began this chapter with the needs of a survey more extensive than could be undertaken by chaining alone, yet only an isolated piece of work, such as the plan of a township, a mining concession, or an area open to allotment or sale to settlers. The principles of triangulation are the same, whether the survey is an isolated patch or part of a complete scheme for the whole country. But it is important to have a precise idea of the dangers and the bad economy of doing survey work in small patches instead of making each operation part of a large scheme for the complete map.

In a new territory, where land belongs originally to the

Government, and is sold piecemeal, the only secure method of delimiting the boundaries of property is by reference to a complete triangulation of the country. This is forcibly stated in a letter addressed by Sir David Gill, then Her Majesty's Astronomer at the Cape, to Earl Grey, who in 1897 was administering the Government of Rhodesia. The following extracts from this letter are taken from the introduction to the *Report on the Geodetic Survey of South Africa*, Volume III.

"The point which it is always difficult to bring home to the lay administrative mind is that it is impossible to survey a country properly or to grant indisputable titles to land by surveys made in a patchwork way.

"When Government has a particular bit of land to be disposed of, it seems to be supposed that one has only to send a surveyor to set up beacons, survey the ground, and bring back a diagram of those beacons—and sell the land according to this description.

"Assume the surveyor to be competent and honest, the result will be certain points marked on a piece of paper, representing pretty accurately the shape of the piece of land so surveyed ; but in many places there will be no sufficiently well-marked topographical features, such as well-defined river boundaries, etc., to locate precisely where in the country the particular farm is ; there will be nothing to indicate the latitude and longitude of any particular feature of the map (i.e. its position on a general map of the country) ; and there will be no accurate topography on the diagram, because the price which the surveyor receives for such survey makes it impossible for him to include accurate topography in his work. With the approximate methods of base measurement necessarily used by such a surveyor there will also be some appreciable error in the scale of the map ; and beyond a rough orientation by compass (and the direction of the magnetic meridian is subject to large secular variation), there is nothing to indicate the true north of the diagram.

"Afterwards, when you come to patch such surveys together, you can see that no small trouble must arise, and that shortcomings and overlaps occur.... Then comes the further possibility, the dishonest proprietor. A particular piece of land is bought from Government. The proprietor finds a convenient spring or piece of rich land outside his boundary ; there is no neighbour to be hurt, or perhaps only a distant proprietor. It is not a difficult matter to shift a beacon—there is no one particularly interested, and the beacon is shifted....In this way large tracts of land have been stolen from Government in Cape Colony.

"There is one, and only one remedy for all this, and that is to connect all detached surveys with a general system of triangulation ; and it will save the Government and the inhabitants generally a vast amount of money to establish this triangulation as quickly as possible."

We are here in the difficulty that embarrasses all Governments of new territories: they cannot grant proper titles to the land, nor carry on any of the operations of settlement, until the country is properly surveyed; and they cannot afford to have the survey made until the country has begun to pay its way, and the more urgent demands for roads, bridges, and railways have been met. All that can be insisted on is that there must not be a month of unavoidable delay in setting to work on the complete survey of the country. Every pound that is spent in patchwork survey for special purposes is very largely wasted.

Simple levelling.

The plan which results from triangulation, either by chain or theodolite, represents the ground as if it were all projected upon a level plane; and no attempt has been made, so far as we have gone, to show the undulations and inequalities of the surface. To do so fully would require the construction of contours, to represent the courses of lines running at definite intervals of height above sea level. But this belongs rather to topographical mapping than to the survey of a small area, and it will be treated later.

Without aiming at a complete system of contours, it will usually be necessary to have some knowledge of the variations of height above sea, for local purposes of drainage or irrigation; and this at its simplest involves running certain lines of levels across the plan, by the use of the surveyor's level and staff.

Putting aside for the time all the details of construction and adjustment of the instrument, the level may be described as a telescope which is set at right angles to a vertical axis, and can be swept round in a horizontal plane. Any object seen on the cross wires of the telescope is on the same level with them, or with the centre of the object glass of the telescope.

The levelling staff is a pole, usually rectangular in section, with a face divided into feet, tenths, and hundredths of a foot, numbered from the bottom upwards. (Plate XII.)

Suppose that this staff is stood upon the ground at a distance from the level, and that the observer, looking through the telescope, sees that the horizontal wire cuts the image of the staff at the height 7·61 feet, whereas the centre of the object glass is 4·27 feet above ground. It is clear that the ground at the base of the staff is 7·61 − 4·27 = 3·34 feet *below* the ground on which the level stands, provided that the telescope is really pointing horizontal.

Similarly, if the reading of the horizontal wire is 9·03 feet upon a second staff, the ground at the foot of the second staff is 9·03 − 7·61 = 1·42 feet lower than at the foot of the first. And it should be noticed that this result is obtained without requiring any knowledge of the height of the object glass above ground, which varies each time the instrument is set up, by variation in the spread of the legs of the tripod, and is not quite conveniently measurable in ordinary instruments. The essence of the method is the use of the two staves, so that the height of the level itself is eliminated.

In the above explanation of the use of the level we have made the important reservation "provided that the telescope is really pointing horizontal." The surveyor in the field cannot be continually revising the adjustment of his instrument, and it is characteristic of a good method of survey that the way in which the instrument is used should eliminate automatically errors due to imperfect adjustment.

In the use of the level this end can be attained with great simplicity. All that is necessary is that the two staves should be placed at equal distances from the telescope. The reason for this will be seen at once, when we consider in what way the instrument is likely to get out of adjustment. Reduced to its simplest parts, the level consists of a telescope fixed on an axis *V*, with a bubble *B* firmly fastened to the tube of the telescope. The axis *V* must be set up vertical, and the test of verticality is that the ends of the bubble *B* should not move along the scale when the instrument is rotated about *V*. The bubble may not be central on the scale, but so long as it does not move along the scale when the instrument is rotated, the axis is vertical. Hence the process of getting the axis vertical, which is required every time the instrument is set up, does not in theory depend upon the adjustment of the bubble or of the telescope.

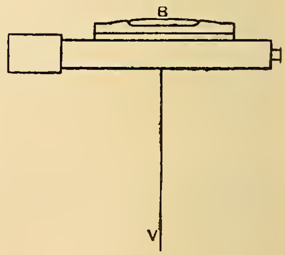


Fig. 12.

1. Levelling Staff.

2. 12 inch **Y** Level.

.evelling.

Now if the bubble is not in the centre of its run when the axis is thus found to be vertical, the bubble is out of adjustment. And even if the bubble is in adjustment, it does not follow that the telescope below is parallel to it.

These errors are adjusted from time to time by the methods given in any textbook on the use of the instrument. But they are apt to vary from day to day or from hour to hour while the instrument is in the field. The former does not affect the results if care is taken to make the test of verticality of the axis as above, not that the bubble is central, but that it remains at rest when the instrument is turned about the vertical axis. But the effect of the second error is that the telescope is pointing up or down at some small angle to the horizontal when the axis of rotation is made truly vertical. The resulting error of reading on the staff will be strictly proportional to the distance of the staff. Hence if two staves are at the same distance, the errors in reading will be the same, and the difference of the two readings, which is the quantity required, will be unaffected by the error.

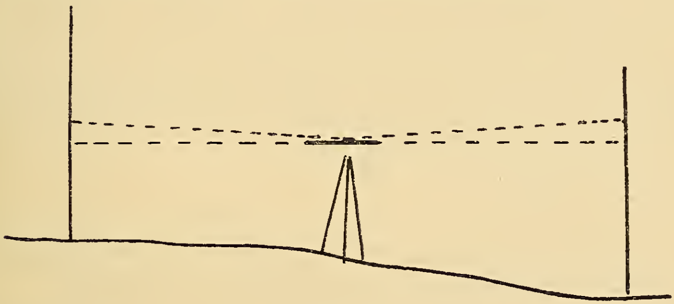


Fig. 13.

Suppose, then, that we wish to run a line of levels from A to B. We mark out suitable stations K, L, M,... in the line AB, for the staves. We set up the level midway between A and K, and find the difference of height of the ground at A and K. Then we set up midway between K and L, and so on. Each difference of height is then independent of the errors of adjustment of the instrument, and it is not possible for the effects of these errors to accumulate, since they are automatically eliminated at each step.

We should notice also that this process eliminates the effect of the curvature of the Earth. The line of sight of the telescope, being perpendicular to the vertical of the observer, is a tangent to the sphere and consequently passes higher and higher above the surface as it proceeds. Owing, then, to the curvature of the

Earth, all staff readings are too high by a very small amount, which would become serious in time if sights were taken always forward from one station to the next, but is eliminated without conscious trouble by the method of setting up the instrument always half-way between the two staves. Thus no correction for the curvature of the Earth appears in ordinary levelling operations at all, even though they extend over hundreds of miles. Paradoxers who imagine that the Earth is flat are fond of quoting this as a confirmation of their idea.

In a precisely similar way, there is no need to take any account of refraction if the level is always set up midway between the two staves. The effect of refraction will be to raise each staff in the field of view of the level, so that the readings are slightly too small. If observations were taken always to a forward staff this effect, extremely small for any one ray, would accumulate steadily, and would be very difficult to calculate. It is important, therefore, to notice that by the proper use of the two staves the effect of refraction is completely and automatically eliminated.

Detailed sections.

If we wish to make a section in great detail we may modify the above process without any damage to the essentials.

The staff may be set up at any number of intermediate points between A and K, and the difference of height from A or K found. These observations will be affected by the instrumental error, but since the distances are short the effect will be small. And these observations will be used only to refer points between A and K to either A or K ; nothing will be carried on from them into the next section, which will start from K unaffected, as we have seen, by the instrumental error.

The limitations of this process.

We have been considering the process of running a line of levels as it may be used for particular purposes in a piece of isolated survey. The heights will be reckoned from a quite arbitrary datum, and will have no connection with mean sea level.

The process of determining a general system of heights above mean sea level, as part of the organised survey of a whole country, will be considered in a later chapter; see Chapter VI, page 133.

And we should notice that the process here described is quite unsuited for a preliminary determination of heights and contours for an exploratory map. We shall deal with the processes proper to this purpose in Chapter V.

CHAPTER V

COMPASS AND PLANE TABLE SKETCHING

IN previous chapters we have dealt with the route traverse of the explorer; and with the methods of mapping an isolated township or mining concession. We have to deal now with a problem of quite another kind: the production of the first attempt at the topographical map of a district, or of what is called in the language of military topography "a sketch." It is a map, in the sense that it covers all the area with a uniform degree of thoroughness, and does not merely draw a line across the country; and it is a map also, in the sense that it aims at representing the whole topography of the ground, the relief as well as the plan. It is a sketch, in the sense that it is made with simple and portable instruments, rapidly, and with strictly limited means; and it has no claim to great precision.

Exploratory mapping of this kind has many uses. In warfare it serves to produce temporary maps which shall serve all the purposes of a regular topographical map far in advance of the possibilities of a regular survey: such, for example, was the map of Burmah made in 1885 by two officers of Royal Engineers at the time of the expedition to Mandalay. In peace it may serve as a necessary preliminary to more detailed operations of survey, or to illustrate the work of a scientific expedition making a thorough study of an unmapped region, in geology, archaeology, or what not. And finally, in the teaching of geography it is admirably adapted to serve as a means of instruction in mapping which is within the powers of students, and can be executed in a limited time, with relatively simple instruments.

Such a topographical sketch may be made with the prismatic compass and a simple instrument for measuring slopes, such as the Watkin clinometer. Or it can be made with much greater accuracy, but at the expense of heavier and more costly tools, with the plane table and a clinometer of the pattern used on the Survey of India, and known familiarly as the Indian clino. In all the operations of survey the accuracy obtainable is limited by the time which can be given to the work, and the amount of baggage which it is possible to carry with the party. It is of great importance to have a clear appreciation of this principle. Much time may be saved by careful consideration before starting, of the degree of accuracy aimed at, and of the precise equipment necessary to obtain this in the most economical way. And much time is wasted by aiming at minute accuracy with rough and rapid methods, on the one hand; or by using for what should be rapid work an instrumental equipment more suited to a higher degree of deliberation and precision.

Whatever the instrumental outfit adopted, the same principle runs through all sketching, that a framework must be constructed by triangulation from a measured base, and that all detail must be hung upon this framework. If the position of one point of the triangulation can be determined in latitude and longitude by astronomical methods, such as we have already sketched in Chapter III, so much the better; and again, if the sketch can be orientated correctly by an azimuth determined astronomically, again so much the better. But such determinations should be regarded as outside the limits of the methods of field sketching themselves. They add an excellent finish to the result, but they are not an essential part of the process, and we shall not deal further with them in these chapters.

Compass sketching.

The instruments are

(1) the prismatic compass, of which the military pattern is by far the best, and also the most expensive, because it is fitted with arrangements for marching by night, which are not essential in work by day. (See Plate XIII);

(2) the protractor, a graduated scale by means of which the observed angles are laid down on the drawing board, and

distances are scaled off. Again, the military pattern, as described in the *Manual of Map Reading and Field Sketching*, is the best, and more expensive than simpler patterns, which can be used, though not so conveniently;

(3) a board on which drawing paper can be mounted, and which should have some kind of waterproof cover to protect the work from damage by rain;

(4) a good pencil, of the degree of hardness HH or HHH, which will take and preserve a fine point like a needle, and which should be protected in the pocket by a point protector.

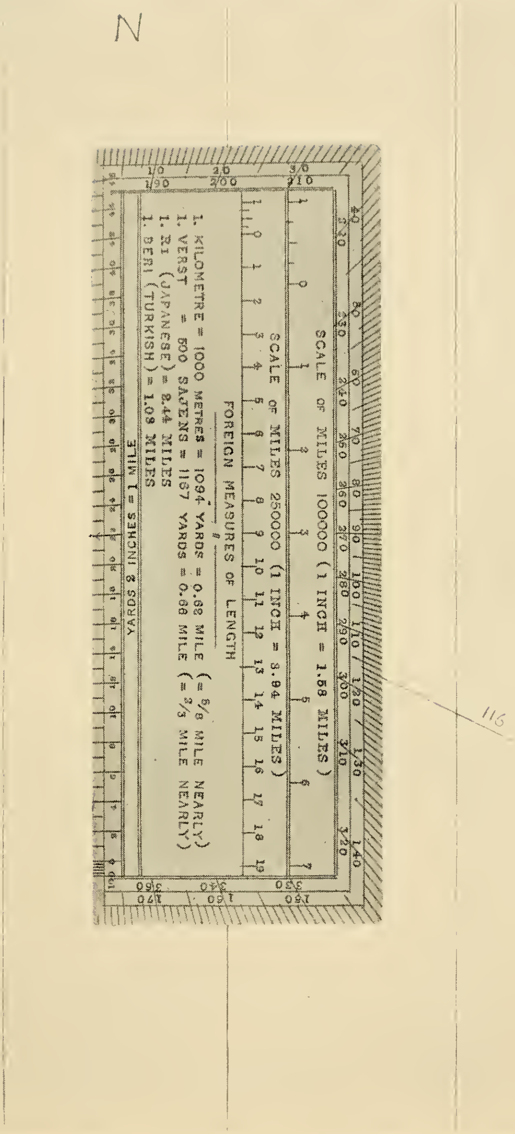
It may not be superfluous to observe, for the benefit of the beginner, that good quality in paper and pencil is essential to success. The paper has to stand a great deal of wear and much rubbing out; and it will often get damp. At the end of work in the field it must be in condition to be cleaned up, inked in, and perhaps coloured. Only good drawing paper will be in this good condition when the sketch is finished; inferior paper will have gone to pieces. Nor can any good work be done unless the pencil will take and keep a fine point; and inferior pencils are the cause of endless waste of time and inaccuracy in work. Therefore do not grudge the few pence that will buy the best paper and pencils instead of the very inferior stuff in ordinary use.

The compass.

It would be tedious to describe in detail the features of an instrument which cannot be understood until the instrument itself is taken in the hand, but which then become almost self obvious. We will confine ourselves to some general remarks on compasses and their use.

The compass card must be graduated right round from 0° to 360°. Any other method of division is almost useless. The readings increase as one turns from magnetic north, reading zero, through east to south, and round again by west to north.

It is essential that the compass, when not in use, should have the card raised off the point by the catch fitted for this purpose,



The Service Protractor.

or the card will rattle about, and the point of the needle on which it rests will be blunted.

To try if the point is in good condition, open the cover out flat and lay the compass on a level table (as in Plate XIV). When the card has come to rest, turn the compass steadily in a horizontal plane, and see that the card remains at rest though the case is turned. If the point is good the card will not drag after the case but will remain almost unmoved.

The prism, with one face ground into a lens, allows the eye to see at the same time the graduated compass card, and the distant object. To provide for differences in the focal length of different eyes, the prism is mounted on a slide, so that the card can be brought into clear focus for any eye. Place the compass at the edge of a level table, and draw out the prism to the end of its slide. Look in at the compass card, and gradually depress the prism until the divisions of the card are seen perfectly distinctly. Note the position of the prism in its slide, and if the compass is your own property make a mark to show where the prism should be placed without having to redetermine it on another occasion.

In the use of the compass it is necessary to acquire the trick of seeing comfortably at the same time the distant object, the line in the cover of the compass superposed on it, and the compass card mingling with it, so that one may read the degrees of the card to which the line points.

It is possible to see at the same time the distant object and the line close by, because they are viewed through the slit above the prism; this slit restricts the pencils of light entering the eye to pencils of narrow angle, so that the eye can focus on them readily enough, though they come from objects at such different distances.

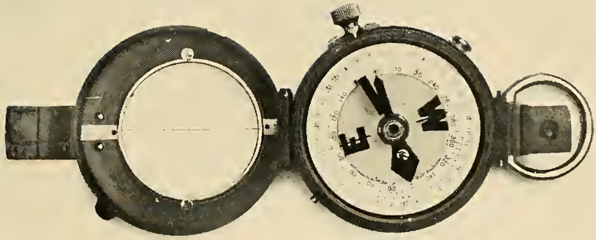
It is possible to see the wire coming down over the compass card, because the view slit crosses the pupil of the eye from top to bottom. The light from the distant object enters the upper part of the pupil, and forms an image on the retina. The light from the compass card, reflected by the prism, enters the lower part of the pupil, and also makes an image on the retina. Across the centre of the field of view, where the illumination from the two sources is fairly equal, the two images are visibly superposed, and one may see the wire as if it were actually coming down and cutting the compass card. To get the right effect, it is necessary that the two images should be nearly of the same brightness. Their relative brightness can be altered by moving the eye up and down along the slit, so that more or less of the pupil is exposed to the light from the object, and less or more to that from the card. The compass card, or dial, is engraved on mother-of-pearl in the best compasses, because that reflects a great deal of light, and gives an image of the card as bright as the image of the distant landscape, which is often very bright indeed.

It is very common to see a beginner with the compass tilting it forward and downward, in the effort to see the two images plainly at the same time. This has the effect of dropping the card away from the prism, and putting the scale divisions out of focus. When one has determined the proper position for the prism, as explained above, the loss of focus is a plain indication that the compass is not being held level, which is dangerous, because the card may foul and give a quite wrong reading. Therefore it is well to be very sure about the proper position of the prism, and use this control over the tilt of the compass.

Avoidance of local deflections.

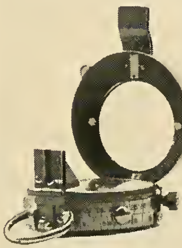
It is a commonplace that the compass becomes deranged and gives false readings if there is a mass of iron anywhere in the immediate neighbourhood. Yet it is very common to see beginners with the compass leaning against a bicycle or an iron gate, or taking bearings from the point of vantage that a bridge over a railway gives. Such mistakes are, of course, soon realised and avoided; but it is not so easy to guard against less obvious sources of error, such as a water main under the road.

Should there be any suspicion that abnormal attraction exists at the spot from which bearings are taken, it is easy to walk directly towards the objective, and repeat the bearing observation twenty or thirty yards further on. If there was



1. Prismatic Compass. Mark VI. Opened out flat.

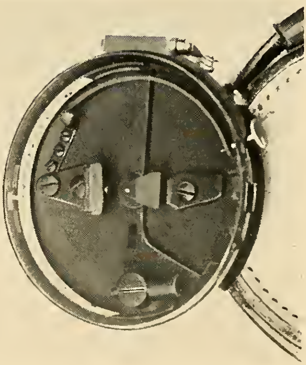
2. Compass in use.



3. Compass in position for use.

4. Clinometer in use.

5. Watkin Clinometer.



6. Interior of Clinometer.

Instruments for Compass Sketching.

local attraction at the first point, it will probably be different at the second, and the error will be detected.

These remarks apply to strictly local attractions, such as are caused by fairly small masses of iron at close quarters. In some countries, such as South Africa, the whole ground is full of magnetic rocks, and the compass is practically useless.

The compass sketch.

The principle is exactly the same as in triangulating with the theodolite. A base is measured, and a framework of triangles is observed. The principal difference is, that the angles of the triangles are not determined as such, but as the differences between the observed magnetic bearings of the respective sides. Each side of a triangle is drawn as a line making a certain observed angle with the magnetic meridian, and is subject to the errors which are inseparable from these determinations of magnetic bearing. Hence we may expect errors of at least half a degree to occur with frequency. And a deviation of half a degree is equivalent to a shift of one-twentieth of an inch at a distance of six inches, which is very much larger than the uncertainty of drawing. Hence we must realise that compass sketching is far from being an exact process, and must avoid putting too much time into a method which is incapable of giving anything like accuracy. Its merit is that it is quick, and that the instruments required are easy to carry about.

Plotting the bearings.

The observed magnetic bearings are plotted with the protractor. The paper is ruled with parallel lines to serve as magnetic meridians, and one end of these lines is marked North. To protract a given bearing from any point the protractor is placed with its centre on the point, and its long side parallel to the meridians as drawn on the paper. If the angle is between 0° and 180° the ray will lie to the east, and the protractor will be placed so that it lies east of its centre. (*Note*: the centre of the protractor is the centre from which the angular divisions are struck, and is marked by a small arrow pointing to one edge.) If the angle is between 180° and 360° the protractor is put down to the west of the centre, and an inner line of figures is used. All this is complicated to describe, but it may be learned by inspection of the instrument without any difficulty. To save mistakes, one should always ask oneself, Where roughly is the ray? If this is done, the protractor cannot be placed in the wrong position.

The base.

The necessary qualifications for a base are that it should be possible to see plenty of surrounding points from each end; and that it should be practicable to measure roughly from one end to the other. Generally speaking, one has little opportunity for picking and choosing in selecting the base for a compass sketch. The sketch must be made without delay, and it is necessary to start without an elaborate search for a good base, which is always hard to find. The length of the base may be determined by pacing, or by measurement with a calibrated bicycle wheel. And it should be remembered that even if the base is ten per cent. wrong in length, the effect on the sketch is only that it is increased or diminished in scale; it is not distorted, and if an opportunity occurs it is easy to make a new determination of some length and draw a new scale for it.

In the *Manual of Map Reading and Field Sketching* the base is defined as a line carefully chosen and accurately measured, upon which the accuracy of the sketch depends. This definition evidently needs qualification. In sketching and exploratory work generally the first possible site must be chosen for the base, without delay for consideration of other and perhaps better sites which might be found on further reconnaissance. And the base will be measured, not accurately, but as well as the circumstances of the case permit. The accuracy of the scale of the sketch depends upon it, but not the shape. The unnecessary stringency of the official definition might lead to a great waste of time in an operation where rapidity is often the first consideration.

In pacing a base, it is often necessary to make some allowance for curvature of the way which the observer is compelled to go from one end to the other. Care should be taken that the correction is not overestimated. On looking along a road, the divergences to right or left look very much more important than they really are. Divergences of fifty yards will make a road look very crooked, but they have very little effect upon the length of a mile of road between two points. Two or three per cent. reduction will be enough to allow for apparently quite considerable deviations.

The measured length of the base is laid off by means of the scale on the protractor, giving hundreds of yards on the scale of two inches to the mile.

The ruling points.

The points that are chosen to make the triangles are termed *ruling points*. They will be natural objects such as church towers, isolated trees, haystacks, and so on. Trees are to be avoided as much as possible, because a tree that seems to be very easily distinguished from one point of view may be quite inconspicuous from another, or another tree may be mistaken for it.

Objects which can be seen but not occupied are also to be avoided, because to carry on the triangulation it is necessary to occupy points in succession. Such objects as steeples among trees, which cannot be occupied, and from the base of which nothing is visible, are not much good as ruling points. But they serve subsidiary purposes as "intersected points," as we shall see.

The process of sketching.

Select the base. Occupy one end of it. Take the bearing of the other end, and plot it. Then take and plot the bearings of any points round about that seem to be suitable for ruling points. Be sure that plenty of these points are taken at the start, for as the work proceeds one will find that some of the chosen points prove to be unsuitable, and must drop out of use. Unless plenty have been taken to start with, there is danger that too few may be left.

Pace from one end of the base to the other, and scale off the distance from the protractor, making if necessary a suitable deduction for crooked pacing and slope. The further end of the base is now fixed. Take bearings to as many of the ruling points as possible. At least two points should now be determined, one on each side of the base. Proceed to these, and continue the process of observing and plotting the rays to the ruling points.

When the framework is thus built up, the second stage of the process begins. There will be important points, say at cross roads, which have not been fixed by intersections; they will now be fixed by resection, that is to say, by taking bearings from each to two ruling points already fixed, and drawing rays back on those bearings until they intersect. The point of intersection will evidently fix the point under occupation.

Round about the intersected and resected points, the detail is sketched in by eye estimation. This will not be very accurate, but it will be rapid, which is the most important consideration. And error cannot accumulate to a serious extent, because the whole is controlled by the triangulation. The accomplished sketcher learns to economise in the use of instruments, and after the triangulation is done, he relies principally upon estimation for his intermediate detail. Also, he does not wait till the triangulation is done to begin the detail, but puts in as much as possible around each point that he occupies.

Facility in sketching cannot be taught except in the field, and success depends upon cultivating an eye for country, so that the greatest possible economy of means may be practised. But it is possible to show certain ways of economising.

For example, if it is important that a given road should be fixed as accurately as possible: it is sufficient to fix every alternate angle by resection, and to put in the intermediate angles by rays drawn down the road. Or again, if a village is to be sketched, it is usually wasteful of time to work right through it from one side to the other. Instead of doing so, work round the outside of the village, fixing points on the roads that approach it, and the directions of those roads. Having laid down the roads leading to the village, it will generally be easy to sketch the whole of the necessary detail of the village itself without being obliged to make any instrumental fixings inside. Many time-saving methods such as this will be learned by experience.

The clinometer.

This instrument measures the angle of slope. As with the compass, it is tedious and unnecessary to describe the instrument minutely, since its use is almost self-evident when the instrument is taken in the hand. (See Plate XIV.) But a few principles that are not quite evident may be examined here.

In the first place, remember that an error in the zero of the clinometer is fatal to success in its use. If the compass has an error of zero, the whole sketch is slewed round by that amount, but no further harm is done. But if the clinometer has such an error, that is to say, if the clinometer reads angles of elevation too small, and angles of depression too large by the same amount, the effect on the differences of height measured with the instrument are very serious. The difference of height between the top and the bottom of a hill would seem to depend upon whether the observations were made from the top or the bottom.

Hence the state of adjustment of the clinometer should be examined every day that it is used, for the process takes only a minute or two. Observe the same ray from opposite ends. Suppose that it reads Elevation 2° at one end, and Depression 3° at the other. Then evidently the clinometer reads half a degree low, and a correction to allow for this must be applied to all the readings made with it. It is better to determine this correction and apply it mentally, than to try and adjust the instrument by opening it up and turning the adjusting screw. This is a tedious process; and it is apt after a little to leave the screw loose, so that the error varies with every jar that the instrument receives.

The clinometer measures the elevation or depression of one point as seen from another, in angle. To convert this into difference of height in feet we must know the distance between the two points in yards. This is taken from the sketch by means of the scale of yards on the protractor. We then apply the rule

$$\text{Difference of height in feet} = \left\{ \begin{array}{l} \text{horizontal distance in yards,} \\ \quad \text{divided by twenty, and} \\ \quad \text{multiplied by the slope} \\ \quad \text{in degrees.} \end{array} \right.$$

The proof of this rule is very simple. A slope of one degree is equivalent to a rise of one foot vertically in a distance of 57·3 feet horizontally. Since 57·3 is an awkward number to deal with mentally, we substitute 60, which is near enough to correspond to the accuracy of the whole process. The 60 becomes 20 because the vertical intervals are measured in feet, while the horizontal distances are measured in yards, by old standing tradition. The rule now becomes evident.

It is easy to see that the process is the more accurate the shorter the distances involved. Suppose the slope is one and a half degrees, and the distance 2460 yards. The vertical interval is 2460 divided by 20, and multiplied by 1·5, or 185 feet. But suppose that the slope had been one and three quarter degrees; the vertical interval would then have been 215 feet. A quarter of a degree, which is less than the instrument can give with certainty, makes a difference of 30 feet in the result, and this difference is evidently proportional to the horizontal distance between the two points. At a thousand yards a quarter of a degree makes a difference of twelve feet, so that it is useless to expect to obtain heights with the clinometer which are correct within a few feet. In gently undulating country, where the distance from point to point will tend to be large, while the uncertainty in the measure of the slope is an important part of the whole quantity, the results given by the clinometer are very likely to be inconsistent and confusing.

Assumed datum height.

In making a compass sketch it is not commonly the case that the height of any point above sea level is known. It is then necessary to make an intelligent assumption of some height to start with. This is called the assumed datum, or given height; and all others are reckoned from it as zero. All figures of heights entered on the sketch should be referred to this datum; they should never be entered as differences from some other point, but always as heights above sea level or datum, with the assumed datum.

Sometimes it is convenient to determine the height of the top of a tower which may be visible though the base is not. Such heights should be entered in a list on the edge of the sheet; no figure, except the height above sea of the ground itself, should ever be written alongside the object on the sheet.

Contouring with the clinometer.

The most ready method of showing the relief of the ground is by sketching the contours or form lines: the latter being the rougher and more sketchy attempts at the former. Since time is always of the greatest importance in this class of work we must be careful that we limit the use of the instrument to the smallest possible number of observations, and that these observations are so disposed that they produce the greatest effect.

The first step is to obtain the heights above sea, or above datum, of the ruling points; this gives a framework of spot heights upon which to construct the contours. We have already seen how the height of one point is found when the height of some other visible point is known.

The second part of the process is to find how the contours lie round about one of these spot heights. Suppose that the ground slopes away uniformly in a given direction, at a slope of 2°. What is the interval in yards on this slope between contours having a given vertical interval? The question is easily solved by inverting the relation given above, and writing it

$$\text{Horizontal interval in yards} = \left\{\begin{array}{l}\text{vertical interval in feet,} \\ \quad\text{multiplied by twenty and} \\ \quad\text{divided by the number} \\ \quad\text{of degrees in the slope.}\end{array}\right.$$

Thus if the vertical interval adopted for the contours is 25 feet, on a slope of 2° the contours are spaced at a distance of 250 yards apart.

Suppose then that the spot height is 284 feet. Down the slope the first contour is that for 275 feet. Here the vertical interval from the spot height to the first contour is 9 feet, and its horizontal distance is therefore nine twenty-fifths of 250 yards, or 90 yards. Take the protractor and scale off 90 yards along the line which marks the direction in which the slope has been measured. This brings us down to the 275 contour; thence scaling off successive distances of 250 yards we obtain points on the 250, 225, 200, and succeeding contours, so long as the slope remains uniform.

Repeating this process in a different direction we obtain other points on the same contours ; and these are eventually joined up by sketching.

It is clear that this process may be very wasteful of time unless care is taken that the lines of points so determined are dominant in the construction of the contours. It is almost impossible to lay down in a book the principles of economy in contouring which can be learned only by practice in the field. But one general rule is clearly useful. Run these lines of points, or contour ranges, as we may call them, along the ridges and the valley bottoms. With a range along each crest and one up the floor of the valley it is possible to sketch the whole of the valley contours without the possibility of going far wrong.

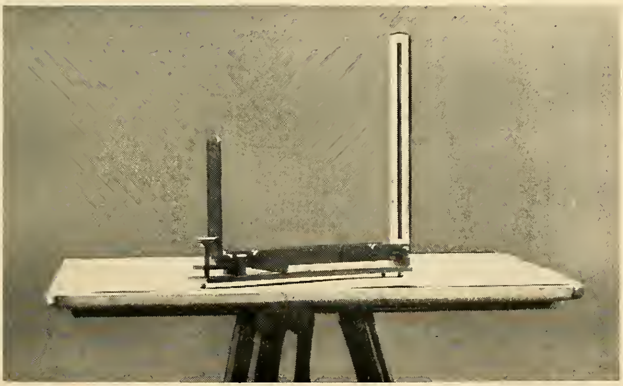
Beginners are apt to find this process of contouring with a clinometer somewhat confusing, and are to be seen working out the necessary small calculations on paper. This should never be required. The student should train himself to do all the calculation mentally, always remembering that the process is at best only a rough one, and that quantities of a foot or two have no real significance. Otherwise it would not be legitimate to use the convenient whole number 20 in place of the more accurate 19·1.

The older pattern Service protractor has scales which show the horizontal distances between contours for each degree of slope on two different scales. These are not of much use, since it is difficult to interpolate for the fractions of degrees. It is far better to accustom oneself from the start to work out mentally the distances in yards, and to take these off the scales of yards found on the protractor.

Height above ground of the observer's eye.

In strictness it should be necessary to take account of the fact that the observations are made from a point about five feet above ground. On short rays one may take sufficient account of this by observing to some object such as a bush or the top of

1. Plane Table and Sight Rule: School of Military Engineering pattern.



2. Indian Clinometer on Plane Table.

nstruments for Plane Tabling.

the hedge, which is judged to be of about the same height as the observer. On long rays the effect of neglecting this precaution becomes inappreciable.

The plane table.

The plane table is unique among survey instruments in that it enables the surveyor to draw a map without measuring any angles or doing any numerical work, except in the contouring. The plane table is, in fact, a drawing instrument, by means of which the map is drawn in the field without the intervention of any angle measuring instruments. It is exceedingly well adapted for rapid survey, and is very much used for making maps in a hurry, as may be necessary in military operations in an unmapped country, or during any rapid exploration.

The instrument consists of a drawing board covered smoothly with drawing paper, and mounted on a light but rigid tripod, upon which the board can turn, and can be clamped in any position desired. The accessories are:

(1) a sight rule, preferably of boxwood, having folding sights which can be turned up at each end. One sight has a narrow vertical slit in it; the other consists of a vertical wire stretched across an open frame;

(2) a trough compass, which is a long compass needle mounted in a narrow box, with a short scale at each end. When the needle is pointing to the centre of the scale at each end it is parallel to the sides of the box;

(3) a hard, well pointed pencil of good quality.

The sight rule should be graduated along one edge in inches, and along the other with a scale of yards corresponding to the scale on which it is proposed to work: very frequently the scale of two inches to one mile.

The plane table has two principal uses, which must be distinguished one from another. It can be used to produce a complete map, entirely by its own resources, without the use of any other instrument than the accessories which normally accompany it; the triangulation can be made with it, and the whole detail filled in with it. Or it can be used to fill in the detail after the triangulation has been made with the theodolite. The first is the use to which it is put in rapid and exploratory mapping ; the second is its rôle in the more leisurely operations of the precise survey of a large country, such as India or South Africa.

We will begin by considering its use in rapid survey or reconnaissance.

Graphical plane tabling.

By graphical we mean that the plane table is to be used as a drawing instrument, to make the complete map without other instrumental aid. Both triangulation and detail are to be done with it.

The principles of the triangulation are naturally the same as those which we have already considered in compass sketching, and it will not be necessary to repeat that the process consists of measuring a base, and building up on it a framework of well proportioned triangles.

Measurement of the base.

The base must be chosen in as open and level a piece of country as can be found, and its ends must be marked in some conspicuous way, so that they are visible one from the other, and from the surrounding points which will be occupied in succession to extend the base and start the triangulation. Plane tabling is a much more accurate process than compass sketching, and a correspondingly greater degree of care is required in choosing the ground for the base.

If time allows, beacons may be erected to mark the ends of the base and the ruling points. But beacons are by no means necessary in a rapid graphical triangulation, and we shall suppose that they are dispensed with. But we shall remember always that the more accurately defined the ruling points are, the more accurate will be the result.

Let us take two solitary trees or posts on a straight open road, being careful to see that they can be identified with certainty from the surrounding country, and not confused with neighbouring trees or posts. We shall get the base as long as possible: perhaps from half a mile to a mile long.

We have now to measure the base, and the more accurately the better. If chain or steel tape is available, it should be used. Failing these, a good deal can be done with a carefully calibrated bicycle wheel; and failing any kind of measuring instrument the base must be paced. The error of the result may in this case be three or four per cent. But this affects only the scale of the map, not the relative configuration of points marked upon it. And for many purposes the exact scale of the map is not very important, so long as the topography is correct.

Plotting the base on the plane table sheet.

The base is measured in yards, and the length corresponding, on the scale of the intended map, is taken from the scale of yards on the edge of the sight rule. Consider the position of the base in the area which is to be mapped, whether it is to the centre or to the side; draw a fine line with the sight rule in the convenient position, and lay off on it the length representing the base measure, making fine perforations in the paper with the sharp hard point of the pencil, so that other rays may be passed accurately through these points when required. It is well to draw continuations of the line on which the base is to be laid off, at each end of the sight rule, so that the rule may be laid down accurately along its original direction in a subsequent step of the process; usually the base line is so short that the rule cannot be laid down on it again with any great precision.

Call the ends of the base *A* and *B*.

Set up the plane table at *A*, as close as possible to the mark. In plane tabling on the scale of two inches to one mile, one hundredth of an inch represents about eight yards on the ground, so that divergences of a yard or two from the exact position of the station are hardly visible upon the map, being within the limits of error in drawing. Lay the sight rule along the line of the base on the table, and turn the table till the line of sight falls on *B*; then clamp the table. Beginners find some difficulty in sighting along the rule, and are seen looking sideways in very awkward positions. It may be helpful to say that the correct position for plane tabling is as nearly as possible the correct position for wicket-keeping in cricket.

Beginning the triangulation.

The last process has set the plane table. That is to say, the base line drawn on the table is parallel to the base line on the ground. And the point A on the table is over the corresponding point on the ground. We can therefore draw the ray from A to any other point by placing the sight rule so that its edge passes through A on the table and is directed to the point C on the ground. A convenient way of manipulating the sight rule is to stand the pencil (hexagonal) with one corner on A, holding it with the left hand, and with the right hand swing the sight rule about this corner as a pivot until it is sighted on the point C. Then carefully rule a line passing through A towards C. It is essential that the pencil have a fine needle-like point, and that it be held carefully to make a line really parallel to the edge of the rule. It is not necessary to draw the whole line AC. Make an estimate of the distance of C; suppose it is one mile and a half. This will be three inches on the paper if we are working at two inches to one mile. Draw then a piece of the line only, about three inches from A. If the piece is not long enough it may be lengthened later. But it should be remembered that all the rays drawn must be rubbed out in the end, so that it is economy to draw as little of the ray as will serve its purpose.

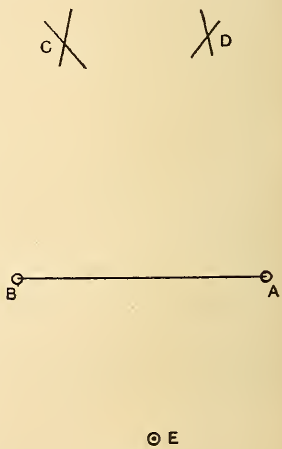


Fig. 14.

In the same way draw rays to other points D, E, F ... which may be useful as ruling points. We leave A with the knowledge that all the points C, D, E, F, ... which are to be mapped lie somewhere on the lines AC, AD, ... which have been drawn; their precise positions will be determined by other rays drawn from B ... intersecting these first lines.

Now move the table to B, and set it by laying the sight rule along the line BA and turning the table until the rule is set on A. The table is now set ; that is to say, it has been moved from A to B parallel to itself, so that any line already drawn on the table is parallel to its position on the ground. Having set the table we draw rays BC, BD, ... to the points already observed from A, or to as many of them as are visible from B ; and thus C, D, ... are fixed.

Two points, one on each side of the base, must be fixed by the intersections of two rays only, from A and B ; and it is important to see that these intersections are as nearly at right angles as possible. A good intersection is a blunt intersection. When the rays cut one another acutely a small error in either will make a good deal of difference in the place of the intersection.

From C and D we proceed to fix other points ; and we must not accept any point as well fixed unless it depends on three rays which intersect in a point without visible deviation. Working on in this way we build up a framework of triangles upon the base in the same way as we did in compass sketching. But the accuracy of the result is considerably greater.

Choice of stations.

Only experience in the field can teach how to select the stations of a triangulation with advantage ; and the selection will naturally be governed by the nature of the country. The stations must fulfil many conditions :

(1) they must be in commanding positions, so that stations all round are visible from them ;

(2) they must be well marked natural or artificial objects, such as a sharp summit of a hill, or the trunk of an isolated tree, or the top of a tower. The top of a tree surrounded by low growth, and the point of a steeple, are not suitable objects to select for the continuation of the triangulation, since they cannot be occupied in their turn ;

(3) they must make well conditioned triangles, with no very acute angles.

It will often happen that without a preliminary reconnaissance and occupation of the proposed stations, the surveyor will be deceived. A point ahead may appear to be an admirable station, but when it is occupied it may be found that further progress is obstructed by natural or artificial obstacles which could not be seen from the last station. It is therefore advisable to draw rays to more points than are really required for the triangulation. This will allow for the dropping out of stations which prove in the end to be unsuitable.

It is one of the great advantages of plane tabling that a great number of rays may be drawn with very little trouble, so that superfluous rays need cause no regret, and the survey can go ahead without preliminary reconnaissance. In a theodolite triangulation the case is very different. Here a reconnaissance is absolutely necessary, for selecting and beaconing the stations, and by far the best kind of reconnaissance is a plane table triangulation.

The use of the triangulation.

When the triangulation is complete our plane table sheet is covered with a series of rays intersecting in points, which are conspicuous points about the country, tops of hills, isolated trees, church towers, and so on. The triangulation is the skeleton of the map, but the visible map is not yet begun. It may be that we do not propose to go any further immediately. We have laid out the framework of triangles; from this we can select the particular scheme best fitted for observation with the theodolite, and we are then ready to beacon the country for the deliberate observation. But if time presses, and we wish to have an approximately complete map as quickly as possible, we must dispense with the precise triangulation, and proceed at once to fill in the detail of our plane table sheet.

The map is to show the natural features of the country, hills, valleys, and rivers, and the artificial features, railways, roads, and towns. These, the most important topographical features, are not as a rule marked by upstanding conspicuous points suitable for triangulation stations, while, on the other hand, very excellent triangulation stations, such as isolated rocks or trees, are not features that will eventually appear at all upon the topographical map. Our skeleton, then, is no part of the map proper, and is destined to disappear in the end, leaving no sign of the rays which constructed it, and only the small triangular signs to mark the stations which were used.

Accuracy of the graphical triangulation.

The sight rule can be set upon an object with an accuracy of two or three minutes of arc; this is readily seen if we consider that the diameter of the sun or moon is about thirty minutes of arc, and that they are very large objects to set upon if we view them along the sight rule when they are near the horizon. It is not hard to set with an accuracy less than one tenth of the diameter of the moon. On the other hand, the error of a compass bearing, observed without a tripod or other rest for the compass, is likely to be at least half a degree. Hence the rays drawn on the plane table are very much more accurate than those plotted from compass bearings. By increasing the bulk and weight of our apparatus we have much increased its accuracy. This is a simple example of the general principle that the accuracy of any survey process is limited by the weight one is prepared to carry and the money to be spent.

Difference in principle between plane tabling and compass sketching.

It is important to note the difference in principle between plane tabling and compass sketching, as regards the construction of the triangulation. In compass sketching each ray is plotted independently as an absolute magnetic bearing. In plane tabling the board is set up at each new triangulation point by sighting back with the sight rule on one of the other points already well fixed. The process depends only on the care with which the settings are made, and the stability of the table. Up to this point the compass does not enter at all into the work; and we are free of the various errors, such as local attraction and daily variation of the compass, which limit so much the accuracy of compass work.

Intersected points.

The stations of the triangulation are perhaps two or three miles apart. As each one is occupied we take advantage of its commanding position to draw rays to all the conspicuous objects round about—not with the idea of occupying them in turn as triangulation stations, but in order that they shall be well fixed by intersecting lines. In this way a great number of steeples, chimneys, well marked trees, and such objects, will have been put in on the plane table sheet. These are called Intersected points. In what follows they serve as auxiliary to the principal points of the triangulation; and like them, are destined in great part to disappear from the finished map, since they are often of no topographical importance.

The use of the trough compass.

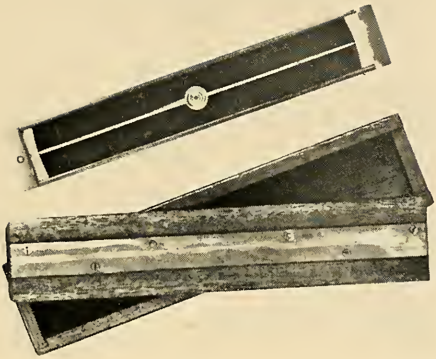
At some point of the triangulation, when the table is orientated by setting on another triangulation point, the trough compass is taken from its case and laid on the table, with the end of the needle which is marked with a cut toward the north. The compass is turned until the needle points to the zero of the scale at each end. The needle now lies in the magnetic meridian, and the sides of the box, being parallel to the line of zeros of the scales, are also in this meridian. Draw pencil lines along the sides of the box, and mark the north end. (See Plate XVI.)

Now at any point whatever of the ground we are able to set up the plane table in approximate orientation. Set up the table; take out the trough compass and place it on the compass lines drawn as above, taking care that the north end of the needle lies to the end marked north. Then turn the table until the needle points to zero. The table is now orientated as accurately as the compass permits, that is to say, within about a quarter of a degree, unless there are magnetic disturbances about.

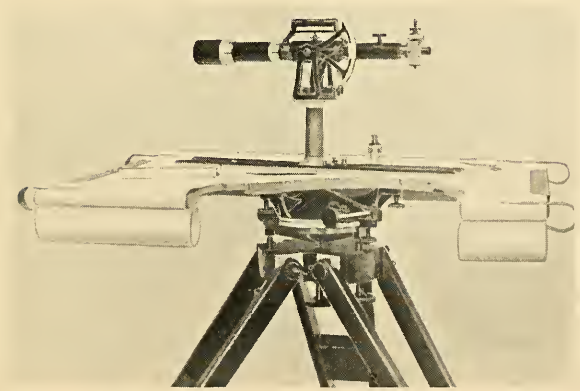
The purpose of this orientation by compass is to facilitate the process of resection which follows.

Filling in the detail.

Up to the present we have been fixing well marked points by drawing intersecting rays from other points previously determined. When a sufficiency of these have been fixed, we begin the new operation of putting in the important topographical detail, the roads, fords, railway bridges, and so on, which are inconspicuous objects in general, as viewed from the ruling points, and cannot be determined by intersections. But, on the other hand, the ruling points should be quite conspicuously visible from them; and if three are visible we can (with certain limitations to be discussed at a later stage) set up the plane table



1. Trough Compass and Case.



2. Plane Table and Telescopic Alidade: United States Coast and Geodetic Survey.

Instruments for Plane Tabling.

and determine the place on the map, by the process known as resection. Perhaps retrosection would have been the better term, since the process consists of drawing rays backwards from the ruling points. A point determined by resection is often called a plane table fixing.

Plane table fixing by resection.

Whenever three ruling points, suitably disposed, are visible, a plane table fixing may be made. The conditions for suitability are

(1) that the points are not too close together, neither is one nearly opposite another;

(2) that they do not lie nearly on a circle passing through the point which is to be fixed.

The reason for these restrictions will appear in due course.

By means of the trough compass set up the table in approximate orientation. Set the sight rule so that it is directed to one of the points, while its edge passes through the place of this point on the table; and draw a ray back. Do the same for the other points. If the three ruling points were correctly fixed, and the table in correct orientation, the three rays would meet in a point, which would be the point on the table corresponding to the place where the table stands on the ground.

More often than not the three rays do not meet accurately in a point, but make a small triangle, which is called the triangle of error. This is not due primarily to any error in the positions of the ruling points, nor to inaccuracy in drawing the rays, but to error in the orientation of the table as set up by the trough compass. The compass cannot be relied on to within half a degree at the best; and there may be iron pipes under the road, affecting it. Moreover, owing to the convergence of the magnetic meridians, lines drawn along the magnetic meridians at different parts of the sheet will not be accurately parallel to one another. In dealing with the triangle of error we assume that the whole of the error is due to this faulty setting up of the table.

Solution of the triangle of error.

It might be supposed that when there is a triangle of error, the true place which we are trying to fix would be at the centre of gravity of the triangle. But this is entirely wrong. It is not necessarily inside the triangle at all, as will be seen from the following considerations.

Let A, B, C be our three ruling points on the map, and O the point in process of fixing. If the table is not rightly orientated it is rotated about the point where it stands on the ground, and we may represent this by turning it in our figure about the point O on the map, so that A, B, C are moved to A', B', C' on the table.

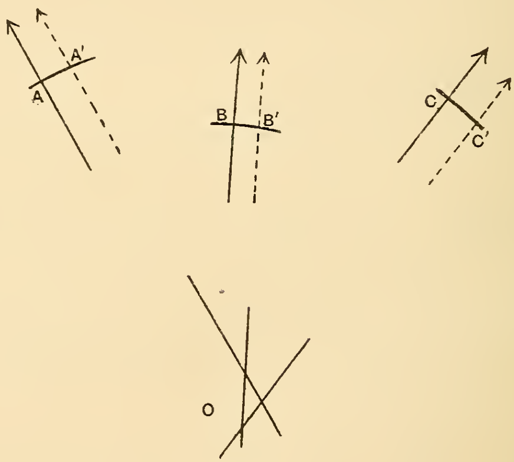


Fig. 15.

Now draw the rays again. Since the real points are distant, the new rays will pass through A', B', C', and will be parallel to the old rays. They will intersect to form a triangle; but O is more likely to be outside than inside the triangle.

The student is advised to draw a few cases for himself. He will then easily understand, and be able to prove, the following rules for constructing the point O from the triangle of error.

Rule 1. If the table is set up within the triangle formed by the three points on the ground, the place of the table on the map will be inside the triangle of error; if not, it will be outside.

Rule 2. The point *O* will lie always to the right or always to the left of the three rays, as one looks along them to the points from which they are drawn. (It will be seen that Rule 1 is really included in Rule 2, but it is convenient in practice to state the two separately.)

Rule 3. The perpendicular distances of *O* from the three rays are proportional to the distances from the table of the corresponding points on the ground.

To take an example as in the figure. Let the three rays be drawn as shown, and let *O* be outside the triangle *ABC* on the ground.

By Rule 1 *O* on the map is outside the triangle of error.

By Rule 2 it cannot be in either of the sectors marked by shading.

By Rule 3, for the proportions of the perpendiculars, it cannot be in the remaining right-hand sector, but must be in the left, at the point indicated.

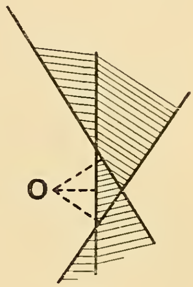


Fig. 16.

The method of making a plane table fixing is complicated to explain. After a little instruction and practice in the field it is perfectly easy and rapid in execution. And it is the most ordinary operation in plane table survey. Point by point plane table fixings are made all along the roads, rivers, and railways; and thus the detail of the map is quickly filled in. It will be understood that only practice in the field can show how to economise effort by making the fixings at the points where they are most effective. No written explanation can give an eye for country.

Check on the solution of the triangle of error.

If the triangle of error is large, or the surveyor inexperienced, it is well to have a check on the accuracy of the solution that has been made. This is very simple. By hypothesis the triangle has arisen from bad orientation of the table. When the first solution has been made, lay the sight rule along the point which the solution gives, and one of the ruling points which has been used. Look along the sight rule, and the distant point will be off the cross wire. Unclamp the table, and turn it till the point comes on. Then clamp, and repeat the resection. This time the triangle of error should be exceedingly small, if not an exact point, and the solution should give a result very near the first solution. If it does not, something is wrong. Inspection of the solutions will probably show that an error has been made. If, however, the solutions are made according to the rules, and yet give discordant results, then it is probable that there is some error in one or more of the ruling points, and this must be put right by revisiting the triangulation points until all is verified. It is no use trying to get good results from resections until the ruling points are really laid down in their true places.

Case in which the solution fails.

The solution fails when the point which is to be fixed lies on or near the circle passing through the three chosen ruling points. If it lies exactly on the circle the solution becomes quite indeterminate. However wrong the orientation of the table may be, the three rays meet in a point, and it will appear that a perfect result has been achieved. But turn the table round into another orientation, and repeat the process. Again the three rays meet in a point, though quite a different point. This curious result depends on the well-known proposition that all angles in the same segment of a circle are equal to one another.

If the point to be fixed lies very nearly on the circle, the result is very nearly as indeterminate, and no good solution can be obtained. Great care must be taken, therefore, that the three ruling points are chosen so that there is no chance that the problem may become indeterminate in this way. If the three points in order are A, B, C, try to ensure that B is nearer than either A or C. The circle passing through them will then lie far away from the point which is occupied, and the solution will not fail.

Remarks on the part played by the compass.

It is essential that the beginner should plainly understand the part played by the compass in this operation. The compass is an uncertain instrument, and cannot be relied upon to give the orientation right within half a degree. For this reason the orientation of the plane table, when it is set up by compass for the resection, is always to be considered suspect. The size of the triangle of error is an indication of how much it is wrong; and the solution of the triangle of error eliminates completely the effect of the wrong orientation. In fact the compass is used only for convenience, in order that the triangle of error may be small. The compass is not indispensable, and if it is lost or broken the process may be worked without it. Set up the table by estimate in about the right orientation, and make a solution. The triangle of error will be very large, but it can be solved approximately. Re-orientate the table on the result of the first solution, and make a second. This will come out with a very much smaller triangle. If necessary repeat the process again, and this time the result will be satisfactory.

It is clear from this that the rôle of the compass is quite subordinate, and that any error in it will not affect the ultimate accuracy that is achieved.

The plane table a modern instrument.

The discovery of the right use of the plane table is of comparatively modern date, and its credit belongs to the Survey of India. The instrument itself is ancient; but so long as it was employed only for fixing points by intersection, or so long as it was set up by compass, and resections were made by two rays only, it was not a very valuable instrument. The introduction of the method of resection by the solution of the triangle of error made it at once an instrument of precision, unexcelled for convenience and rapidity of work.

Plane table traverse.

In closely wooded or otherwise obstructed country the method of resection may fail because three points cannot be seen. In such cases it is necessary to make a plane table traverse through the awkward area.

Suppose it is required to map a road passing through a village. Make a plane table fixing on the road as near the village as possible. Draw a ray to represent the direction of the road to the furthest visible point. Take up the table, leaving a mark to show where it stood, and pace to the forward point; then measure off the paced distance along the ray which has been drawn. This will give the place of the forward point with fair precision. Set up the table there; orientate it on the back point; draw a new ray forward as far as possible; and proceed as before. In this way the road can be drawn in, leg by leg, until it comes out again into open country, and the whole can then be checked by a plane table fixing. Probably the result of this will not agree with the position as carried through by the traverse, and it will be necessary to adjust the traverse to make it fit on to the plane table fixings.

Adjustment of a traverse.

Suppose that the traverse $ABC...M$ ends at M, and that a plane table fixing at this end makes the position M'. It is

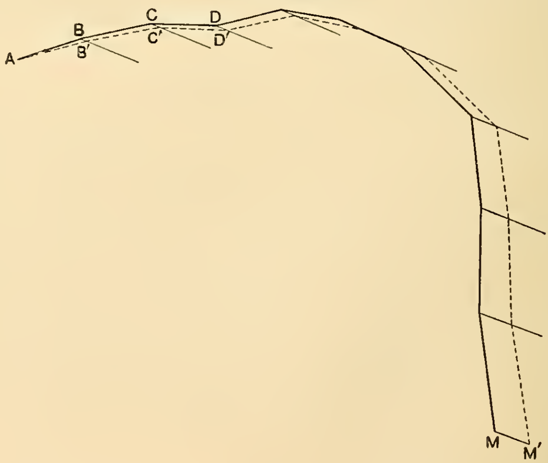


Fig. 17. Adjustment of traverse. The full line is the original; the dotted line is the traverse adjusted to close on M'.

required to adjust the traverse so that it closes on M'. Join MM' and draw lines parallel to MM' through each angular point of the traverse. Each of these points must be moved along its corresponding parallel by a fraction of the length MM'

proportional to the distance from A. This rule is of course arbitrary. It is not pretended that the result is precisely right; but some systematic method of adjustment is required, and this appears to be the best.

In practice the rule is simplified thus: Suppose there are ten legs to the traverse, ending at B, C, D, ... M. The B is moved one tenth of MM', C is moved two tenths, and so on, which brings M to M'; and the traverse is adjusted.

Heights and contours.

For rapid and approximate work the heights and contours can be done with the Watkin clinometer, precisely as in compass sketching, and it is not necessary to repeat here what we have already said on pages 109–112.

For more accurate work the relative heights of the triangulation points are determined with the theodolite, and other heights are determined from them with the Indian pattern Clinometer, commonly called the Indian clino. We will defer a description of this instrument to the chapter on Trigonometrical Survey. See Chapter VI, page 161.

Characteristic signs, and style of drawing.

The appearance of the finished sheet will depend very much upon skill and care in draughtsmanship, and particular attention must be paid to the conventions which are adopted for the representation of both natural and artificial features. These conventions vary to some extent with the style of the survey—for rapid reconnaissance work the style is less elaborate than in the more leisurely operations of an organised survey. For the former, see the characteristic sheet in the official *Manual of Map Reading and Field Sketching*. For the latter, reference may be made to the margins of published maps, or to the characteristic sheets published by the Survey departments.

Elaborate plane tables.

The instrument that we have described is the pattern adopted in the British military service, and carried by field companies of the Royal Engineers. It is set up level by estimation only, and its sight rule has only plain sights, without any optical aid.

Much more elaborate instruments have been introduced, with levels and levelling screws to set the table truly horizontal; with telescopes on the sight rules (then called telescopic alidades), and other refinements which add very much to the cost and the weight of the instrument, while detracting very much from the convenience and rapidity of handling it. (See Plate XVI.) Opinion is divided as to the utility of these elaborations, and it is not possible to decide dogmatically for or against them. But there is one consideration which is weighty against the elaboration of the plane table. The work is done on a sheet of paper; and however carefully this may be seasoned and mounted on linen, it is subject to distortion by moisture, especially in the tropical climates where it is so much employed. This is an argument in favour of keeping the instrument as simple as possible, and not trying to obtain with it too minute an accuracy.

It should be said, however, that within the last few years there has been a change in the opinion formerly held at the School of Military Engineering, Chatham. The Close-Brooker telescopic alidade, with a parallel rule attachment, has come into ordinary use, and it is found that the increased accuracy which may be obtained with it compensates for the greater weight and cost.

Limitations to the accuracy of graphical plane tabling.

The method of graphical plane tabling discards numerical measurement and computation, and relies upon pointing, generally without optical aid, and upon drawing. Every line drawn upon the table is liable to be in error by an amount on the border line of visibility; these errors accumulate until they become quite considerable, and cannot be tolerated on a map with any pretensions to accuracy.

Further, there is a difficulty to be discussed more in detail later—the question of the projection, and the effects of the Earth's curvature—which make it impossible to carry on a survey continuously through a number of sheets, and troublesome to derive latitudes and longitudes of the places mapped.

Hence plane table triangulation has strictly limited uses. It is admirable for exploratory and reconnaissance work, but it cannot be used as the basis of a deliberate survey. This must depend upon theodolite triangulation and calculation.

But as an instrument for filling in the detail of a precise triangulation the plane table is unsurpassed, and we shall have further occasion to consider it.

Tacheometer and Subtense Traverses.

The principle of subtense measurement is simple. It is required to measure the length of a ray over rough country unsuitable for ordinary traversing. At one end of the ray two marks are erected in a line at right angles to the ray. Their linear distance apart is measured by the party who erect them; and their angular distance apart is measured with a theodolite from the other station.

Then if 2θ is the angle subtended by a length $2s$, the distance is $s \tan \theta$.

This is the method generally employed on long rays. The marks are poles set up perhaps fifty feet apart, and the angles are measured by the method of repetition. The method has often been used on boundary surveys.

Over shorter rays it is possible to invert the process, and instead of measuring the angle which is subtended by a definite distance, one measures the distance included in a fixed angle. Wires or marks at fixed distances are inserted in the field of the theodolite or level, and a graduated staff like a levelling staff is observed. The further away the staff, the greater is the length of it included in a fixed angle of sight. The fixed marks in the telescope, called stadia marks, are standardised so that one has the factor, frequently 100, by which one multiplies the length read on the staff to obtain the distance of the staff from the observer.

The factor evidently varies with the distance of the stadia marks from the optical centre of the objective of the telescope, which is changed in bringing to focus objects at various distances. It is not hard to prove that the necessary correction for this can be obtained by the simple process of adding, to the distance computed as above, the distance from the centre of motion of the instrument to a point on the axis, outside the objective, at a distance from the optical centre equal to the focal length. Thus there is a small and slightly variable correction to be added to the observed distance to obtain the correct result.

This is not difficult to do; but the necessity for doing it can be avoided by introducing into the telescope a third lens, called the anallatic lens, which eliminates the small correction just described, and gives at once the true distance from the centre of motion of the instrument. A theodolite or level fitted with this device is called a tacheometer. The instrument is more useful in making detailed plans of a small area than in geographical work.

Correction for slope.

There is often some confusion as to the correction required when the ray is observed on a slope. Without going into the proofs, which are quite simple, we may state the rules shortly as follows:

When the subtended angle is measured on the horizontal circle of the theodolite, no correction for slope is required.

When stadia lines or tacheometer are used with a graduated bar placed horizontal, the apparent distance must be multiplied by the cosine of the slope to give the horizontal distance.

When the graduated bar is placed vertical, the apparent distance must be multiplied by the square of the cosine of the slope.

Summary of exploratory methods of survey.

It will be useful to sum up briefly the methods which we have been considering, suitable for preliminary mapping, exploration, or reconnaissance.

A single-handed traveller, whose main business it is to get through the country, on exploration or on official duty, cannot make a map. But he can

(1) make a compass traverse of his route, and fill in a small amount of detail on each side;

(2) make astronomical determinations of latitude and azimuth, and with much more difficulty of longitude, which fix the main points of his traverse, and serve as a general check upon it.

(3) Small areas of country can be sketched with the compass and clinometer.

(4) Larger areas can be mapped by graphical plane tabling.

A traveller like Dr Sven Hedin, who makes long journeys alone in Central Asia, relies on methods 1 and 2.

Soldiers on active service, who want to illustrate a report on the dispositions they have made in a certain position, may use method 3.

A small party of surveyors, sent into unmapped country to make a rapid exploration and map, will use method 4, supported if possible by 2.

The most successful explorer will be the man who knows precisely the advantages and possibilities of all the methods, and makes skilful use of any or all of them as circumstances may dictate.

CHAPTER VI

TOPOGRAPHICAL SURVEY

Regular topographical survey.

In the preceding chapters we have considered the various operations of survey which may, and should, form part of the work of any explorer, or of any pioneer in the development of a new country.

Such work is of the utmost value in the early stages of the development of the country. But the time soon comes when a systematic survey of the whole must be undertaken.

No compilation of patchwork survey can produce a map worthy of the name, and the sooner the survey of the country is put upon a systematic footing, the greater will be the ultimate saving of expense, because the less scattered and incomplete survey will there be to scrap.

Preliminary considerations.

Before laying out the plan of our operations we must consider whether our aim is restricted to producing a map which shall have no sensible error anywhere; or whether we desire that our operations shall be of the refinement required when they are to make a contribution to geodesy, properly so called: that is to say, to the determination of the size and shape of the Earth.

For the present we will deal with the former case, and suppose that we are to undertake the topographical survey of a large isolated island, of area about 10,000 square miles. The work is to be good, but not of geodetic accuracy. The methods employed are to be as economical as is consistent with the production of a first-rate topographical map. The island is mountainous and the country fairly open, so that it does not present any difficulties of an exceptional nature. It is suitable for a good theodolite triangulation, with plane table detail.

The operations divide themselves into the following sections:

1. Determination of mean sea level.
2. Preliminary plane table reconnaissance.
3. Beaconing for the triangulation.
4. Determination of a latitude, longitude, and azimuth.
5. Measurement of the bases.
6. The theodolite triangulation.
7. Determination of heights by theodolite.
8. Calculation of the triangulation and heights.
9. Transference of the triangulation points to the plane table sheets.
10. Mapping by plane table.

Determination of mean sea level.

The zero point for heights must be the mean level of the sea on the coasts of the island. This must be determined at one or more points by the maintenance of tide gauges.

The tide gauge consists essentially of a well, connected with the open sea by a pipe of small diameter, allowing the water in the well to assume the average level of the open sea, but damping down the quick oscillations of the waves. A float in the well is connected with an indicator and scale, so that the height of the water in the well can be read at intervals; or better, it is connected with a pen drawing a trace upon a clock-driven drum, giving a continuous record which can be measured up and the results tabulated.

The selection of a site for the tide gauge is often a matter of some difficulty. We require the height of the open sea, and not the height of the water in some inlet or harbour, which is often modified by prevailing winds and currents. We require that the record shall be continuous over a long time, not interrupted by choking of the pipe with sand or weed.

The observed oscillation of the tide is the sum of a great number of oscillations of very different periods and amplitudes, the shortest periods being the halves of the solar and the lunar days, the longest the period of revolution of the Moon's nodes, nineteen years.

Further, variations of the barometer affect the height of the sea, a fall of the barometer by one inch being accompanied by a rise in the sea of about one foot.

Hence it is not possible to lay down any definite period during which tidal observations should be continued. Fifteen days' observation will cover the principal lunar tides, and this may be taken as the absolute minimum. The best procedure is to set up the tide gauge as early as possible, and to prolong the observations as long as possible.

For the ordinary purposes of topographical mapping one station is enough. But if it is proposed to carry out precise levelling, and especially if there is any chance that questions of rising or tilt of the land will arise, then several tide stations will be required. In the present chapter we shall be content with one station.

It is essential that the tide gauge shall be set up on solid ground, so that there shall be no question of the permanence of the zero of the scale. It has usually happened that the longest series of tidal observations have been made at ports; but the value of these series has been much depreciated by the fact that ports are very often on made ground, with no guarantee against gradual settlement. Sometimes indeed it is found that the whole ground itself rises and falls with the tide.

The zero of the tide gauge must be connected with one point of the triangulation by a carefully observed line of levels. (See pages 95, 187.)

A discussion of the instrumental details of tide gauges, or of the manner of reducing tidal observations, is entirely outside the scope of this book. Reference may be made to the *Publications* of the Survey of India, the *Handbooks* of this Survey, and to Sir George Darwin's work, *The Tides.*

The plane table reconnaissance.

The success of the whole operation depends upon obtaining a good triangulation ; and the difference between a good and a bad triangulation depends largely upon the efficiency of the reconnaissance which must precede the choice of the stations. It is surprising how many small impediments combine to interrupt the mutual visibility of stations that might be expected to be in full view of one another. Hence it is not safe to take for granted the most seemingly obvious suitability of any particular station. A plane table reconnaissance starts without taking much trouble over the measurement of a base, for the precise scale of the sketch is immaterial. Rays are drawn to three or four times as many points as are likely to be wanted, for it is certain that as the work proceeds it will be necessary to drop many of the points for obstruction on one ray or another. At the conclusion of the reconnaissance the surviving points will be carefully studied, from the point of view of planning a well-conditioned system of triangles, and of obtaining a good connection with the measured bases.

During the preliminary reconnaissance the ground should be beaconed, and care should be taken that not only the general localities are intervisible but the beacons themselves. Want of care in this respect may cause endless trouble afterwards, for the actual triangulation with the theodolite is a slow and laborious business, and the failure of a single station means that a number of other stations must be re-occupied. Hence no pains may be spared in making sure that every ray in the selected arrangement is really observable.

It is hardly necessary to say that the most anxious attention must be given to the selection of sites for the bases.

The reconnaissance ladder.

In suitable country the plane table triangulation is easy. But it may be required to cross a low and forest-clad district where it will be necessary to build towers for the instrument, and the selection of the sites for these towers is difficult, because until they or their equivalents are erected it is impossible to judge of the suitability of their positions. To get over this difficulty a French officer of Artillery, Commandant Lucien Durand, has introduced into survey the tall observation ladder that is used for the control of artillery in modern practice. This ladder can be carried on a waggon and run up in an hour. From the opening in the platform at the top the surveyor can work his plane table, and can decide very well whether or not the position is suitable for the erection of a tower station. The same officer has designed a very steady construction of poles which makes an excellent and inexpensive tower. (See Plate XVII.)

Plan of the triangulation.

It is not necessary that the principal triangulation should cover the whole country with a net of triangles. If the country is long and narrow a backbone of quadrilaterals is sufficient, as in the figure. If the breadth is too great to make this sufficient, a chain of quadrilaterals at right angles to the first will strengthen the skeleton.

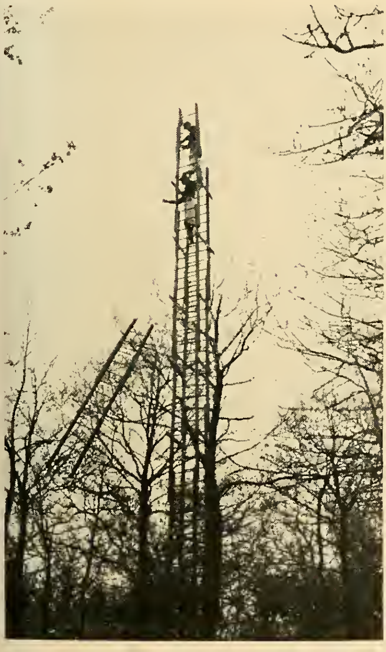
The purpose of forming the triangles into chains of quadrilaterals is to provide the necessary control without unnecessary repetition or duplication. Were the chain a chain of triangles only, there would be no check upon the survival of a gross error. A regular system of quadrilaterals gives the most simple arrangement consistent with strength.

It will often happen that more rays can be observed from a certain station than are required by the plan. To observe these rays would confuse the work without adding anything of importance to its accuracy. Hence the desirability of making a strict programme of the rays to be observed at each station, neglecting all others.

The triangles must be well conditioned: that is to say, they must be strong in shape, having no angles less than 30° about, and if possible none less than 40°. The size of the triangles will depend so much on the nature of the country that no general rule can be laid down, beyond saying that the larger they are the better.

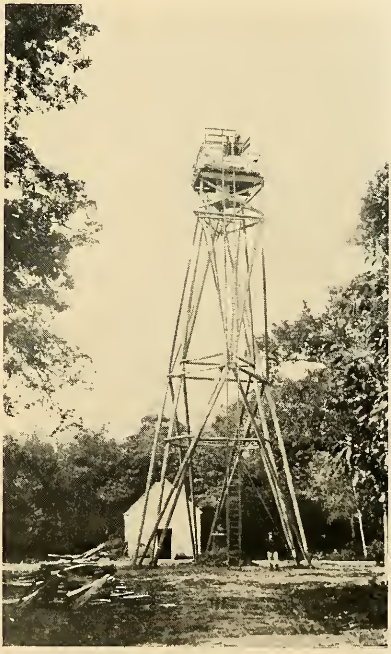
The connection of the bases with the chains of quadrilaterals also depends very much on the ground. The main idea is that

1. Reconnaissance ladder on the march.



2. Reconnaissance ladder in course of erection.

Reconnaissance ladder and beacon. Service Géographique de l'Armée.



3. Double tripod scaffold for theodolite and observer.

Designed by Commandant L. Durand, 11e Régiment d'Artillerie.

a chain should start from one base and close on another. Then the comparison between the length of the second calculated through from the first and the length of the second as actually measured gives the best possible control over the accuracy of the whole chain.

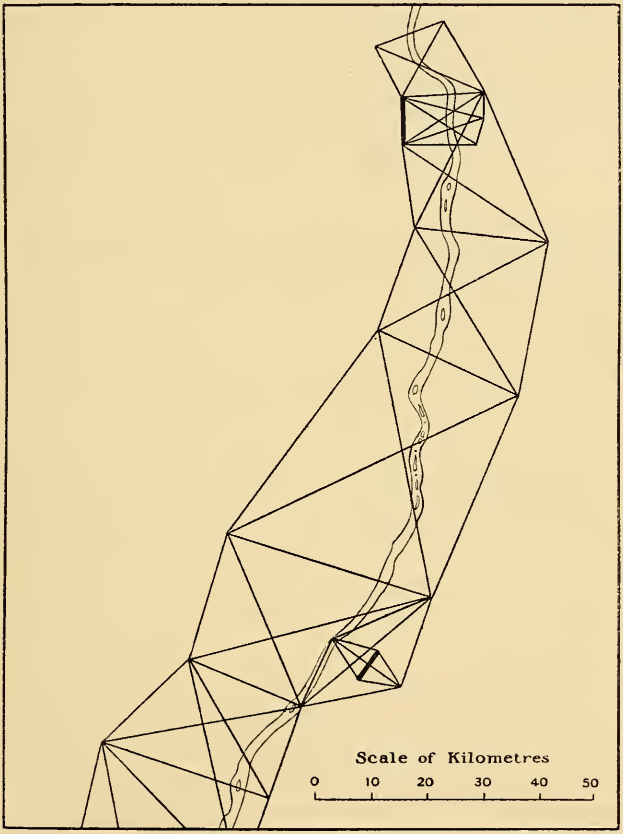


Fig. 18. Diagram of Geodetic Triangulation up the Nile Valley from Cairo to Beba. The two heavy lines are bases.

Beacons.

Beacons are of two principal kinds: the luminous and the opaque. In most countries, when the ray is more than eight or nine miles long it is necessary to use luminous beacons or signals, for the haze in the air very quickly obliterates the contrast between the opaque signal and its surroundings, so that it becomes invisible.

Luminous signals are either heliographs, for use with the Sun by day; or powerful lamps, nowadays usually acetylene, for work at night. In a fine climate like South Africa, the 'helio' can be observed at a range of 100 miles and sunlight is sufficient to let the work proceed without undue delay. In less favourable climates lamps provide a more certain mark for observation; but there may be difficulties in observing at night, for reasons of health or safety, that make it necessary to restrict operations to the day. On cloudy days it is sometimes possible to use powerful lamps instead of helios. Night observation has the great advantage that irregular refraction and disturbance of the air are much less than by day, so that the results are more accurate.

In either case, the effective use of luminous signals requires that the organisation and control of the signal parties shall be of a high order. Each party must use every endeavour to send its signal in the right direction so long as it is required, and must then move without delay to the next station. In general the discipline must be military to ensure the punctual carrying out of the lonely, dull, but all-important duties of the helio or lamp parties.

The heliograph.

It is impossible to enter into details of the mechanical construction of this instrument. Essentially it is a plane mirror from three to eight inches in diameter, mounted on a tripod in such a way that it may be turned by means of a slow motion screw to follow the Sun, and cast the reflected beam in a constant direction. There is a sight vane carried on an arm, which is set in the first instance upon the station to which the beam is to be directed; and a small round patch is left unsilvered in the centre of the mirror. So long as the black spot thus formed in the beam is kept centred on the white patch of the sight vane, the beam is being sent in the right direction.

It is sometimes a matter for surprise that the beam can be directed with the necessary accuracy, until one remembers that the Sun, and therefore the beam, has a diameter of half a degree. The light from the mirror therefore diverges in a cone of angle half a degree, equivalent to about 1 in 115. At a distance of ten miles the beam covers a front of about 150 yards, and a careful operator has no difficulty in directing the beam within this distance right or left of the object.

When lamps are used, at night, the distant station is invisible, and some means must be devised for sending the beam in the right direction. But it is hardly possible to go into such detail in this place.

It is interesting to remember that the limelight was invented by an officer of the Royal Engineers to make the connection between Wales and Ireland, after many weeks had been wasted in waiting for the Sun.

Opaque signals.

The opaque signals must be large, so that they may be visible at a distance; and they are best constructed so that the theodolite may be placed in position without taking down the signal; otherwise there is some danger that the signal will not be re-erected in its original position, and there will be a discontinuity between the observations made to that station before and after its occupation.

The construction of the beacons will vary with the materials locally available and with the ease or otherwise of transport. They should be symmetrical about their vertical axis when seen from any position; therefore the quadripod is preferable to the tripod. A good form of signal is that shown in the frontispiece to *Colonial Survey Reports*, Vol. 2. Its appearance on service is shown by the accompanying photograph of a beacon on the Uganda-Congo boundary, for which I am indebted to Captain Jack, R.E., British Commissioner. (See Plate XVIII.)

In unsettled countries the surveyor has the advantage that he can cut down trees to make his signals; an official manual recommends a form of beacon built of 120 saplings. He can also clear the tops of hills of inconvenient timber, leaving the best tree standing in which to build a station. In civilised and closely settled countries this is not possible; but church towers and other buildings go far to supply the need. The Ordnance Survey of England constructed a station above the cross on the dome of Saint Paul's, and took off temporarily some feet of the top of the spire of Norwich Cathedral. Such operations being impracticable under ordinary circumstances, it is very difficult to carry out a piece of triangulation in England for instructional purposes on any considerable scale.

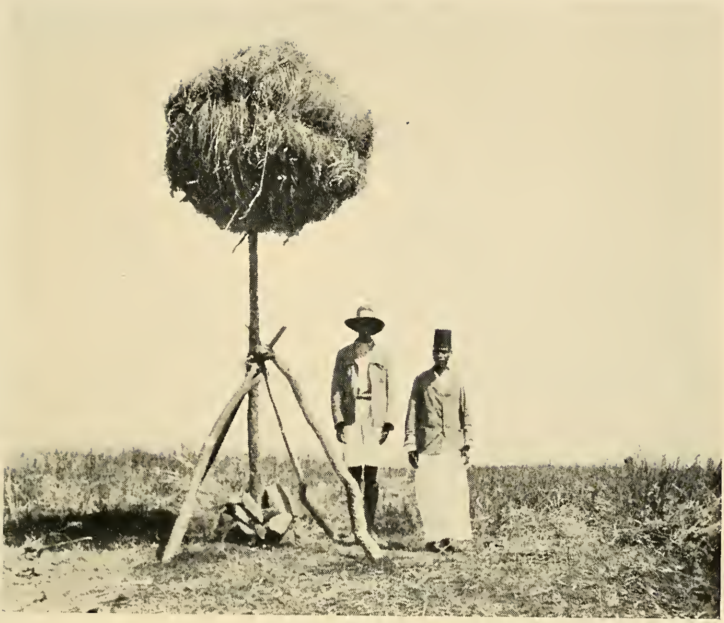
Permanent marks underground.

In all cases the visible signal should be considered as a temporary representation of an underground mark, which is buried for safety, and so protected and identified that it may be recovered at any time. To ensure this is not easy. Some of the principal stations of the Ordnance Survey of England are now lost, owing to insufficient attention to this question of permanent marking.

The form of the underground mark depends on local circumstances. It will take some such form as a copper bolt let into the rock at a depth of say two feet, and protected by a pyramid of masonry, or a large cairn of stones. In settled countries a few square yards of ground should be bought and enclosed; it may then be committed to the charge of the local authorities. In unsettled countries it is much more difficult to protect the stations, because the natural tendency of the native is to take the first opportunity of digging to see what it is that the white man has buried so carefully. In these countries also great trouble is often experienced in maintaining the opaque signals, and much time is wasted through their destruction during the course of the work.

Self-centering beacons.

With the usual construction of beacons a great part of the time taken in setting up the instrument is consumed in centering it over the station mark. And a considerable part of the gradual loss of accuracy in the progress of the chain of triangles is



1. Beacon for intersected point.

2. Quadripod beacon for triangulation.

Phot. by Capt. E. M. Jack, R.E.

caused by errors in this setting up and centering. To avoid these difficulties an excellent form of self-centering beacon has been introduced by the Survey of Egypt. The beacon consists of a concrete pillar carrying on top a brass casting with three radial V-shaped grooves planed at 120° apart. The three levelling screws of the theodolite base, or the three feet of the helio, stand in these grooves. The instrument can be put up only in one position, which is automatically the correct one, and no error of centering is possible. When the station is not in use the pillar is covered over and protected in the usual way. This self-centering device seems to be worthy of general adoption.

Beaconing.

The selection of sites for the beacons is done by a reconnaissance party making a plane table sketch well ahead of triangulation party, and erecting the beacons on the points which make the best conditioned system of triangles. The beaconing party is responsible for leaving everything in order for the triangulators; and they must take great care that all the rays are cleared and fully visible.

Initial latitude, longitude, and azimuth.

The triangulation and plane tabling will eventually produce a map in which all parts of the ground are shown in their correct relation one to another; but they will give no information as to the place of that country on the Earth. To fix the map down on the Earth, and to obtain its orientation, we must make astronomical observations.

By determining the latitude and longitude of one of the triangulation points we, so to speak, pin the map down at one point, leaving it free to turn about that point. By determining the azimuth of one of the rays from this point to any other, we fix the map in its right orientation.

Hence the necessary astronomical observations are

An initial latitude and longitude.

An initial azimuth.

It might be supposed that there would be some advantage in determining the latitudes and longitudes of a number of different points. But for our present purpose this is not so. The reason will be discussed more fully in the chapter on the astronomical observations for geodetic purposes. For the time being it will be sufficient to say that every observed latitude and longitude is affected by local irregularities in the direction of gravity, due to the unequal distribution of mass in the crust of the Earth. Hence if one observes the latitudes of two stations in the triangulation one will probably find that the difference of the observed latitudes does not correspond with the difference of latitude resulting from the triangulation. Such discordances are of the highest importance in geodesy. But in a simple topographical survey they are embarrassing; and it is usually best to confine oneself to a single latitude and longitude; and a single azimuth.

Observation of latitude.

The determination of latitude will be made by the observation of stars near the meridian: the method of circum-meridian altitudes. Observations of the stars are always to be preferred to observations of the Sun, both because they are more accurate in themselves, and because a number of stars can be observed on one night, so that a determination of the accuracy desired can be obtained very much more quickly than if the Sun were used.

Two or three nights' observation with a five-inch micrometer theodolite taking four pairs of north and south stars each night, should give the latitude correct to one or two seconds of arc, which is less than the probable value of the local deviation of gravity, and is sufficient for all topographical purposes.

Should a more elaborate determination of the latitude be desired, it will be obtained with the zenith telescope, or with a large theodolite constructed to serve as a zenith telescope.

Observation of longitude.

The longitude of the initial station is the difference between its local time and the time of the meridian of Greenwich.

The local time at the initial station will be determined by the observation with the theodolite of pairs of stars east and west, as near the prime vertical as possible. Or, more elaborately, it will be determined by a portable transit instrument set up at the initial station.

The difficulty, as always, lies in obtaining the time of the Greenwich meridian. With the extension of wireless telegraphy this difficulty becomes less year by year, and will shortly disappear. It is therefore not necessary to discuss the difficult and now out of date methods of obtaining Greenwich time independently of the telegraph or wireless. By the use of wireless it becomes relatively easy to determine longitude well within a second of time. When it becomes a question of one or two tenths of a second all kinds of complications arise, which need not be discussed here. (But see Chapter VIII, page 198.)

Observation of azimuth.

The azimuth is obtained by observation of stars east and west, near the prime vertical, or of circumpolar stars at their greatest elongations. These observations give the difference of azimuth between the stars and the terrestrial station, and also the true azimuths of the stars at the moments of comparison; whence the true azimuths of the station are immediately derived.

If the triangulation is being made with opaque signals, so that no provision is made for illuminating the signals at night, it will generally be convenient to establish a supplementary mark at a moderate distance, say one mile, from the initial station. This mark can be more easily illuminated than one at a greater distance; and the difference of azimuth between the mark and the triangulation station chosen for the initial azimuth can be determined during the ordinary course of the triangulation by day.

There will be no difficulty in determining the initial azimuth in this way with an accuracy of two or three seconds of arc, which is sufficient for the purposes of the survey with which we are dealing at present. Local deviations of gravity have their effect on azimuths as well as on latitudes and longitudes; and it is useless to aim at a degree of accuracy which cannot be achieved except by the elaborate discussions of geodesy.

The bases.

Recent improvements in the means of measuring bases have altered our conception of the relation of the base to the triangulation. When base measurement was difficult one thought of the triangulation as built upon a single base, whose measurement was by far the most delicate, the most anxious, and the most uncertain part of the whole operation. If it were possible to measure a second base in another part of the country, well and good. But it would never have been thought remarkable if a whole survey rested upon one base.

Nowadays base measurement has become so relatively easy that it is possible to plan a chain of triangulation and to stipulate that bases shall be measured at intervals of 200 or even 100 miles apart all along the chain. The measurement of a base becomes a kind of control carried out at intervals as part of the routine; it is no longer the solemn and fundamental operation that it was.

Essentials of base measurement.

The essential steps in the process of base measurement are the following:

1. Determination of the field standard in terms of the national standard of length.

2. Measurement of the distance between the base terminals on the ground in terms of the field standard.

3. Correction of the measure for temperature and any other causes of variation, and reduction to national standard.

4. Reduction to the horizontal, and then to mean sea level.

For topographical purposes bases may be measured by means of tapes laid along a straight and level road or railway track, and stretched to a constant tension with a spring balance; or by a wire or tape hung under constant tension in the natural curve —the catenary—supported at each end by frictionless pulleys suspended from trestles, and carrying near each end a divided scale which is read against marks carried on tripods set up along the line of the base.

The tape laid on the ground serves very well when there is a convenient railway track with little traffic, such as is often available in large and new countries. In the absence of such ready-made sites for the base, it is easier to use the wires hung on tripods some feet above the ground. Much rougher country can be crossed, and it is easier to go up and down hill. We shall consider the latter method as the standard modern method, and shall deal with it first.

The tape or wire.

The modern tape or wire is either 100 feet or else 24 metres long between the divided scales. It is made of an alloy of nickel and steel (36% nickel) which has the remarkable property that its coefficient of expansion is only one tenth that of ordinary steel, ·000,000,5 of its length per degree Fahrenheit, instead of ·000,006. The trade name of this alloy is Invar.

These tapes or wires have the great advantage that they are extremely portable. When wound upon their reels they may be sent by post to the National Physical Laboratory or to the *Bureau Internationaldes Poids et Mesures* at Breteuil, and there compared with the laboratory copies of the national standards of length. For a comparatively small fee the laboratory will determine the correction to the assumed length, and make a determination of the coefficient of expansion with temperature. Thus without any difficulty a survey department in, we will say, Fiji, may send home the standard tapes from time to time to be re-compared with the laboratory standards, and may thus ensure a very strict control over the lengths of the wires or tapes that are in actual use in the field.

This provides in a very simple and inexpensive way for the reference to the national standards of length.

Use of the suspended tape in the field.

The base will be from four to twelve miles long: the longer the better. It must be chosen so that one end is visible from the other; and it is generally convenient that the ends shall be on slight elevations, which much facilitates the choice of the stations for the base extension, that is to say, of the small triangulation connecting the base with one of the principal sides of the main triangulation.

The ends of the base will be marked by terminals sunk in the ground, or perhaps carried on concrete pillars.

Simple but firm tripods, carrying small upright pillars engraved with fine lines, will be set out in the line of the base, at distances apart equal to the tape length between its zeros of the engraved scales.

The tape is suspended over frictionless pulleys, carried on straining trestles which can be adjusted easily so that the tape can be brought up close to the marks on the tripods. The tape is kept in tension by weights hung on each end.

At given signals observers at each end make series of simultaneous readings of the scale on the tape, against the marks on the tripod.

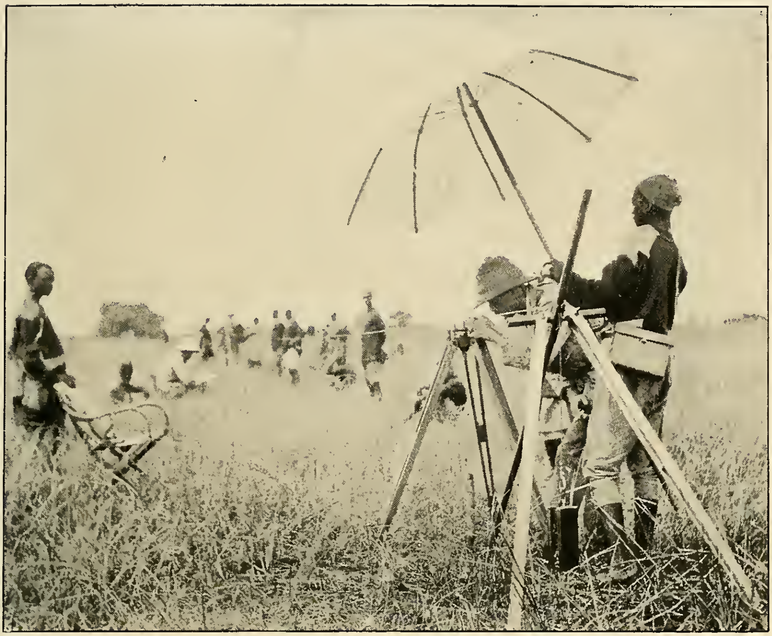
The tape is then carried on to the next tripod section, and the operation is repeated.

As soon as the tape party is clear a levelling party determine the difference of height between one tripod and the next. When this is done, the tripods in rear can be carried forward and set up ahead in the line of the base. With good organisation and drill it is possible to measure five kilometres per day in this manner.

At the beginning and end of each day's work the field tapes are compared with the tapes which have been standardised in the laboratory, and which are not subjected to the risks of injury in the field.

The accuracy obtainable in this way is limited only by the number of wires which are employed, the number of times that the measures are repeated, the precautions that are taken to avoid damage to the wires, and finally, by the residual error in the comparison of the standard tapes with the laboratory standards of length.

With very little precaution it is possible to measure topographical bases in this way with an accuracy of 1 in 200,000, which is amply sufficient for any work which does not aim at geodetic accuracy. We shall consider the refinements desirable in the measure of geodetic bases in a separate chapter.



1. Taking readings on the wire, Semliki Base.

2. Adjusting the straining trestle and wire before reading.

Measurement of Semliki Base, Uganda-Congo Boundary.

Phot. by Capt. E. M. Jack, R.E.

Use of the flat tape in the field.

The tape laid on the ground will probably soon become obsolete, except for operations on a small scale.

A convenient way of operating with such a tape is as follows:

Provide the tape with two handles filed flat at their extremities. The distance between these extreme surfaces is the length of the tape which is compared with the standard. The handles are furnished with lugs, over which are hooked wire stirrups with a loop at the end, to take the hook of a spring balance.

Pickets are driven into the ground in the line of the base, at tape lengths apart, and strips of zinc are nailed to the tops of the pickets. The tape is held at one end by a spike through the loop of the stirrup, and is strained to the right tension by a spring balance hooked into the other stirrup. The flat ends of the handles should then come over the zinc strips. At a given signal observers at either end steady the tape, and draw a sharp point along the flat ends of the handles, so as to make marks on the zinc strips. The tape is then carried on to the next section, and the operation repeated. No attempt is made to join up the tape lengths accurately, but the distances between the pairs of cuts on the zinc are measured with scales or dividers, and the small excesses or defects added to the tape lengths. The thermometer is laid alongside the tape on the ground, and is read at frequent intervals to give the temperature correction.

Working in this way it is easily possible to measure a base with an accuracy of 1 in 75000, provided that a good site can be secured. But unless a straight railway track is available the suspended tape is easier to manage though it requires a larger party.

For details of the use of tapes laid flat on the ground reference may be made to Wilson's *Topographical Surveying*.

Correction for slope.

With modern ideas of ground suitable for base measurement, the correction for slope sometimes becomes considerable; but it is always very simple.

The correction may be expressed in terms of either the vertical difference in height of the ends of the tape, or the slope of the straight line joining the ends.

Considered in its simplest possible form the problem is as follows:

Let L be the length of the tape, or the distance between the zeros at the two ends; and let H be the difference in height of the two ends. If θ be the slope of the tape, then $\sin \theta = H/L$;

and the correction for slope is $-L(1 - \cos \theta) = -H^2/2L$.

Hence, whether the slope or the difference of vertical height is measured, the correction to the measured length of each span is very simple. Modern practice favours the use of the differences of vertical height, measured with an ordinary Y-level, rather than slopes measured with an instrument such as the Abney level.

It may seem to be likely that the above simple assumption as to the form of the correction is not applicable to the case of a tape hanging in its natural curve. An exact investigation shows, however, that except in the most minutely refined work, the above formula is amply accurate. (See page 187.)

Reduction to sea level.

It is an invariable principle that maps should be drawn as if the ground were projected on the sea level surface. A moment's consideration shows that this is necessary. Think of two parallels of latitude crossing the Drakensberg from Natal to the Orange Free State. The ground on the latter side is nearly a mile further from the centre of the Earth than the low land in Natal. Hence the linear distance between the parallels will be greater by about one part in four thousand on the west side of the range. But it would be quite impossible to represent the difference on the map, since such a representation would require that the sheet should be stretched locally wherever the ground was high. Hence the necessity of reducing always to sea level.

The reduction is of great simplicity, being almost automatic in its operation. Let h be the mean height of the base above sea level, and R the radius of the Earth, supposed spherical. Then the simple reduction of the measured length L of the base is evidently $-Lh/R$ very nearly. This is quite sufficient except in extremely accurate geodetic work; the latter we will consider in a later chapter.

With our base thus reduced to sea level the calculation of the whole triangulation, depending on the base, is automatically reduced to sea level also, as we shall see almost immediately.

The theodolite triangulation.

The theodolite is set up directly over the station mark, and is levelled, so that the horizontal circle of the instrument is truly horizontal. The telescope is sighted on each of the other stations in turn, according to the programme; and the horizontal circle is read by the microscopes at each setting. It is important to notice that the angles thus measured are not the actual angles between the successive pairs of beacons, such as would be measured by a sextant, but are those angles projected on to the horizontal plane of the station occupied. If the Earth is considered spherical these angles are the same whatever the height of the stations above sea level, even when the various stations are at very different heights. Hence the justification for the statement of the preceding section, that when the measured base is reduced to sea level the whole of the triangulation is automatically reduced to sea level also.

The details of the manipulation of the theodolite are dealt with in the *Textbook of Topographical Surveying*. We will confine ourselves here to the points which are especially concerned with the horizontal triangulation.

Suppose that there are four stations A, B, C, and D to be observed. A round of angles consists of settings on A, B, C, D, and A in turn. It is important to notice that the station A is observed to twice. The reason for this is that small errors are introduced into the measured angles if the instrument is not perfectly stable during the course of the round; and this cannot be ensured absolutely. If we repeat the observation of A at the end of the round we ensure that the measure of the angle DOA is independent of any settlement of the instrument that may have occurred during the course of the round from *A* to *D*. In fact any such movement affects only the particular angle under measurement at the time when it occurred. At the same time

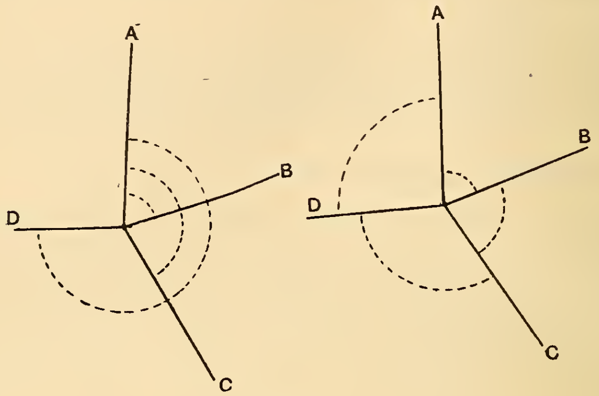
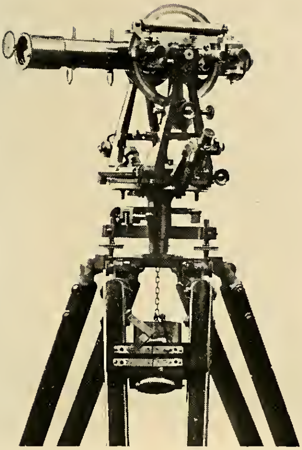


Fig. 19.

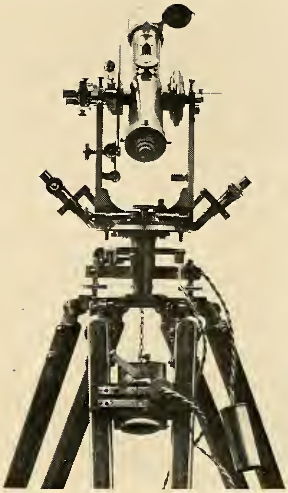
the near concordance that there should be between the first and the last settings on *A* is a measure of the stability of the instrument during the round. This is an important principle, to which attention should be paid.

There are, however, cases in which the simple process described above must be modified. In a bad climate it will happen that sometimes one and sometimes another station is visible; but never all at once. In such a case one establishes a reference mark at such a distance that it is always visible; and one measures the angle between this mark and any other station that may become visible. The differences between the bearings of all the stations from this reference mark give eventually the angles that should have been observed directly. For simplicity we shall assume in what follows that the whole round of angles can be observed in the manner first described.

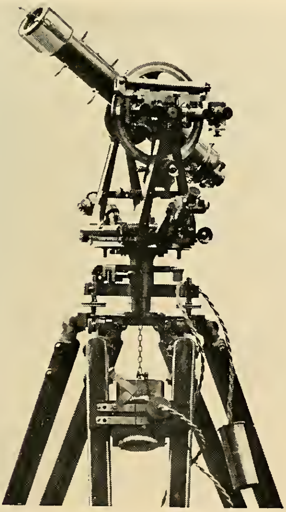
To obtain the necessary control and to detect blunders, as well as to eliminate by repetition the accidental errors of the observations, the round of angles must be repeated one or more times. We take care to arrange the work so that each repetition



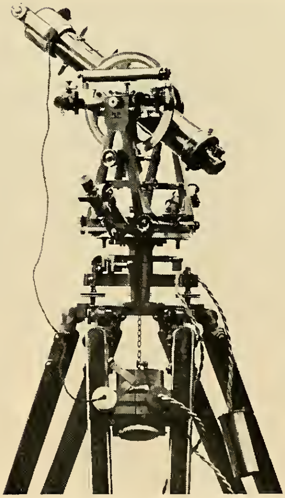
1. In position for Triangulation.



2. From the eyepiece end.



3. With reflector over objective for lamp illumination.



4. With attachment for electric illumination.

Five inch Micrometer Theodolite. *Cambridge Observatory.*

is made on a different part of the circle, whereby accidental errors of the circle graduation are to some extent eliminated. In the very best instruments these errors rarely exceed two or three seconds of arc; but there are many instruments in use, made by well-known makers, in which the errors of graduation are by no means so small. It would be a very long and tedious business to determine them and introduce corrections for them; and it is usually sufficient to so arrange the observations that repetition tends to eliminate them.

Check on the accuracy of the triangulation. Triangular error.

In a small triangle, of one or two miles per side, the curvature of the Earth may be considered negligible, and the three angles of the observed triangle should add up to 180°. In larger triangles this is not strictly the case. We remember that the angles are measured in the horizontal planes through each station; and when the triangle is large the curvature of the Earth throws these planes out of parallelism with one another. The result of this is that the three angles of the triangle should add up to more than 180°, the excess being called the 'spherical excess.' This is easily calculated, and depends on the area of the triangle. Deduct it from the observed sum of the three angles, and the result should be 180° exactly. In practice it will differ from this quantity by a small number of seconds, and this difference is called the 'triangular error.'

The average triangular error is a measure of the precision of the triangulation. In the most precise work, of geodetic accuracy, the average error will be less than one second of arc. In good topographical triangulation it will be two or three seconds. Experience will show what limit should be set to the average triangular error on any particular piece of work; and when the standard is laid down the observations must be repeated as many times as may be necessary to arrive at the desired degree of accuracy.

This test of the triangulation by considering the triangular error gives a simple and invaluable means of control, and of securing that the work is up to the standard required.

Spherical excess.

The spherical excess of a triangle may be calculated from the formula

$$E = ab \sin C \frac{\operatorname{cosec} 1''}{2\,(\text{radius})^2}.$$

When the ellipticity of the Earth is taken into account it is usual to work with the radius of an oblique section making an angle 45° with the meridian. See Auxiliary Tables of the Survey of India, Table III.

If the triangles are less than 100 miles a side it is sufficiently accurate to apply to each angle a correction of one third of the excess.

Except in very accurate work it is sufficient to measure the area of the triangle from a chart, and to use the formula

$$E = \frac{\text{area of triangle in sq. miles}}{1000} \times 13''\cdot 15.$$

Refraction of horizontal angles.

Refraction is usually supposed to act in a vertical plane; and so long as it does so it can have no sensible effect upon the horizontal angles. But in the neighbourhood of steep slopes the layers of air of different temperatures are not horizontal, and a ray of light passing through such a region may suffer deviation in the horizontal plane. Such effects will in general take place only near the ground; and for this reason it is important to avoid rays which in their course approach near intervening ground. Such rays are called 'grazing rays.'

It is difficult to say how high a ray must pass over intervening ground to avoid the disadvantage inherent in a grazing ray; but so long as obviously grazing rays are avoided it is usually safe to hope that such small remaining effects of horizontal refraction as may be left will be of a non-systematic character, and will be eliminated in the average. There are, however, certain cases where this is not necessarily true, such as in the triangulation up the valley of the Nile, where the stations are alternately on opposite cliffs, and the cooling of the air over the water might very well produce systematic effects. Much attention is being given to this problem by the officers of the Survey of Egypt.

A recent publication of the United States Coast and Geodetic Survey, on the Texas-California arc of primary triangulation, gives a striking instance of well determined lateral refraction. The line between two stations Clayton and Kennard passes very close to a steep slope of a flat topped hill. During most of the observations the wind was blowing from the hill across the line between the stations, and the results gave excessive closing errors to the triangles involving this line. The observations made when the wind was blowing across the line towards the hill gave values which closed the line in a satisfactory manner. It became evident that the former were in error by about seven seconds of arc.

Determination of heights by theodolite, or Trigonometrical Heights.

The method of trigonometrical heights provides a rapid way of determining differences of height of the triangulation points.

During the occupation of each station, after the horizontal angles have been measured, the apparent angular elevation of the beacons at the other stations are measured with the vertical circle and microscopes of the theodolite. These measures differ from the horizontal angles in that they are absolute elevations or depressions, and not merely differential measures.

By careful attention to the rules for the measurement of vertical angles the errors of the instrument may be very nearly eliminated, except that there is no possibility of eliminating the errors of division of the circle by repetition on different parts of the arc. The serious errors inherent in this method are those due to refraction.

The vertical refraction of a horizontal ray is large; it depends upon the density of the air intervening in the path of the ray, which varies very rapidly during the day, and is almost impossible to calculate. But there are two principles of working by which this effect may be in great part avoided: the observations should be made at the time of day when the refraction is a minimum, that is to say, in the early afternoon; and the rays should be observed from opposite ends under circumstances as nearly the same as possible. It is then assumed that the effect of refraction on the observation at each end is the same; and it is easy to see that the effect is thereby eliminated.

When it is not possible to take the reciprocal observations from each end, some assumption must be made as to the law of refraction, based upon an analysis of the observations that have been made reciprocally. But to pursue this part of the subject is beyond the scope of the present chapter. The results are especially unsatisfactory in mountainous regions with glaciers and perpetual snow. Hence the heights of the inaccessible snow-clad peaks of the Himalayas, which are determined by this method, are subject to some uncertainty.

It will be noticed that when two points at a considerable distance apart, and of no great difference of height above sea, are reciprocally observed, each is measured as a depression at

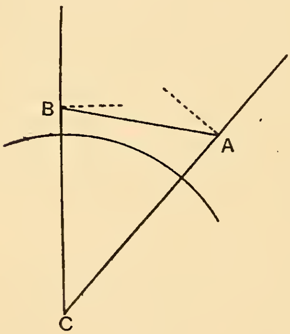


Fig. 20.

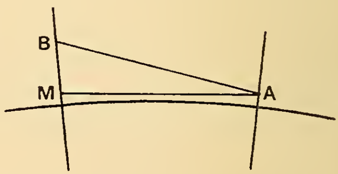


Fig. 21.

the other, in spite of the fact that refraction raises each of the rays to some extent. This is a necessary consequence of the curvature of the Earth; but the size of the effect is a little surprising to the student, until he remembers how small the Earth really is, and that two points four geographical miles apart subtend an angle of four minutes of arc at the centre of the Earth, so that each is depressed from the other by $2'$.

The formulae are very simple.

Let A, B be the two stations, and M a point vertically below B at the same distance from the centre of the Earth as A.

Since AB is very small compared with AC, we may take

$$BM = AM \tan BAM. \qquad \text{(Fig. 21.)}$$

And it is easily seen that BAM is equal to half the difference in the *depressions* of the two stations, seen from one another: provided that the refraction is the same at the two ends.

Hence if s be the distance in feet between the two stations, their difference of height in feet is $s \tan \frac{1}{2}$ (difference of depressions).

If only one angle is observed it is necessary to introduce a numerical allowance for refraction. Whenever reciprocal observations are obtained, as above, the refraction at either station is $R = \frac{1}{2}(\theta - \text{sum of observed depressions})$ where θ is the angle ACB, which can be calculated from s and the radius of the Earth. It is found that the ratio $R : \theta$ is generally about 0·07.

Now it is easily seen that for an observed depression D at B the angle

$$BAM = \tfrac{1}{2}\theta - \text{refraction} - D.$$

And if refraction $= 0{\cdot}07\,\theta$ this becomes

$$BAM = 0{\cdot}43\,\theta - D.$$

Or since the distance along the surface corresponding to an angle of $1''$ at the centre is about 101 feet

$$BAM = \frac{4''{\cdot}25 \times \text{distance in feet}}{1000} - D$$

$$= \kappa - D \text{ say.}$$

And then as before

$$\text{difference of height} = s \tan(\kappa - D).$$

This is the simple theory on which the table for κ given in the *Textbook of Topographical Surveying* is based.

The whole of the above theory is a rough approximation; but it is probably sufficient, in view of the uncertain effects of refraction.

We must also take into account in the calculation the height of the theodolite above ground at each station, and also the heights of the signals to which the observations are made. It is tedious to puzzle out the rules of signs for these small corrections; but it is quite easy to apply them when the rules are given. See *Textbook of Topographical Surveying*, pp. 28 et seq.

When all precautions are taken the errors of this process amount to one or two feet on a ray of thirty miles, when the angles are observed at each end. For rays observed only from one end, and especially when there is a probability of anomalous refraction, such as occurs in mountainous regions with glaciers, the uncertainty is considerably greater; but it may of course be reduced by combining the results of a number of observations taken from different stations.

The heights of most of the principal peaks in the Himalayas depend upon rays observed from one end only. Lines of levelling have been carried up to stations in the hills, and from these trigonometrical heights of all or of many of the 10,000 permanently snow-clad summits have been observed. During the course of such work Mount Everest had been observed to on many occasions without any suspicion that its height was extreme, for it is very inaccessible, and does not appear strikingly prominent compared with other peaks. Only when the observations were computed in due course in the Survey Department at Calcutta was it found that this peak is higher than any other known; and not until after the Tibet Expedition was it certain that there is not a higher peak behind it.

Barometer heights in topographical survey.

Although the barometer cannot be relied upon for the principal determinations of height in regular survey, it is often useful in special circumstances, when the other methods fail.

For example, suppose that it is necessary to determine the depth of a canyon with almost perpendicular walls. Very probably the bottom of the canyon cannot be seen from the top, and methods depending upon observed rays are useless, or at any rate can be employed only at the cost of great trouble in occupying many intermediate stations. In such a case a barometer trip to the bottom and up again will give results which are sufficiently accurate, in a few hours. Similarly the barometer may be employed in contouring densely wooded hill country, in which no view can be obtained, and which is being surveyed by traverse. This method is much used in Nigeria.

Calculation of the triangulation.

The observations made at each station are entered in 'angle books,' from which the observed angles are abstracted, the means taken, and the results brought together in the form of 'abstracts of angles.'

Let the figure represent a part of a chain of quadrilaterals under observation. A portion of the abstract of angles may read thus:

Observed angles at Y:	EYD	31°	57′	28″
	DYF	45	6	15
	FYE	282	56	9
		359	59	52

It will be noticed that the angles at the station do not add up to precisely 360° as they should. This is due partly to the errors of observation, partly to the errors of the divided circle, and partly to movement of the instrument in the course of the round.

Now suppose that in the course of the computation we have arrived at the length of the side DE and that we wish to proceed. Let us do so by solving the triangle DEY. From the abstract of angles at Y we take out

$$EYD \quad 31^\circ\ 57'\ 28''$$

and from the abstracts of angles at D and E we take out

$$\begin{array}{ll} YDE & 55^\circ\ 28'\ 16'' \\ DEY & 92\ \ 34\ \ 42. \end{array}$$

The sum of these is 180 0 26,

and by calculation we find that the spherical excess is inappreciable, which leaves the triangular error

$$+26''.$$

Now we cannot solve the triangle until it has been made into a perfect triangle, whose angles add up to exactly 180°. If we are concerned with this triangle alone, the best thing that we can do is to divide up the error into three equal parts and apply one to each of the angles, so that the sum of the thus corrected angles is exactly 180°.

This being done we can find the length of either of the sides EY or DY, being given the other side DE and the angles of the triangle.

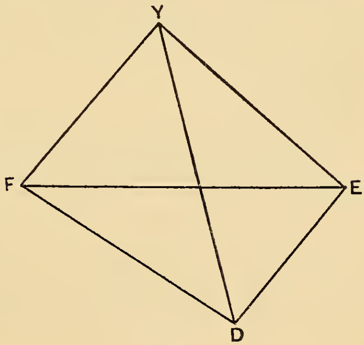


Fig. 22.

For by elementary trigonometry

$$\frac{DY}{DE} = \frac{\sin DEY}{\sin DYE},$$

whence $$DY = DE \operatorname{cosec} DYE \sin DEY,$$

and similarly $$EY = DE \operatorname{cosec} DYE \sin YDE.$$

Thus either DY or EY is easily found.

Distributing the excess of 26″ over the three angles we have for the corrected values :

Angle at D	55°	28′	7″
Y	31	57	20
E	92	34	33
	180	0	0

Thus if $\log DE = 3{\cdot}8337549$,

$$\begin{aligned} \log DY = \log DE & \quad 3{\cdot}8337549 \\ + \log \operatorname{cosec} DYE & \quad 0{\cdot}2763299 \\ + \log \sin DEY & \quad \bar{1}{\cdot}9995610 \\ \hline & \quad 4{\cdot}1096458 \end{aligned}$$

and similarly $\log EY = 4{\cdot}0259149$.

This example is taken from the work of a vacation survey class in the Isle of Wight.

Proceeding to the next triangles we can find FY from the triangle FYE, since YE has been found; or we can find it from the triangle FYD since YD has been found. We thus arrive at two values of FY which will probably not agree precisely with one another, because of the arbitrary character of the corrections which have been applied to reconcile the slightly erroneous angles in the triangles. And if we had gone a different way round, deriving FY through FD or FE we should have obtained other slightly differing values of FY.

In ordinary topographical work not of high precision we shall take the mean of the various values we obtain for any side; and proceed. But in precise work this is not possible, and some way must be found of determining such a set of corrections to the angles that we arrive in the end at the same result precisely, whichever way we go round. This is called the adjustment of the quadrilaterals, and is a process much too elaborate to be described here.

Closing one base on another.

By the above process we may start from the measured length of one base and calculate right through the chain of quadrilaterals until we arrive at another measured base. We shall then have two values for this base: the directly measured value; and the value carried through by calculation from the first base. These two values will generally differ from one another by a slight amount; and it is usually assumed that the former is correct. We have then to investigate the corrections that are to be applied to the triangulation, in order to make the measured and the calculated lengths of the base agree with one another. It will be evident that this is a more elaborate piece of adjustment than the first, and far more unsuitable for description here.

Calculation of the geographical positions of the triangulation points.

For general purposes the most convenient way of defining the position of each point is to give its latitude and longitude.

We have determined an initial latitude and longitude of a station *A*, the azimuth of the line *AB*, and the length in feet of *AB*. The problem is to determine the latitude and longitude of *AB*, and the azimuth of *A* at *B*. For the purposes of precise survey it is not sufficient to resolve *AB* along and at right angles to the meridian through *A*, and convert these resolved distances into differences of latitude and longitude. We have to take account of the curvature of the Earth, and of the fact that owing to its spheroidal shape the curvatures along and at right angles to the meridian are not the same. The necessary formulae are somewhat complicated, and the analysis by which they are established still more so. It must be sufficient to say here that the Survey Tables of India, reproduced in extended form in the *Textbook of Topographical Surveying*, pp. 209 et seq., have reduced the computation to a simple form, by a process of great ingenuity.

We should note that this process demands a knowledge of the size and shape of the Earth, as a basis for the tables.

The calculation gives the differences of latitude and longitude between *A* and *B*; which being added to the co-ordinates of *A* give those of *B*. It gives also the azimuth of *A* from *B*, technically called the 'reverse azimuth,' which is not quite 180° different from the initial azimuth, on account of the convergence of the meridians towards the pole.

Now to proceed from *B* to *C*: We have the measured angle *ABC* and the azimuth of *BA*, from which we deduce the azimuth of *BC*, and the process of carrying on from *B* to *C* proceeds as before.

Thus we obtain the geographical positions of all the triangulation stations. Any selection of them can now be plotted on any plane table sheet in the manner to be described presently.

Calculation of rectangular co-ordinates.

If however the area surveyed is small, and it is a question only of plotting a single sheet or small number, it may not be worth while to perform the above calculation of the latitudes and longitudes. For the purpose of plotting the plane table sheets it is sufficient to calculate the rectangular co-ordinates of the other stations with respect to axes through the initial station, treating the triangulation as if it were on a plane instead of being on the spheroid. This is simpler to calculate, but we shall see that it is not so simple to plot; and there is great difficulty eventually if geographical positions should be wanted after all.

Construction of the plane table graticule.

The plane table graticule is a construction of meridians and parallels drawn on the table, so as to permit the plotting of any station whose latitude and longitude have been derived from the preceding calculation. The projection upon which the graticule is drawn is an approximation to the polyconic projection. The quantities required are derived from tables such as those given in the *Textbook of Topographical Surveying*, pp. 227 et seq., and the method of construction is given on p. 93. See also the author's *Map Projections*, pp. 58, 118. This work can be done in the field, with only the sight rule of the plane table and a pair of dividers. When the graticule is plotted it is easy to interpolate and plot any station whose geographical position has been determined.

At first sight this method may seem to be elaborate, and the beginner may imagine that something much simpler might be devised to serve its purpose. It will be found, however, that for the orderly conduct of a regular survey nothing less systematic will serve. Generally speaking, when the triangulation is complete and calculated, the work of plane tabling the detail is divided up between a number of surveyors, who undertake each a definite block bounded by certain meridians and parallels. Each plane table will be plotted so that it includes an area somewhat larger than that assigned to the particular table; and the triangulation points will be plotted all over the sheet. To have these well determined points all round outside the area actually being mapped is a great convenience.

Mapping the detail by plane table.

When the surveyor goes out into the field with his plotted sheet he first visits some of the principal points, sets up the table there, and sights round to the other points within view, to see that the rays come right, and that no mistake has been made in the plotting. At one of the stations, while the table is set, he puts on the compass lines for the trough compass. He also takes the opportunity of drawing rays to prominent objects which will serve as intersected points.

This being done, the work of mapping proceeds as in graphical plane tabling, and we need not repeat what has been said on the methods of fixing by resection. Since the positions of the calculated points are correct far within the limits of visible error, the general accuracy of the whole will be much better than in the graphical process, and a second resection should always give an exact cut of the three rays, without any triangle of error.

The determination of heights and contours will be very much more exact than in the graphical process, because they will be all based on the theodolite heights of the triangulation stations.

The spot heights at the resected points will be determined with the Indian pattern clinometer (see Plate XV), which consists of a brass bedplate with a bubble and levelling screw, set up along the ray on the board, and levelled. Two leaves standing up at either end of the base plate carry respectively a small sight hole, and divided scales of degrees, on one side, and of tangents of degrees, on the other side of a vertical slit. The observer, looking through the sight hole at the distant point, reads off the tangent of the elevation or depression of the distant point. He then scales off its horizontal distance, multiplies it by the tangent, and obtains at once the vertical interval between the plane table and the distant station. He must not forget to take account of the height of the table above the ground, in calculating the spot height.

This process is about ten times as accurate as determining spot height with the Watkin clinometer; and being based upon accurate fundamental heights, it gives points for contouring with all the refinement which can be desired, except for detailed engineering.

When the spot height is fixed, the slopes are observed with the scale of degrees on the other side of the opening in the vane, and the process of calculating mentally the places and spacing of the contours are almost exactly similar to those which we have already described fully in Chapter V, pages 109–112.

When the section allotted to the surveyor is complete he inks in all the lines and figures which are to stand, clears up with rubber all those which are not required, and sends in the field sheet to headquarters. The great advantage of this system is easily seen. The field work comes in block by block all ready for the draughtsman, who has only to redraw it on the finished sheet, when it is ready for reproduction. There is very little possibility of confusion or misunderstanding, or of some portion of the work being missing. All this tends strongly to good order, efficiency, and economy in the operations of the survey.

Precise traversing.

It must always be remembered that in certain types of country triangulation and plane tabling are impossible, as on the Gold Coast, a nearly flat and densely forested region, where it is impossible to obtain a view of any importance. In such country it is necessary to construct a framework of traverses, run with the theodolite and steel or invar tape along lines of clearance cut through the forest. This is expensive, and exceedingly unsatisfactory, because in a few months the lanes are grown up again, and the labour seems to be lost.

The methods of work vary much in different countries, and for an account of them we may refer to such books as the *Handbook of the Southern Nigeria Survey.*

The process of topographical survey which we have described here is that which, with small differences, is in use in all the principal surveys of the world. It is admirably suited to the rapid production of maps on topographical scales, especially where the detail is not too crowded.

It is not, on the other hand, so suited to the production of large scale cadastral maps showing intricate boundaries of property. In such cases it is usually necessary to break down the triangulation into small triangles of about a mile a side, by the theodolite, and to cut these up in turn and fill in the detail with the chain. This was the method by which the whole of the detailed survey of the United Kingdom was carried out. It is very accurate, and very expensive. But it has no geographical interest, and we shall not consider it further in this book.

The Ordnance Survey of Great Britain and Ireland.

The beginnings of the Ordnance Survey may be traced to the Highland rebellion of 1745, when the Quartermaster General to the forces of the Duke of Cumberland made a map of the Highlands, which proved so useful that it was extended to the Lowlands, and the intention was formed of making a map of the whole kingdom. The project was continually interrupted by war, and not very much progress was made with it.

In the year 1783 Count d'Adhemar, the French Ambassador, transmitted to Mr Fox a memoir of Monsieur Cassini de Thury, proposing to connect Greenwich and Paris by a triangulation, in order to determine the difference of longitude between the two Observatories. The British Government accepted the proposal, and entrusted to General Roy the task of planning and directing the enterprise. The first step was to measure a base on Hounslow Heath. Thence a chain of triangles was carried across the Surrey Hills and through Kent to Dover, from which the connection was made to Boulogne, Calais, and Dunquerque. It is interesting to notice that in this early work the observations were made to lamps, at night.

These operations made it possible to bring out a really accurate map of Kent. Immediately the demand arose for equally good maps of Sussex and of Essex; the Admiralty required that the chain of triangles should be continued westward to the Land's End and Scilly, for the improvement of the Channel Charts; and then began that movement in favour of a complete survey of the Kingdom, for which General Roy had been looking ever since his early experience in the Highlands.

The principal triangulation of the United Kingdom occupied roughly the first half of the nineteenth century. Unlike modern triangulations of the first class, it was extended over the whole country, and not merely confined to chains along the meridian and parallel. It was made with the celebrated three foot theodolites constructed by Ramsden.

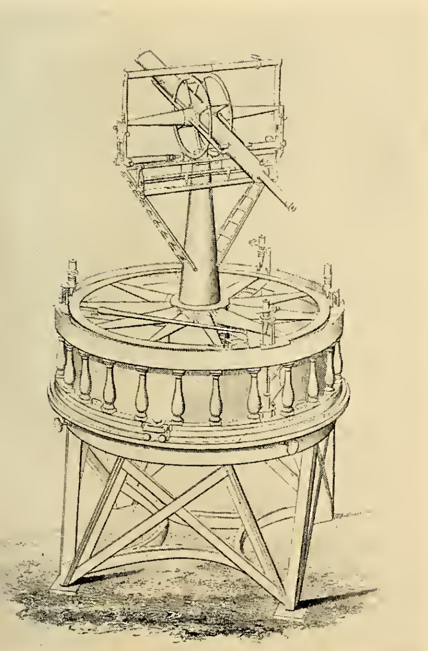
The survey of a thickly settled country cannot be conducted without the right of access to property of every kind ; and in the English survey this right was interpreted very liberally. A great platform was erected over the Cross of Saint Paul's Cathedral in London, and a section of the spire of Norwich Cathedral was temporarily removed to make a station for the instrument. These stations are marked beyond any probability of loss. But the stations in the open country are not so well identified, and some of them could not be recovered if they were required for a revision of the triangulation. More unfortunate still, one end of the principal base on Salisbury Plain is lost, by the mischievous enterprise of some persons unknown, who dug up the bronze gun which was sunk in the ground to serve as a terminal. It is now generally recognised that the right way to preserve triangulation stations and principal bench marks of the levelling is to buy the small plots of ground on which they stand, fence them in, and entrust them to the care of the local authorities.

The connection between Wales and Ireland involved great difficulty owing to the rarity with which very long rays can be observed in the moist climate of the west. The difficulty was overcome in the end by the invention of the limelight, and observation at night. The extension northwards to the Shetlands was possible only because of the fortunate situation of the small islands Faira and Foula. Further extension to the Faeroes is impossible.

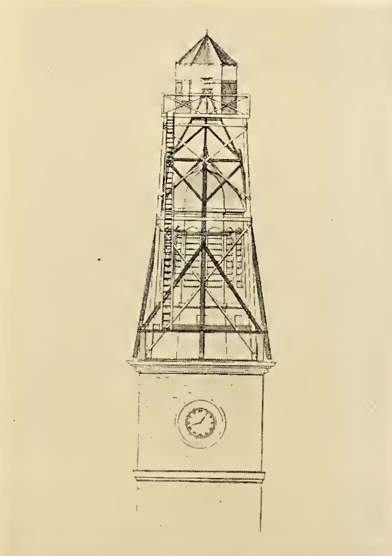
The triangulation of the United Kingdom rests on the two bases of Salisbury Plain and Lough Foyle ; it was not found possible to measure a good base in Scotland. Indeed it was the opinion of the surveyors that there was not in the whole of Scotland a site on which a base could be measured with possibility of connection to the triangulation. Modern improvements in base apparatus have at last removed from Scotland this reproach.

The 'breaking down' of the principal triangulation into the smaller secondary and tertiary triangles eventually covered the

1. Measurement of the Lough Foyle Base.



2. The Great Theodolite.



3. Scaffold on Gravelines Church for the connection with France.

nce Survey. Principal Triangulation.

country with a net of triangles averaging little more than a mile a side. So minute a subdivision was required because the detail was all to be fixed by chaining. It is a peculiarity of the survey of the United Kingdom that not only the horizontal detail, but also the contours, are all chain surveyed. The great expense of accurately surveyed contours made it impossible to place them as close as was desirable; and it is now recognised that less accurate contours at a smaller vertical interval would have been more valuable than the less frequent levelled, pegged, and chained contours which must in course of time become obsolete by changes due to weathering and to cultivation.

The latest report of the Ordnance Survey, dated 1912 May 28, gives much interesting information on the present state and future intentions of the Department. The Survey is now 118 years old. In that time it has completed the trigonometrical framework of the United Kingdom, which occupied altogether some sixty years; it has produced the one-inch map of the whole Kingdom, and revised it twice; the six-inch and twenty-five inch maps of Great Britain, with one revision; and the six-inch map of Ireland with one revision. The twenty-five inch map of Ireland will be finished in 1914.

A great part of the work of the Survey now consists in the systematic revision. It is now the rule that no large scale map shall be more than twenty years unrevised, and that the small scale maps shall never be fifteen years out of date when they are issued. And the more important alterations, such as new railways, are shown very nearly to date. With the rapid extension of industrial development the amount of detail to be shown, and the complication of the map, become continually greater.

"A hundred and seventeen years ago the surface of the three Kingdoms presented an appearance on the maps very different from what we are accustomed to, and this is of course especially the case in and near what are now the great centres of population. We must picture a map which shows no railways, no system of metalled roads, no post or telegraph offices, few factories, a map dotted with small towns, showing by their plans their medieval structure. Yet in the country we should find the boundaries of counties and parishes but little changed, and we should find the same immemorial hedges." (*O. S. Report*, 1912.)

After a rather long repose the scientific side of the survey has been awakened within the last few years, and important works are in progress. Owing to its early date, and to its pioneer character, the principal triangulation of the country, though absolutely sufficient for the practical needs of mapping, is possibly below the standard required in modern discussions of the figure of the Earth; but owing partly to the difficulty of measuring a base in Scotland, it was not easy to define precisely how far it falls short of the desired standard. To test this matter a base has been measured at Lossiemouth, and a portion of the triangulation is being re-observed in connection with it. At the same time all the principal stations of the triangulation are being examined, and re-marked in more permanent fashion than was thought necessary at the time when they were occupied for observation.

"So far as the mean sea level is concerned, the datum in use on Ordnance Survey maps at present has no scientific value. Steps are being taken to determine with all available precision satisfactory values of the mean sea level in Cornwall, and on the North Sea. The revised network of levels and the precise values of mean sea level will not only serve practical purposes better than these have been served in the past, but will provide data for the determination of the vertical movements of that portion of the earth's crust which is Great Britain." (*O. S. Report*, 1912.)

An important feature of the new programme of levelling is the provision of fundamental points based on the solid rock.

The cost of the Ordnance Survey is nearly a quarter of a million per year, and about one tenth only of this is received from the sale of maps to the public. But on the other hand, it is probable that the amount saved to the public by the existence of the Ordnance Survey maps is several millions per year. And the work of Government could not proceed without the Survey. The value of maps and plans furnished to Government

Departments during the year 1911—1912 was more than three times the value of those bought by the public.

India.

The Survey of India has a long and honourable history, and no country of the world has contributed more to the advancement of geodesy, the thorough organisation of topographical survey, or the methods of work in difficult frontier country. Only in the methods of map reproduction has the Survey of India failed to maintain the highest level; and great improvements have been made in this respect in recent years. The frequent references to Indian methods in the British official textbooks show how great an influence this celebrated department has exercised on the survey work throughout the Empire.

Canada.

Until within the last few years the great amount of survey that was done was for special purposes, and since it was not done under the control of any one authority, nor in any systematic manner, the greater part of it was inevitably wasted, from the point of view of the production of a topographical map of the country. This is now happily changed. A geodetic survey is in progress under the direction of the Chief Astronomer and the topographical survey is being pushed forward by the Militia Department, while the reproduction of the maps has been undertaken by the Geographical Section of the General Staff in London. The diagram of sheets published is to be found in the Catalogue of Maps published by the latter department.

Australia.

The conditions in the Commonwealth very much resemble those in Canada. A great deal of miscellaneous survey has been carried out without much result in the production of topographical maps. A good deal of primary triangulation is now being done, but there is not yet much information available, and it does not appear that the publication of maps has yet been begun.

South Africa.

The geodetic triangulation is complete, and a great part of it is included in the arc of the 30th meridian, to which reference has already been made. The Orange Free State has been surveyed topographically on the basis of the geodetic survey, at the joint expense of the British and the Colonial Government. A reconnaissance survey of Cape Colony has been made in part, but this is now suspended. No topographical survey exists in Natal, the Transvaal, or in Rhodesia, and the want of such a survey is not only a danger from the point of view of defence, but is a standing obstacle to the development of the country.

British Tropical Africa.

The tropical possessions in Africa are in a much more forward condition, in regard to survey, than the much older states to the south. At first much money was spent rather ineffectively in desultory survey, but great progress has been made since the establishment of the Colonial Survey Committee in 1905. It is the duty of this committee to make such recommendations as will ensure the rapid and economical prosecution of accurate surveys where these are required, and the rendering the results available as speedily as possible for use by the Home Government, the Colonial Governments, and the public.

This committee publishes an annual report, which is full of the most interesting information, and should be read by all students who are interested in the survey of the Empire. In the first report, dated August 1906, special attention was drawn to "the importance of enforcing the rule that work should be taken up systematically by blocks according to a definite programme. This is a principle which cannot be too strongly insisted on, but which has been largely neglected in the past; the observance of this principle is a fundamental condition of efficient and economical work." The excellent results of the criticism exercised by the committee may be seen in the very satisfactory records of progress in the later reports.

The work of the Colonial Survey Committee was at first principally in tropical Africa, but it has gradually extended its interest to other colonies and dependencies.

Boundary Surveys.

The survey and delimitation of international boundaries in Africa have been the means of surveying many of the outlying portions of the tropical protectorates, and the great variety of the conditions to be faced has led to great improvements in the technical methods employed. It is unfortunate that there is not available any general account of these operations, which are of the highest interest.

A detailed summary of the length of each boundary, the date of its survey, ratification, and demarcation, is given in the Colonial Survey Report. The general course of the operations is as follows:

"First there is an international agreement drawn up on broad lines; each government then appoints Commissioners, who meet at one end of the boundary and march along it, exploring and mapping the boundary zone. The Commissioners, having arrived at the other end, agree upon the geographical position of the principal features and decide upon the details of the frontier, paying special attention to the incidence of tribal boundaries, and to the future nationality of the villages. They then march back along the line, erect pillars, and inform the chiefs. The protocol in duplicate is drawn up and signed, and each Chief Commissioner forwards the protocol and maps with a report to his Government. The protocol is then approved by the two Governments, and in some instances a fresh agreement on the terms of the protocol (with perhaps some minor modifications) is drawn up and signed by the representatives of the Governments."

Great Britain is interested in about 17,000 miles of boundary in Africa, of which about 10,000 have now been surveyed, principally within the last fifteen years. The result of this activity is that the perimeters of our African possessions are more accurately surveyed than the interiors, and the land boundaries better than the sea coasts.

In other parts of the world also the demarcation of boundaries has involved interesting surveys, notably on the Alaska Boundary, the boundary between Chile and Argentina, surveyed by the officers of the British Arbitration Commission, and the Akaba boundary between Egypt and Sinai.

These have provided instances of the delicacy with which the fixing of an international boundary must be conducted, or the dangers which arise from any looseness or ambiguity in the definitions, so long as there is not a chain of conspicuous beacons erected at intervals along the boundary with the consent of both parties. There are now no "hinterlands" in Africa, the partition of the continent is complete, and the boundaries are well defined by treaty or convention. It is highly satisfactory to know that the actual delimitation of these boundaries is making such rapid progress that there will soon be very little left unmarked.

CHAPTER VII

GEODETIC SURVEY

THE present meaning of the word Geodesy is the same as the old meaning of the word Geometry: the measurement of the Earth. And it is a great pity that the word is sometimes used, in examination schedules, to mean elementary survey.

Figure of the Earth.

The principle which underlies the measurement of the Figure of the Earth is exceedingly simple.

Suppose first that the Earth is, to the best of our knowledge, spherical; and consider how we should measure the radius of the sphere. Take two stations on the same meridian, and determine the latitude of each. This gives the distance between the two stations in angular measure on the sphere. Now, by triangulation, measure the distance between the two stations in terms of the unit of length that we prefer, say metres. We then have the result that so many metres are equivalent to so many degrees, minutes, and seconds of the arc on the sphere. If the difference of latitude is n'', and the distance between the stations along the meridian is M metres, then the radius of the meridian in metres is given by the equation

$$\text{Radius} = M \operatorname{cosec} 1''/n.$$

This is the principle of the method used by Eratosthenes in his celebrated attempt to measure the Earth, in the third century B.C.

If similar operations carried out in many different latitudes on various meridians gave always the same value for the radius, we should have the clearest evidence that the Earth was a true sphere. But in fact we get different values for the radius when we determine it in different places. This was suspected in the latter part of the seventeenth century; but the errors incidental to early operations of the kind led to some confusion; and it was not until the celebrated measures made under the auspices of the French Academy in Peru and in Lapland had been brought to a successful conclusion that the law of the variation was definitely established for the northern hemisphere. The further one goes north, the larger is the distance corresponding to a degree of latitude: the flatter, therefore, is the Earth.

The measures made in Peru and in Lapland, combined with those made in France, were consistent with the hypothesis that the Earth is a spheroid of revolution, or, in other words, that all the meridians are similar ellipses. They were consistent with this idea, but they were by no means sufficient to prove it; and in the middle of the eighteenth century grave doubt was cast on the matter by the result of the Abbé de Lacaille's measure of an arc of meridian at the Cape of Good Hope, which seemed to show that the southern hemisphere was prolate, the degree decreasing in length as the pole was approached.

It was some time before the explanation of this difficulty was discovered; and in the meanwhile a somewhat similar discrepancy had been found in England, the curvature of the southern half of England appearing to be less than that of the northern half.

Deviations of the vertical.

The origin of these abnormal results is in the existence of local deviations of the vertical, which have been mentioned already in Chapter VI, page 142. The latitude of any station is the inclination of the Earth's polar axis to the horizontal plane of the station. The horizontal plane is the plane at right angles to the direction of gravity. The direction of gravity is determined by the distribution of matter within the crust of the Earth. If this distribution is abnormal in the neighbourhood of a station the horizontal plane is no longer a tangent plane to the spheroid which represents the general form of the Earth; and if such a place is chosen by bad luck as one of the terminals of an arc of meridian the curvature of the meridian deduced from these measures is not representative of the general average curvature of a meridian in that latitude.

We have said that the direction of the vertical is influenced by the distribution of matter within the Earth's crust. It is also of course affected by the attraction of the visible mountain masses above the level surface. But these latter can be allowed for; and when this is done it nearly always happens that the visible masses prove to be quite insufficient to account for the results obtained. Indeed it not infrequently happens that the deflection of the vertical is in the direction opposite to that which would result from the attraction of the visible mountain masses alone. Such is the case at Dunnose, the station in the Isle of Wight which is the southern terminal of the arc of meridian of Great Britain. Here there is high down to the north, and the English Channel to the south. The density of the water is only about two-fifths that of the surface rocks, and it might be expected that in such a situation the direction of gravity would deviate away from the sea, and towards the land masses to the north. At this station an opposite effect is found. The direction of gravity is deflected to the south; the horizontal plane is tilted to the north; the angle which the Earth's axis makes with this plane is diminished; the latitude of the place comes out too small; the amplitude of the arc of latitude is increased and finally the southern half of the British arc of meridian appears to be flatter than the northern half.

What happens at Dunnose happens to a greater or less extent at most stations. These deviations in the direction of gravity are the most disturbing factor in geodetic work; and we will discuss them a little more fully before we deal with modern determinations of the size and shape of the Earth.

The attraction of the Himalayas.

The problem of the effect of the Himalayas on the direction of gravity in India has been present continually to the Indian surveyors. North of the Indian arc is the immense mass of the greatest mountain range in the world; to the south the Indian ocean is very deep, and the consequent deficiency of density considerable. It might be expected that in India the direction of gravity would be deflected towards the north; and calculation shows that the effect of the visible excess of density to the north, the visible deficiency to the south, should extend all over India.

A great number of careful determinations of latitude were made at stations along the great arc of meridian, but the expected effect was not obtained. The discordances between the astronomical and the geodetic latitudes were considerable; but they did not fit in at all well with the deviations which the visible masses should have produced. It appeared that some cause was at work which in great part annulled the effect of the mountain attraction. This was the first indication of the law which now plays so large a part in these enquiries, that in some way the expected effect of mountain masses is compensated, as if there were underlying deficiencies of density which nearly balanced the visible masses.

About the year 1860 Archdeacon Pratt, of Calcutta, a distinguished mathematician from Cambridge, applied himself to the mathematical investigation of this problem, and arrived at the above result, that the attraction of the mountains is not so great as their visible masses would lead one to expect. The then Astronomer Royal, Sir George Airy, proposed to explain this in the following way: Conceive that the Earth is composed of a solid crust about forty miles thick, with a liquid below. The strength of the crust would not be nearly sufficient to support the weight of the superincumbent mountain masses; therefore there must be some support for them, and this may be in the form of protuberances beneath the mountains, of the lighter crust into the denser liquid below. In such a way the mountains would be in equilibrium because they are practically floating like icebergs in the ocean, buoyed up by the intrusion of their "roots" into the liquid.

This "roots of the mountains" theory has been the subject of much interesting discussion, especially by the Reverend Osmond Fisher, in his *Physics of the Earth's Crust.* Mathematicians have in general felt themselves compelled to reject the internal fluidity of the Earth, on account of certain tidal phenomena, into which we can hardly enter. But the important idea that the principal mountain masses are nearly in equilibrium, their visible excess of weight balanced by invisible defect of density below, as if they were floating, has by gradual steps become an established principle of geodesy.

If the visible excesses of dense material in the mountains are counterbalanced by deficiencies underneath, it is clear that we may expect also that the visible deficiencies of matter in the oceans should be balanced by excesses of matter in the ocean beds. Evidence for this supposition cannot be found however in the observations for latitude, so well as in the conclusions to be drawn from the determinations of gravity by the pendulum, to which we must now refer.

Gravity survey with the pendulum.

The mathematical theory of the attraction of a spheroid at any point of its surface, or at an external point, provides a formula which expresses the force of gravity, and thence the time of oscillation of a pendulum of known length, at any place. Knowing the shape of the Earth, we can predict the rate of swing of the pendulum; and alternatively, it is evident that if we carry an invariable pendulum about the world, and determine the time of its swing at different places, we have a means of determining the figure of the Earth independent of the triangulation and latitude method explained above. When sufficient observations were accumulated it was found that the two independent methods of arriving at the ellipticity of the Earth gave results which were in tolerable agreement, though they were not identical. For the moment the discrepancy need not concern us.

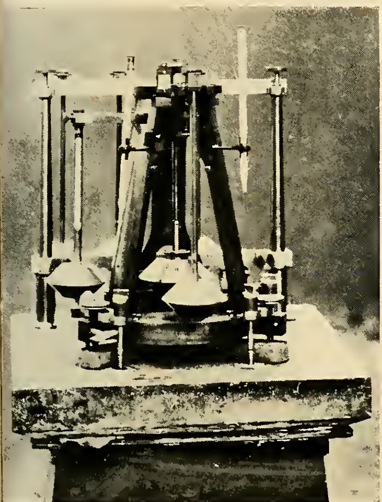
But it was also found that the pendulum observations on high mountains, as in the Himalayas, gave peculiar results. It is easy to calculate the intensity of gravity at a given height above the surface of the Earth, and to allow for the increase which should be due to the mass of the mountain on which the pendulum is established. But observation discloses the remarkable fact that the mountain mass itself has not the expected effect; the pendulum swings pretty much as if it were somehow supported at the height of the mountain, but unaffected by the mountain mass. In other words, the attraction of the mountain is more or less compensated.

Further, it was pointed out by the French geodesist Faye that a similar effect is found on oceanic islands: similar in cause, though opposite in its immediate effect on the time of swing of the pendulum. On those volcanic islands which rise steeply from deep ocean the force of gravity, as determined by the pendulum, is in excess, the excess being about that amount which can be attributed to the mass of the island standing above the ocean floor. In other words, if the pendulum could be swung on the surface of the sea, without the material support of the island, then the time of swing would be normal.

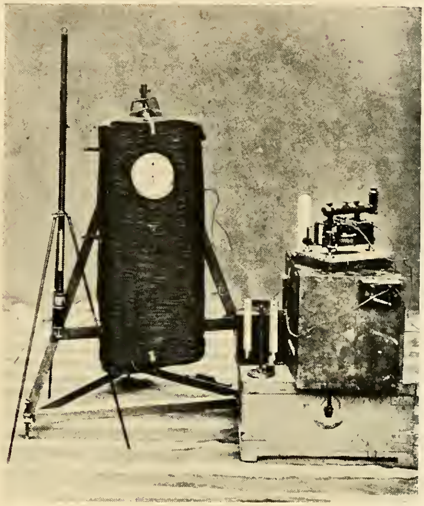
This important result has been confirmed, within recent years, by the work of Hecker, who has made several long voyages, including a circumnavigation of the world, comparing all the while the readings of a large number of mercurial barometers and of boiling point thermometers. Both these instruments determine the pressure of the atmosphere; but whereas the height of the barometer is affected by the intensity of gravity, the boiling point of the thermometer is not. It may well seem remarkable that this method can be made of delicacy sufficient for the purpose in view, and there are indeed many instrumental difficulties to be overcome. But these observations seem to place beyond much doubt the result suggested by the island pendulums, that over the surface of the ocean gravity is normal; it is not diminished as might be expected by the small density of the water as compared with rock; and the simplest explanation seems to be that the rocks below the ocean floors are extra dense, to balance the deficiency above.

Gravity in India.

Recent very interesting work of the Survey of India shows that the problem in India is more complicated than had been supposed. In the foothills of the Himalayas the "compensation" is partial; immediately to the south of the mountain range the



1. Half-second Pendulums.



2. Clock and Flash Box.

Gravity Survey.

3. Latitude with Zenith Telescope.

compensation is more than complete, so that there is a defect of density underlying these regions.

A few figures will serve to show the nature of these results.

All observations are referred to Kew as the base station. The value of *g*, the acceleration due to gravity, is taken to be 981·200 centimetres at Kew. The Indian pendulums were swung at Kew, and the mean time of vibration was 0·5067001 seconds. The same pendulums swung at Dehra Dun gave for the mean time of vibration 0·5072528 seconds. That is to say, as compared with Kew they lost one swing in something less than ten thousand. Now by the theory of the pendulum the square of the time of oscillation multiplied by the value of gravity is constant for all stations. Hence we deduce for Dehra Dun the value $g=979{\cdot}063$ cm.

This has now to be corrected for the diminution of gravity due to the height of Dehra Dun above sea level. Without allowing for the attraction of the ground above sea level the reduction is $+0{\cdot}210$. The correction for the attraction of the "visible masses" is $-0{\cdot}075$; so that the value at sea level is 979·198 cm. But the sea level value computed for Dehra Dun from Helmert's general theory for the whole Earth is 979·324, which is greater than the observed value even without the allowance for the visible masses. Instead of having to allow for the attraction of the equivalent of a plateau some 2200 feet high, it appears that the effective attraction is as if a depth of 3600 feet were annihilated. There is a large deficiency of gravity, therefore, at Dehra Dun.

Similar observations made at many stations show that while in the foothills of the Himalayas the attraction of the mountain masses is partially, but not fully compensated, immediately to the south is a "ditch" of deficient density, before the attraction becomes normal. It is clear that results of this kind must eventually throw much light on all questions of the theory of the Earth's interior, and especially on the methods of mountain formation. They have a general interest outside their technical geodetic importance, and for this reason we have dealt with them in some detail.

The theory of "isostasy."

The convergence of these various lines of investigation to the same point seems to have fairly established the general law of balance: where there is excess of mass above it is balanced by deficiency below, and vice versa. To this condition the American geodesist Major Dutton gave the name "isostasy," signifying that the crust of the Earth is in a general condition of hydrostatic equilibrium, as if it were floating, though it is not necessarily doing so.

The question then arises, to what depth must one go before this state of balance is fully established? Very elaborate investigations on this subject have been made of late years by the United States Coast and Geodetic Survey. Starting with the assumption that there must be some definite depth at which the compensation becomes complete, they have tried to determine the depth, and have arrived at the result 120 km. It is quite impossible to deal here with the methods of this exceedingly elaborate and arduous piece of work; and it does not seem to the author to be sufficiently established that there is any one depth at which the compensation becomes complete. Much light will be thrown upon this question by the discussion of the Indian results which has been undertaken to test the applicability of the hypothesis to India.

It should be understood that the theory of isostasy does not require that the compensation is locally complete everywhere, but only that there is general compensation of the principal masses which are raised above the Earth's surface. In India great complications are introduced by the existence of a subterranean range of excessive density running parallel to and south of the Himalayas, with a "ditch" of deficient density between this and the mountains.

The form of the ocean surface.

In connection with this subject of mountain attraction it is natural to speculate what effect is produced upon the form of the ocean surface by the attraction of great mountain masses. Several calculations have been made which show that if the mountains can exert the full effect that their visible masses entitle them to, the elevation of the free surface of the ocean must be considerable. Colonel Clarke (*Geodesy*, p. 94 and following) gives a method of calculating the order of the effect upon the height of the sea surface produced by the attraction of the Himalayas, and shows that it might amount to as much as 600 feet. "This calculation," he proceeds, "shows us that large tracts of country may produce great disturbances of the sea level, but it is at least questionable whether in point of fact they do." The compensation of the mountain masses nullifies the effect in great part, we may be sure, and leaves little scope for the existence of great differences in the sea level radii of the Earth.

Nevertheless it is common to meet in books the statement that the sea level at Calcutta is about 330 feet higher than it is at Cape Comorin; and that the sea on the Pacific coast of South America, close under the Andes, is 2000 feet higher than it is at the Sandwich Islands. These statements are based on calculations such as Colonel Clarke gives; but they are sometimes said to be supported by the results of direct levelling. Such a statement is on the face of it absurd. The surface of the sea must be a level surface in the sense that spirit levelling from one point to another could give no evidence of rise or fall. Any attraction of mountain masses which changed the form of the sea surface would have an equivalent effect on the results of the instrumental levelling.

Geodetic measure of an arc of meridian.

From what we have seen of the effect of local irregularities of gravity it is clear that no close accordance may be expected between the geodetic amplitude of an arc, measured by triangulation, and its astronomical amplitude, measured by determinations of latitude or longitude at each end. In order that the effects of these local abnormalities may be eliminated as far as possible it is usual to proceed in a way which may be described briefly as follows:

Select as the initial point a station which seems to be free, as far as may be judged, from the influence of attraction by visible masses. Starting from this point we may from the triangulation calculate the latitudes of any number of points in the chain, using in the calculation tables founded upon one or other of the well-known results for the figure of the Earth: let us say Clarke's first figure. Compare these geodetic latitudes with the observed latitudes of the same points. The differences

Geodetic *minus* Astronomical latitude

are the material on which we shall found a revision of the figure which was adopted in the tables.

If these differences are scattered at random, and show no tendency to grow steadily bigger or smaller, or first bigger and then smaller, they must be due in great part to local irregularities of gravity. But if they run in a systematic way the probability is that some modification in the adopted figure would make them smaller, and we proceed to find that figure which gives the best fit between the astronomical and the geodetic places. It is not hard to calculate the effect upon each comparison of a definite change in the assumed axes of the Earth, a change in its assumed ellipticity, and a correction to the adopted initial latitude. The various corrections will appear as the unknown quantities, with calculated numerical coefficients, in a series of equations, one for each latitude station. The solution of these equations of condition by the method of least squares gives the values of the corrections which reduce to a minimum the sum of the squares of the residual differences. And the theory of probability shows that this is the most probable result that can be found from the mass of somewhat contradictory material given by the observations. In other words one finds what corrections must be made in the original assumptions to produce the best fit between astronomy and geodesy over the arc in question.

Similar considerations determine the method by which the observations of longitude and azimuth may be made to contribute to a revision of the size and the shape of the Earth.

The outstanding discordances between the observed astronomical latitudes and the figure of the Earth which fits them best are by no means inconsiderable. For example, Clarke's 1866 figure is deduced from 40 latitude stations. The discordances of the British stations are as follows :

Greenwich Geod. *minus* Astron.	$+0''\cdot94$
Arbury	$+1''\cdot40$
Clifton (Yorks)	$-2''\cdot19$
Kellie Law	$-0''\cdot65$
Stirling	$-0''\cdot24$
Saxavord	$+1''\cdot95$

The extreme discordances of all are at two Indian stations :

Dodagoontah	$+3''\cdot87$
Kalianpur	$-3''\cdot69$

If we remember that one second of arc in latitude is equivalent to one hundred feet it at once becomes clear that it is hopeless to try to make an accurate and consistent map on a basis of astronomical positions. Discordances of several hundred feet will arise, which are intolerable.

The principal geodetic arcs.

The first man to apply the principle of triangulation to the measurement of an arc was Snellius, whose work was published at Leyden in 1617.

The first long arc of meridian was begun by Picard, and extended by the Cassinis. It had an amplitude of eight and a half degrees, and was at first supposed to show that the Earth was a prolate spheroid, contrary to the theory developed by Newton. This was early in the eighteenth century.

In 1735 the French Academy undertook the measurement of the arc of Peru, and of another in Lapland. These, with the French arc mentioned above, provided the first accurate determination of the figure of the Earth.

In 1783 the triangulation of England was begun by General Roy, and connected with the French triangulation.

In the nineteenth century the great meridian arc of Europe, on the 30th meridian of East longitude, was measured from Hammerfest to the mouth of the Danube, under the principal direction of the eldest Struve. Later the whole of Europe was covered with triangulation, which was then extended into Africa. Several arcs both of latitude and of longitude were measured in India; very considerable geodetic operations were undertaken in the United States; and at the end of the century the African arc of meridian, also on the 30th meridian East, was carried from the south of Cape Colony through the Transvaal towards Lake Tanganyika.

At the present day there is great activity in geodetic work. A joint commission of Russians and Swedes have measured an arc of meridian in Spitsbergen, which is probably the most northerly arc possible, while the *Service géographique de l'Armée* has re-measured the "Arc of Peru," in territory which now is Ecuador. An attempt is being made to join up the triangulations of India and Russian Asia. Egypt is actively pushing its portion of the 30th meridian arc southwards to the Great Lakes; while another part of this arc has been measured in connection with a boundary survey on the Uganda-Congo frontier. The United States is steadily carrying forward its chains of triangles over the west and north, and Canada has begun its share of the triangulation of North America. Further south good work is in progress in Mexico and in Chili. The arc of the 30th meridian is of special importance because it is the longest latitude arc that can be measured on the Earth. There seems to be good hope that the African portion will be finished within fifteen or twenty years; the greatest difficulty will be the junction between Egypt and the Danube, through Turkish territory up the Eastern shore of the Mediterranean.

A word should be said on the state of the British triangulation. It is the earliest in date of any of the great triangulations, and on that account is necessarily somewhat old fashioned. In a report on the triangulations of Europe, made to the International Geodetic Association by General Ferrero, the triangular error of the British work is given as about 3″, with the inference that the work is not of sufficient refinement to be attached to the general European net. It seems likely that this criticism is not quite just. The triangulation of England covered the whole country, and much of it was difficult because the country was so flat. Many of the more unfavourable triangles entered scarcely at all into the arcs of meridian and of longitude, and it is hardly fair to burden these with the error of triangulation in other parts of the country. Within the last few years a base has been measured in Scotland by the Ordnance Survey, and some triangulation done to connect it with the existing net. This will provide a check upon the whole which will show how far the criticisms which have been passed upon it are justified. Should it be found that there is room for improvement it is much to be hoped that for the scientific honour of the country there will be no delay in the provision of funds for revision, so that Great Britain may take its rightful place in the arcs of latitude and longitude of Europe.

Geodetic triangulation.

Geodetic triangulation differs from ordinary triangulation principally in the degree of refinement with which the angles are measured.

Accuracy is increased by increasing the size of the theodolite, up to about a twelve inch circle. The modern theodolite of this size is more precise than the older instruments of much greater size, and it is doubtful whether anything is gained by employing larger instruments than the twelve inch. Accuracy is increased by increasing the number of observations of each angle, care being taken to begin each round of angles at a different part of the circle, so that errors of division are eliminated as far as possible. Greater care in the construction of beacons, and especially the use of self-centering beacons, as on the Egyptian Survey, add much to the accuracy of the result; so also in many places does the use of lamps at night, when refraction is more regular.

Recent improvements in base measurement, and the resulting possibility of measuring many more bases than formerly, are important aids to the control of the chains of triangulation. At the same time these instrumental refinements have much simplified the work of adjustment of the triangulation; while an even greater influence in the same direction has been the modern view that it is absurd to give different weights to the observed angles according as the separate determinations of them are more or less accordant among themselves. It is now realised that the errors to be feared are not so much the accidental errors that show themselves in roughness of individual measures, as the systematic errors that repeat themselves and thus escape notice at first. The tendency is therefore to simplify the reductions and to avoid the immense calculations which are so remarkable a feature of such work as the earlier Indian triangulations. Excellent examples of work thus simplified may be found in the published accounts of the geodetic triangulation of South Africa, executed by Colonel Sir William Morris under the superintendence of Sir David Gill, His Majesty's Astronomer at the Cape.

The question arises often, under what circumstances is it worth while to undertake the expense of the greater refinement which shall make a triangulation suitable merely for the framework of the topography into a first class triangulation fit to take its part in the general problem of determining the size and shape of the World? The answer must depend to a great extent upon the relation of the country in question to the principal land masses of the world. If it is isolated, and of moderate size only, then it can contribute little to the solution of the problem. But wherever there is a possibility of junction with other extensive work of the same kind it should be a point of honour with the country to contribute its share in the solution of the great problem.

Principal chains.

In the Ordnance Survey of England the primary, or geodetic triangulation covered the whole country. In modern practice the primary triangulation is run in chains along arcs of meridian and parallels of longitude, so that a large country is divided up into a series of quadrilaterals. On the framework thus built the secondary triangulation is hung.

The chain is usually a chain of quadrilaterals, and complex figures are avoided as much as possible. Bases will be measured at least every two hundred miles along the chain.

The test of the accuracy of the triangulation is, as we have seen, the size of the average triangular error; in the best modern work this is about $0''\cdot75$. To obtain this remarkable degree of accuracy it may be necessary to observe each round of angles nine times.

It is highly desirable that a preliminary calculation of the triangles shall be made as the work proceeds; this tends to give confidence in the success of the operations, and serves to detect at once any considerable error or unusual difficulty that may arise. But to carry out this programme requires a large and strong party.

The astronomical observations.

For precise work the observations for latitude will be made by Talcott's method, with the theodolite fitted to serve as a zenith telescope. It is outside the scope of this book to enter into the details of this work.

The azimuths will be determined in general from circumpolar stars at maximum elongation.

The longitudes will be determined by the interchange of time by telegraph, or by wireless. The time observations will be made with portable transit instruments, and great precautions are necessary to eliminate the personal errors of observation. The introduction of the Repsold Transit micrometer has done much to eliminate this source of error.

The effect of all the visible mountain masses on the direction of the vertical will be calculated rigorously for the nearer masses, and by an approximate graphical process for the more distant. In the future it will be considered necessary to examine how far these effects are compensated by isostasy.

Geodetic bases.

In the chapter on topographical survey we have dealt with the use of invar wires in the field, for the measurement of bases. We will mention now some of the refinements that are necessary when the work is to be of the highest precision.

At the headquarters of an important geodetic survey provision will be made for the standardisation of the wires, to ensure a more complete control than is possible when they are merely returned to some far distant laboratory at intervals.

First it is necessary to provide a standard bar, which should be the unit of length, yard or metre, multiplied by some power of two, so that it can be compared by successive duplication. Four metres or four yards will be the most convenient length. But in fact, ten feet has been the usual length of English bars, though this involves an awkward comparison with the British standard yard. It is not quite clear why, when the yard is the standard unit of length, geodetic measurements have been made in feet. The modern bar will be made of invar. It will be compared with the standard metre at the International Bureau of Weights and Measures at Breteuil, or with the standard yard at the Board of Trade Standards Office, or with the copies of this standard at the National Physical Laboratory or at the

Ordnance Survey Office, Southampton. At the same time the laws of its expansion will be minutely studied.

To avoid duplication of statement we shall speak of the operations in future as conducted in metres. India has recently decided to make the change, and it is probable that the yard and the foot will gradually disappear from geodesy.

The next step is to establish a 24-metre comparator at headquarters, standardised from time to time with the 4-metre bar. This comparator will be in the form of a wall, preferably underground to escape temperature changes as much as possible. It will be provided with tanks in which water can be circulated, to allow for the study of the temperature coefficients of the wires. On this comparator the wires will be standardised before they go into the field, and when they return.

The constancy of the wires depends very much upon the care with which they are treated in the field. They must always be wound upon the special aluminium drums which are made for them, and they must be treated as instruments of precision should be treated, not after the fashion of coils of wire. One of the principal difficulties in the field has been to ensure continuous careful treatment for the wires, and it has sometimes been suggested that if they cost 3000 francs each instead of 30 they would be treated with more respect.

When they are first manufactured they are subject to molecular changes and their lengths are not constant. As they become aged they settle down into stability, and the process may be quickened to some extent by successive very careful annealing. But it does not seem that anything can complete the natural process of ageing except use in the field.

It is essential that the coefficient of expansion should be found for each separate wire. At first it was the practice to test a sample of the rolling from one ingot, and to assume that all the batch had the same constants. It is now recognised that this is not safe and that each wire must be examined after it has been made up into its working form.

There is still some difference of opinion as to the relative merits of wires and tapes. The advantage of wire is that it is less subject to the disturbing influence of wind. Tapes have several advantages ; twist can be detected very easily ; they are not so liable to kink ; and the small divided scale can be engraved on the tape itself, instead of on a soldered attachment, the "reglette." The last is of considerable importance.

Experience of their use in rough country has shown that the wires or tapes can be used on much greater slopes than was considered desirable when they were first introduced. But this requires that the provision for determining the slope of the tape shall be more thorough than was made in the first patterns. Recent experience on the Semliki base in Uganda, and on the Lossiemouth base in Elgin, favours the use of an ordinary Y level, and a special light levelling staff which can be stood on the tripods carrying the fiducial marks against which the tape is read. With this equipment it is possible to measure up slopes of 1 in 3, and to choose for the ends of the base situations which provide a good view of surrounding stations favourable for the base extension.

This involves a thorough discussion of the effect of slope on the horizontal distance between the end marks of the tape, arising from the change in the form of the catenary, and from the difference of tension at the upper and lower ends—a difference which may become so considerable that the pulleys must no longer be frictionless, or the tape will run away down hill. A very complete investigation of the problem has been made by Professor Henrici and his son Captain Henrici, R.E. ; the results are too complex for summarisation here. See Ordnance Survey: Professional Papers. New Series. No. 1.

For rapid work it is essential that the base party shall be well drilled. With a well-trained party a base of 10 km. can be measured completely in 12 days; and it is good economy to arrange that all the bases required for the whole triangulation shall be measured consecutively in a single season if possible.

Geodetic levelling.

The immediate practical importance of the main lines of precise or geodetic levelling is to provide a foundation for all the subsidiary lines upon which the local determinations of height, and the contours, are based. Its ultimate scientific, and perhaps also practical importance, is to discover whether the whole country is gradually rising from the sea, or sinking, or tilting; and at what rate the mountains are growing or becoming denuded.

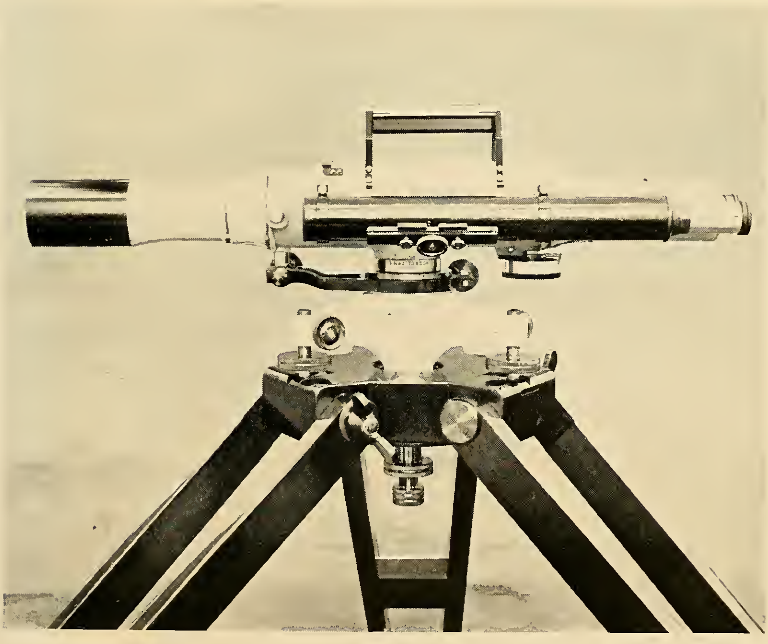
Within the limits of this book we cannot deal with the instrumental precautions which are essential in the conduct of precise levelling. The general procedure is quite similar to that which we have sketched in Chapter IV, page 95; but there are many precautions to be taken to avoid the small but cumulative effects of temperature, of refraction, and of local deviations of the vertical.

It is now realised that the original net of levelling in Great Britain was not observed with sufficient precautions to give an ultimate verdict on the above points. In particular the determination of mean sea level was not satisfactory. A revision of the principal levelling is now in progress; and great attention is being paid to the important question of placing the fundamental bench marks on solid rock.

In India the great earthquake of 1905 provoked a very interesting enquiry into the changes in relative heights produced by the shock. It was found that the difference of height between Dehra Dun and Mussooree had been diminished 5·5 inches, and it was at first supposed that Mussooree had subsided by this amount. But a revision of the line of levels into the plains showed that this was not the case. Mussooree in the Himalaya and Saharanpur in the plains were found to be at the same relative height after the earthquake as before; but the intermediate station of Dehra Dun was higher by five inches both with regard to Mussooree and Saharanpur.

There is great reason to think that this movement was only an exaggeration of a movement that is always going on, and that the Himalayas are gradually pressing forward and up the lower lying ranges to the immediate south of them. For this reason several lines of precise levelling have recently been carried up into the Himalayas, and these are being connected with the older formations to the south. It is hoped that in time this work may give information on the rate of growth of the mountains.

1. Banog Mountain: Terminal station of an Indian line of precise levels.



2. Precise Level: United States Coast and Geodetic Survey pattern.

Future progress of geodesy.

Since four-fifths of the Earth's surface is covered with ocean, over which geodetic operations are in general impossible, it is clear that we shall never be able to obtain a complete determination of the size and shape of the Earth. We shall be compelled to make certain assumptions, as for example that its figure is an ellipsoid of revolution or spheroid, or that it is an ellipsoid with three unequal axes. Then, taking the measured arcs of meridian or of longitude as samples of these figures, we can determine the size and the form which fit them best. Any determination of the figure of the Earth must rest upon a discussion of such a kind; and the result will be the more satisfactory the wider the extent of the Earth's surface represented in these "samples."

At the present time we have the following material available:

The triangulation of Europe, and its connection with Northern Africa.

A certain amount of work in Russian Asia.

India.

South Africa up to Lake Tanganyika, and short arcs in Uganda and in Egypt.

The United States and a little in Canada.

Spitsbergen.

The arc of Peru.

A certain amount in Mexico, Chili, and in Japan.

The most important work of the future is evidently

The connection of India with Russian Asia, and the extension of the meridian arc to the Arctic Ocean.

The extension of the European longitude arc across Russian Asia to the Sea of Japan.

The completion of the African arc, and its junction with the European triangulation.

The extension of the Canadian arcs of meridian to the Arctic Ocean.

An arc of meridian down the chain of the Andes.

Meridian and longitude arcs in Australia.

It will be long before this programme is finished. Meanwhile we may say a few words on the present state of the problem.

No recent attempt has been made to bring into discussion all the available material. The greater part of modern work is discussed with reference to the figures of Bessel and of Clarke.

Bessel's determination was based on the European and Indian results available in 1841, and the old measure of the arc of Peru.

Clarke's several determinations of 1858, 1866, and 1878 depend on considerable extensions of the same material; they take into account the extensions of triangulation in Europe and in India, but have nothing to add from other parts of the world.

The recent determination by Hayford is based on the United States only.

At the end of this chapter we give a table of these results. It will be seen that the differences between them are not very great, and that the contribution of the United States does not suggest that the shape of the western hemisphere is very different from that of the eastern.

Bessel, Hayford, and Clarke in one of his solutions, assume that the Earth is an ellipsoid of revolution. In a second solution (1878) Clarke assumes that the Earth is an ellipsoid not of revolution, or that the equator is elliptical. In a third he assumes that the Earth is a figure of revolution, but not the revolution of an ellipse. He finds that the evidence for the second or third of these hypotheses is so slight that they cannot be said to lead to any positive result. At present there is no real reason for supposing that the equator is not a circle, or the meridian an ellipse.

It would seem that the time has come for a new solution of the problem, to take into account all the material which has accumulated since Clarke's last solution was made. But the necessity of including a discussion of isostasy and compensation very much increases the labour.

Figure of the Earth.

The following table gives the results of the principal discussions of the dimensions of the spheroid :

	Equatorial Semi-diameter	Flattening	Polar Semi-diameter
Bessel 1841	6377397 m.	1/299·2	6356079 m.
Clarke 1866	6378206	1/295·0	6356584
Clarke 1880	6378249	1/293·5	6356515
Hayford 1910	6378388	1/297·0	6356909

From a general discussion of pendulum observations Helmert finds (1901) for the flattening 1/298·3.

Bessel's results were based on the various triangulations of Europe executed at that date.

Clarke's 1866 figure included the French, British, Indian, Russian, South African, and Peruvian arcs so far as they were then complete.

Hayford's figure depends entirely on the geodetic arcs of the United States, and includes an elaborate discussion of isostasy.

With Clarke's figure of 1880 the quadrant of the meridian is 10,001,868 metres, so that the metre is shorter by about one part in five thousand than the ten millionth of the quadrant.

CHAPTER VIII

SURVEY INSTRUMENTS

THIS book is not intended to supply the place of a technical handbook in which all the details of the instruments, the methods of adjustment, and of observation, are given minutely. Such information may be found in full in the *Textbook of Topographical Surveying*, to which reference is made so often, or in other technical works. But it will be well to give here a few notes to supplement the slight accounts of the various instruments given throughout the book.

The Sextant.

The sextant is pre-eminently a sea instrument, and it is not well adapted for use upon land, except under special circumstances.

The sextant will measure angles up to about 130° but not more. Held in the hand, it can be adjusted to allow for the motion of the ship in a way that becomes for the skilled observer almost automatic. It fulfils all the needs of the sailor, who measures elevations above the visible sea horizon, and occasionally angles between the moon and the sun or a star, for the almost obsolete method of lunar distances. It gives results which are nominally correct to 10″ and actually correct to within half a minute of arc, which is just the degree of accuracy required in navigation. The principal systematic error to which the instrument is liable is the error of eccentricity of the graduated arc—the error which in the theodolite and other more precise instruments is eliminated by reading the circle at two opposite points, which is impossible in the sextant.

It is the possibility of this error developing undetected that makes it waste labour to equip a sextant with a stand, as has been done, and to try to make use of it upon land.

On land the sextant cannot give altitudes directly, because there is no visible sea horizon from which to measure. It is necessary to employ what is somewhat confusingly termed the "artificial horizon": a dish of mercury which forms a naturally level reflecting surface, or a reflector of blackened glass which can be set level by levelling screws and a bubble. The sextant then measures the angle between the direct and the reflected images of the sun or star, that is to say, double the altitude of the body. But angles greater than 130° cannot be measured. Hence when the sun at noon is higher than about 65°, which is very frequent in tropical and subtropical regions, the noon altitude of the sun cannot be taken on land with a sextant. This serious limitation is enough to condemn the use of the instrument on shore. Moreover, the sextant cannot measure azimuths except in a roundabout way, which involves a great deal of observation and unnecessary calculation.

If, then, it is necessary to retain the sextant as a subsidiary instrument for work on land, its use should be restricted to those cases in which it must be employed for reasons of secrecy. There are native tribes which would interfere with a surveyor working at an instrument mounted on a tripod who would not be so likely to notice a man lying down on his face taking sights with a sextant. It is said that native Indian surveyors have done good work in trans-frontier regions with a sextant disguised as a praying wheel.

The sextant has often been employed on polar expeditions, on account of its small size and lightness. The observation of such small altitudes as the Sun has in spring in polar regions offers, however, peculiar difficulties when an artificial horizon must be employed; and it is now generally admitted that a small mountain theodolite should always be employed on such work. It has the great advantages that its errors are self-eliminating, and that it can be used with facility to measure azimuths. A modern mountain theodolite of the smallest size weighs no more than a sextant with artificial horizon, and the results that it gives are far more satisfactory.

The theodolite.

For many years the ordinary surveyor's theodolite suffered from a want of intelligence in its design, of which traces still survive in the patterns manufactured especially for engineers. The most conspicuous of these is the four screw levelling device, which inevitably strains the instrument, makes the screws work loose, is thoroughly bad in design, but is still very often made.

The old-fashioned theodolite was effective only for horizontal angles, in which reversal is not much required. When it was found to be advantageous to make the instrument reversible, which requires that the telescope shall be able to pass through the frame, the new pattern was called on this account a "transit theodolite," which name still survives in the makers' catalogues: a stupid name which suggests that the theodolite can be used as a transit instrument.

The circles of the old-fashioned theodolite were read by verniers only, and verniers are awkward to read by day, almost impossible to illuminate properly for reading at night. The greatest modern improvement in theodolites has been the application of the micrometer microscope, which increases the accuracy of reading the circle at least fivefold, and at the same time makes it much more simple and easy: a very unusual accompaniment of gain in precision. The five inch micrometer theodolite has now established itself as the standard instrument for survey of the second order, that is to say, in which geodetic accuracy is not required. The instrument is sufficiently portable for the employment upon boundary survey under the roughest conditions; and the facility with which it can be used for field astronomy makes it invaluable both in teaching and in actual use in the field. (See Plate XX.)

The modern theodolite is especially adapted for the accurate measurement of vertical angles, in which the old instruments were very deficient. The improvements in construction which have led to this result are two: making the instrument reversible, already mentioned; and the mounting of a sensitive bubble upon the frame which carries the verniers or microscopes for reading the vertical circle. Since there is often some misconception as to the part played by these two devices, we may examine them shortly.

It must be remembered that there is a great difference between the measurement of horizontal and of vertical angles: the former are relative, the latter are absolute determinations. Or in other words, on the horizontal circle one measures the difference in bearing between one point and another; on the vertical circle one measures the elevation of a point above the horizon, which is not a visible object on which settings can be made, but must be defined by means of sensitive levels or bubbles mounted on the instrument. To measure an absolute elevation naturally demands that all the effects of errors of adjustment, collimation, zeros of microscopes, and so on, shall be eliminated; and this can be secured by reversing the instrument about a stable axis very nearly vertical. If the approximately vertical axis of the theodolite could be trusted to remain fixed during the series of settings and reversals of the instrument which take place in the course of a series of observations on an object, or even to remain fixed for the pair of observations, "face left and face right," which constitute a complete observation, then the reversal would eliminate all these errors of collimation and zero automatically, and nothing more would be required. But in practice the foundation of the instrument is not perfectly stable. Under the influence of the movements of the observer and the weight of the instrument itself, slight settling takes place between one setting and the next; and perhaps also the position of the microscopes on the frame changes a little by reason of change in the temperature. It is the function of the bubble mounted on the microscope arms to eliminate these changes, and the introduction of this device has very much increased the accuracy of the results.

When the errors of the instrument are eliminated there remain the personal errors of the observer; and these also can be eliminated in great part by a proper use of the principle of reversal. An observer will have a tendency, quite unknown to him, and almost ineradicable, to make settings systematically high or low. This is called the personal error of bisection. It may be eliminated by combining observations in which the error comes in with opposite effects upon the quantity which is to be determined. Observations made north and south of the zenith will be affected with the same error in altitude, but this will produce opposite errors in the resulting latitude. Similarly the personal errors in observations made east and west will have opposite effects upon determinations of time. Thus by preserving a balance between north and south or east and west stars the consequences of these errors will be eliminated in the mean.

Formerly the astronomical observations for latitude were made with a special instrument, the zenith telescope (see Plate XXII). Modern geodetic theodolites are now fitted with the necessary micrometer eyepieces, so that observations for latitude by Talcott's method may be made with them, and the zenith telescope is becoming obsolete.

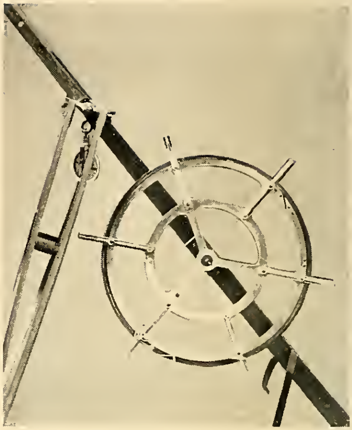
Levels.

Very great improvements have been made in the construction of precise levelling instruments during recent years. In the older instruments it was necessary first to adjust the foot screws so that the bubble was in the centre of its run, and then to walk round to the eyepiece and make the reading on the staff. In the meanwhile the bubble had probably shifted. In the modern level it is possible to see both ends of the bubble by a second telescope fitted alongside the principal, and read with the other eye. The final adjustment of the bubble is thus made immediately before reading the staff, and without changing position. Further, all the essential parts of the instrument are constructed of invar, so that the effects of temperature are almost eliminated.

Three parallel horizontal wires are fitted, and the staff is read against all three. This helps to eliminate accidental errors of reading, and also provides, on the principle of the tacheometer, for the control of the equality of the distances between the forward and the back staves.

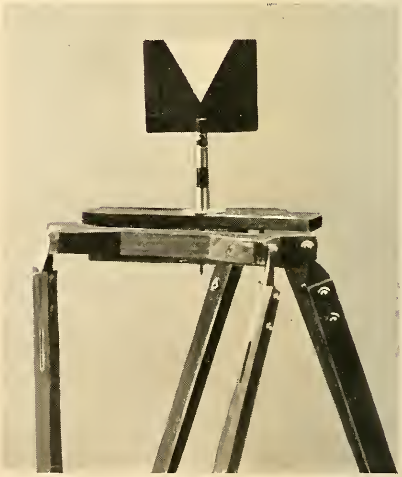
The staves are graduated on both faces, the second graduation being from an arbitrary zero, so that the second set of readings is not a close repetition of the figures of the first. And special

1. Straining trestle.



2. Tape on drum.

3. Mark on tripod.



4. Alignment sight on tripod.

Invar Tape Base Apparatus.

Department of Geography, Cambridge University.

precautions are taken to control at frequent intervals the lengths and the graduation of the staves.

Invar tape or wire base apparatus.

As a result of experience in the field certain modifications have been made in the apparatus as it was designed by M. Guillaume at the International Bureau at Breteuil. We have already mentioned the improvement in the levelling arrangements, which make it possible to measure up slopes as great as one in three. The straining trestles and the mark tripod have also been improved. The apparatus which we illustrate was designed at Cambridge, after learning the experience of measurement on the Lossiemouth and Semliki bases. It was made in the Observatory workshop, largely by the skill of Mr Gordon Dobson, B.A., of Gonville and Caius College. (Plate XXIV.)

The straining trestle has, as is now usual, one leg prolonged to rest on the shoulder of the operator, so that he can take the weight of the wire while he adjusts the other two legs. The novel feature of the design is the swivelling hinge of these legs, so that the tripod is capable of some lateral motion without taking the points of the legs from the ground. This is very convenient in adjusting the wire to the line of the tripod marks.

For convenience and rapidity of work it is essential that the tripod mark should be adjustable over a range of a foot without moving the tripod itself; for on rough ground it is not possible to set the tripod up level at any exact point desired, nor to move it readily by small amounts. The head of the Cambridge form of tripod is a skeleton triangle; and the post for the mark is carried through two battens, one above and the other below the triangle. A wing nut at the base of the post tightens the two battens and holds them, or allows a range of motion and possibility of clamping at any point over a circle of about a foot in diameter.

Longitudes by telegraph.

When two stations are connected by a land line it is easy to arrange for an exchange of time signals, for the determination of the difference of longitude of the stations.

The arrangements usually described for this purpose, with a clock and one or more chronographs in circuit with the signal keys of the observers at the transit instruments, are excellent when the distance is not too great, and the line is in the best condition. When, as often happens in tropical countries, the insulation of the line is poor, and it is not possible to send enough current to operate sounders or chronograph pens, it is possible to get quite good results with the telephone "buzzer." The technical difficulties are naturally much increased when a submarine cable is interposed in the connection between the two stations. It would be out of place here to describe the details of the operations. But whatever the instrumental arrangements, the principle of the method must remain the same. In its simplest form it is as follows.

The observers at each station determine their local time with transit instrument or theodolite; that is to say, they determine the errors of their chronometers on those times. At agreed instants each sends to the other a series of signals in beat with his chronometer. Thus there is a double comparison between the chronometers at the two stations; and the error of each being determined, there is a double determination of the difference of longitude.

The accuracy of the comparison is increased if one of the chronometers keeps sidereal, and one mean solar time. To eliminate the personal equation of the observers it is usual to exchange stations; but this is not always efficacious, and it is better, if possible, to adopt the transit instrument with the moving wire, by which the personality of the observer is very much reduced.

So long as telegraphic longitudes depended upon the maintenance of long land connections, or on the courtesy of the Cable Companies, the opportunities for longitude work were necessarily limited. But the recent rapid development of Wireless has entirely altered the conditions of the problem.

Longitudes by wireless.

In the year 1910 the *Bureau des Longitudes* of Paris organised a service of time signals from the military wireless post of the

Eiffel Tower, in co-operation with the Paris Observatory. Twice in the 24 hours they send out a series of signals which can be received all over the Eastern Atlantic and Mediterranean, and as far south as Dakar and Lake Chad. A well equipped survey party can carry the necessary receiving apparatus without much difficulty, and transmitting apparatus is not needed. It has thus become possible to determine longitudes with facility, which will have a great effect upon the methods of survey in northern Africa. Triangulation in the Sahara is difficult and costly, owing to the great distances over which supplies must be carried. It seems probable that in country such as this triangulation will be superseded by determinations of latitude, and of longitude by wireless. Owing to local deviations of the vertical the results will not be so consistent as those of triangulation, but they will have the great advantage that they can be obtained in country which is almost impracticable for any other method; and especially they will facilitate the rapid mapping of country which is too poor to afford triangulation.

At the time of writing arrangements are in progress for a great improvement in the accuracy of these wireless time signals, and for a world wide extension of their range. At a conference held in Paris in October 1912, at the instigation of the *Bureau des Longitudes*, it was resolved to create an international organisation, which will receive from a great number of Observatories their deduced corrections to the wireless time signals, which will be utilised in correcting the subsequent signals. By this means it will be possible to ensure that, however bad the weather may be in Paris, and however long it may be since the Paris Observatory obtained star observations, the combined resources of European observatories will supply the time correct to within a few hundredths of a second.

The time of transmission of the wireless signal is infinitesimal, so that any observer within range of the Eiffel Tower, whether on land or sea, will be able to determine his longitude with a precision hitherto quite impossible. It will be interesting to see how far it will be practicable to eliminate errors in retransmitting the signals from station to station round the world.

Geodetic pendulums.

The form of apparatus now in general use is due to Major-General von Sterneck. It consists of a set of several small pendulums adjusted to swing in very slightly more than half a second. The pendulums are made of brass, heavily gilded to avoid change by corrosion. They rest by delicate agate knife edges on an agate plane carried by the stand. Each pendulum carries a small vertical mirror on its head, just above the line of the knife edges. There is an arrangement for giving the pendulums a small displacement and then allowing them to swing freely; the arc of vibration is less than half a degree. They are set swinging and gradually come to rest.

A dummy pendulum similar to the others contains a thermometer, to determine the temperature of the pendulums. The stand is massive; but it is not possible to consider it as perfectly free from flexure and vibration. There is therefore a special arrangement attached to the stand to enable the correction for flexure to be determined. The principle of this determination is elegant. If two pendulums hang side by side and one is set swinging, while the other is initially at rest, the latter will gradually take up the oscillations of the former, unless the stand is perfectly rigid. The flexure of the stand is thus determined from the rate at which the first pendulum influences the second.

The periods of vibration of the pendulums are found by comparing them with the beats of a half-seconds clock, which is rated by star transits. Each half-second the clock momentarily opens the shutter before the slit of the "flash-box," and the illuminated slit is reflected in the vertical mirror on the pendulum, and viewed in a small telescope on top of the flash-box. (Plate XXII.)

Thus a line of light is seen in the field of the telescope every half-second; and, as the clock gradually gains on the pendulum, the position of the line moves down in the field, and the time when it coincides with a central horizontal wire can be determined. The interval between one coincidence and the next is the interval in which the pendulum loses one swing on the clock. The observations being continued over a period of several hours, the comparison between the clock and the pendulum becomes of great precision, with a probable error of only three or four parts in ten million.

This apparatus is fairly portable, and the necessary observations for the determination of the value of gravity at a single station may be made in a couple of periods of three or four hours, generally chosen so that one is at night and one by day. But it takes several days to get the clock properly rated by star transits; and thus in the past the greater part of the time at each station has been spent in determining time and rating the clock. It seems likely that in the future much time will be saved by using the wireless time signals to rate the clock.

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