HAND BOOK

OF

PROFESSIONAL INSTRUCTIONS

FOR THE

TOPOGRAPHICAL BRANCH,

SURVEY OF INDIA.

PREPARED BY

COL. J. R. HOBDAY, I.A.,

DEPUTY SURVEYOR GENERAL.

UNDER THE DIRECTION OF

LIEUT. COL. F. B. LONGE, R. E.,

SURVEYOR GENERAL OF INDIA.

Third Edition.

CALCUTTA:

OFFICE OF THE SUPERINTENDENT, GOVERNMENT PRINTING, INDIA.

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CONTENTS.

PREFACE TO THE THIRD EDITION.

In previous editions the chapters were headed "Duties in the field," "Duties in recess," and "Miscellaneous subjects." Since the duties in the field and recess are often interchangeable, and not easy to differentiate, and "Miscellaneous subjects" appears to be rather a vague term, it has been considered expedient to alter these headings, and restrict them to professional subjects. A Chapter on "Traversing" was much needed, and has now been added.

I am much indebted to the following officers for the assistance they have afforded me in bringing out this edition :—

Major H. A. D. Fraser, R.E., for his chapter on "Traversing," and many valuable hints on the chapter on triangulation.

Captain H. H. Turner, R.E., for his memorandum on modern vernier and microscope theodolites.

Captain C. H. D. Ryder, R.E., for many useful additions in the chapter on "Trans-frontier Reconnaissance."

Captains C. L. Robertson, R.E., and F. C. Hirst, I.A., for useful suggestions on the chapters on "Plane-tabling" and "Traversing."

Mr. T. A. Milne for preparing an index, and passing the proofs through the press.

J. R. HOBDAY, Colonel, I.A.,

Deputy Surveyor General.

Calcutta, July 1905.

PREFACE TO THE SECOND EDITION.

The first edition of this Hand-book being out of print and a new edition having become necessary, advantage has been taken of the opportunity to revise the book thoroughly.

The first edition was mainly based on the experience gained in Topographical Surveys conducted on the comparatively small scale of 1 inch to a mile. Now-a-days, however, most Topographical Parties work on the larger scales of 2 or 4 inches to a mile, and various changes in procedure have therefore become necessary. These have as far as possible been incorporated in the new edition. The principal changes are in the matter of the preparation of General Reports of Triangulation and of Atlas Reductions and Records: to these attention is invited.

The book has been interleaved throughout, to enable officers to enter such notes and memoranda as they may wish to record.

A complete index to the book has also been added.

Much assistance in the revision has been derived from notes received from Lieutenant-Colonel R. A. Wahab, R.E., Captain H. M. Jackson, R.E., and Surgeon Captain F. W. Gee of the Indian Medical Service.

I am also greatly indebted to Mr. H. W. Peychers for his care and attention in revising and passing the proofs through the press.

St. G. C. GORE, Lieut.-Colonel, R.E.,

Superintendent, Trigonometrical Surveys.

Dehra Dun, October 1896.

PREFACE TO THE FIRST EDITION.

This Hand-book of the Topographical Branch of the Survey of India is little more than an abstract of the existing orders that have been issued from time to time, for the guidance of officers employed in that Branch, arranged in a convenient form for ready reference. A surveyor's life in India naturally divides itself into two quite distinct periods, *viz.*, The Field Season, and The Recess Season, and it has been considered a convenient arrangement to devote a chapter, sub-divided into sections treating on various details, to each of these periods. Chapter III deals with miscellaneous matters which seem to be more or less dissociated from strictly professional work, and Chapter IV is devoted to geographical reconnaissance. In compiling the first three chapters, I have drawn largely upon the former *Hand-book of the Topographical Survey Department* by Captain R. V. Riddell, R.E., 1878, and the *Manual of Surveying for India*, as well as Colonel Waugh's *Instructions for Topographical Surveying*, Captain Robinson's *Memorandum on the Use of the Plane-table*, and other minor sources. Colonel Wilmer has also afforded me the benefit of his experience. Captain Riddell's Hand-book has been used as an authoritative guide in this Branch for the past twelve years, but in the present day, owing to the accumulation of new orders relating to the subjects contained therein, it has been considered necessary to compile a new Hand-book embodying most of the Circular and Departmental orders up to date.

Chapter IV is due to the pen of Major St. G. C. Gore, R.E., and is principally abstracted from lectures delivered at the Royal Engineer Institute, Chatham, by Major The Hon'ble M. G. Talbot, R.E., late Deputy Superintendent of the Survey of India, and published in the Professional Papers of the Corps of Royal Engineers, in Vol. XIV, 1883.

The lectures were based on the combined experience of Majors Gore and Talbot, during several years' work beyond the North-West Frontier of India, and consequently refer more particularly to a treeless country of alternate mountain and plain, very favourable to the surveyor.

The general principles that underlie reconnaissance work are, however, the same, whatever the nature of the country, and much of Major Talbot's experience is equally applicable to our forest-clad Eastern Frontier. Mr. Ogle who has had great experience in surveying in jungle-clad country, has kindly furnished some notes on the various shifts and expedients to which a surveyor has to resort in work of this class, which are also incorporated in Chapter IV.

G. STRAHAN, Colonel, R.E.,

Deputy Surveyor General,
In charge Trigonometrical Branch,
Survey of India.

Dehra Dun, January 1891.

SURVEY OF INDIA.

HAND-BOOK ON TOPOGRAPHICAL SURVEYING.

Chapter I.

Introductory Remarks.

Preliminary remarks.

1. Topographical surveys have for their object, the accurate delineation of the features of a country, both natural and artificial, with a view to the preparation of maps as complete in all details as the scale of survey will admit.

Class of survey.

2. There are two classes of topographical surveys; one in which the operations are commenced *ab initio*, whilst the other "supplements," or "revises" previous surveys.

The first is necessary in a country where no maps exist on the required scale, or when the existing maps are out of date, and past revision, or of inferior quality.

A "supplementary survey" is resorted to in alluvial cultivated areas, of which modern cadastral surveys by Imperial or local agency, exist, and are of sufficient value to be utilised in the compilation of topographical maps. The details from these surveys are reduced by pantagraph, and transferred to the planetable sections in blue, and checked in the field by the planetablers, and all detail omitted in the cadastral maps, such as hills, ravines, etc., is "supplemented" by actual survey.

It is frequently not an easy matter to decide when a "supplementary survey" will suffice, and when a re-survey is necessary. The process of reducing and transferring the details from a cadastral map to the planetable section is always a laborious undertaking, so that a "supplementary survey" may at times cost more than a re-survey, especially when few topographical items have been shewn on the cadastral maps. Again surveyors, to save themselves trouble, are apt to accept too much of this detail as correct, without examining it thoroughly on the ground, and very close and constant supervision by officers in charge of camps is indispensable.

It may generally be accepted that all cadastral surveys require "supplementary" survey in a greater, or less degree, for the compilation of topographical maps from such material. Items of military importance, and other general utility, are overlooked by the *amins* and *patwaris*, who are not trained to delineate these features, their chief attention being directed to fiscal details, so that a standard map compiled solely from revenue survey material without "supplementary" survey, must always be treated as a "preliminary edition," and published as such.

C. O. No. 105 (Prof.), dated 9th July 1903.

In a "revision survey," copies of the existing maps printed in light blue or grey, or "tracing" prints, are mounted on planetables, and new public works, such as roads, railways, tanks, canals, and changes of river beds, village names, and sites, are inserted, or corrected thereon by surveyors in the field. This information is in the first instance obtained, as far as possible, from Collectors, Executive Engineers of Districts, and Political Agents of Native States, etc., who are supplied with printed copies of such maps, and asked to indicate roughly thereon all changes, errors, and omissions they may be aware of.

Scale of survey.

3. Various considerations influence the choice of the scale most suitable for the survey of any particular district or area, such as the nature of the country itself, military and other requirements, and the time available for its completion. No survey should be undertaken until these points have been thoroughly considered in consultation with the military and local authorities. The scale of the standard topographical maps of India is 1 inch = 1 mile, but the scale of survey is frequently larger. In hilly or jungly country where the land has little value, the population sparse, and roads and artificial features few and far between, the 1-inch scale is generally quite large enough, and the expense entailed by working on a larger scale would rarely be justified, but in well cultivated and open ground, especially where revenue or cadastral surveys have been carried out, the scale of 2 inches = 1 mile is generally preferable as it gives greater detail and enables all village boundaries to be shown, which, in consequence of the small area of the villages in some densely populated parts of India, cannot be done on the 1-inch scale. The resultant standard map on the 1-inch scale is always more artistic and accurate, as it is prepared by photographic reduction of the 2-inch survey specially drawn for the purpose. A 2-inch survey is much easier to examine and check in the field than a survey on the 1-inch scale, especially in intricate country where there is much detail; and it will generally be found in practice, that one can survey almost as fast on the former as on the latter scale.

Special military surveys are sometimes required of limited areas for tactical purposes, and the manœuvring of troops, generally on the scale of 2 inches = 1 mile, whilst surveys on the 4-inch or 6-inch scales are occasionally needed for defensive and other positions. Large areas reserved by the Forest Department are surveyed and published on the scale of 4 inches = 1 mile, and subsequently utilised by reduction in the compilation of the standard 1-inch sheets.

The smaller scales of 1 inch = 2 miles and 1 inch = 4 miles are only used for reconnaissances of hitherto unknown countries, where rapidity of survey is essential, and these should always be replaced, as opportunity occurs, by more accurate detailed surveys on larger scales.

Necessity of collecting information.

4. The survey of any particular tract of country having been decided on, and the scale of survey settled, a party of suitable size is told off to the work under an officer, whose first duty is to obtain from the offices in Calcutta and Dehra Dun, all available data on which to base his work. He should ascertain whether any portions of it have been previously surveyed, triangulated, or traversed, and supply himself with all information in the matter of computations, charts, maps, books and gazetteers relating to the district, to which he can gain access. He should place himself in correspondence with the local officials, and ascertain the nature of the communications, and the best form of transport to be employed, the means of getting supplies, the resources of the country, the possibilities of obtaining local labour and carriage, the general features of the country, and the season during which field work can best be carried out, with regard to climate and general healthiness, etc.

The subsequent success of the work will depend greatly on the care with which these preliminary enquiries have been carried out.

Constitution of a topographical party.

5. The constitution of a topographical survey party depends on the nature of the country, the area to be surveyed, and the scale of survey; but for economical working it may generally be taken to consist of 2 Imperial Officers, 7 Provincial Officers as assistants, and 30 or 40 surveyors, sub-surveyors, etc., 2 writers, and about 400 *khalásis* and menials, including a *daftri*, also a carpenter and blacksmith if procurable. A small police or *burkandaz* guard is generally provided, chiefly for obtaining the pay of the party from the nearest treasury, and distributing it to the various detached parties during the field season.

The administrative officer nominates the *personnel* of the party from officers already under his orders, but it seldom happens that there are a sufficient number of surveyors, *khalásis*, and menials available to form a new party, and the officer in charge must therefore enlist and train additional men (under the orders of his administrative officer) to bring his party up to suitable strength. This can only be done gradually, with a small nucleus of old hands.

Preliminary duties of officer in charge.

6. As soon as the strength of his party has been communicated to him, the officer in charge should submit to his administrative officer, the following indents, notifying the date on which, and place at which, they should be available for distribution :—

(1) Indent for mathematical instruments.
(2) Indent for office forms.
(3) Indent for professional forms.
(4) Indent for stationery.
(5) Indent for medicines.
(6) Indent for drawing paper and type.

He should, in consultation with his administrative officer, decide on the general plan of operations. and on the *locale* of his recess quarters. He should apply for sanction to purchase such tents as will be necessary for office use and for the *khalásis*, menials and guards, and enter into communication with the local authorities with a view to securing, when required, the requisite amount of carriage, which may take the form of carts, elephants camels, mules, bullocks, or coolies; the particular class generally used in the country is almost invariably the most suitable. He should also apply for the services of a Hospital assistant, if considered necessary.

Equipment of a topographical survey party.

7. The equipment of a topographical survey party should be somewhat as follows, modified of course when necessary, to suit special conditions :—

Head Quarter Camp.

1 Large office tent.
1 Small ditto.
1 Large shuldari for police, or *barkandaz* guard.
1 Large shuldari for Hospital assistant.
Large shuldari for Hospital.
Shuldari for every 8 menials.
1 Necessary tent.
Portable wooden trestles for storing tents, etc.
Tarpaulins.
Folding office tables, chairs, etc.
1 Treasure chest.
1 Gong.
1 Box of tools.
Phowrahs, axes, chisels, hammers, etc.
Light deal boxes with hasps, and padlocks, or camel trunks for storing maps, records, instruments, stationery, medicines, etc.
Tin tubes, portfolios, or portable tin-lined cases for maps, etc.
Badges and uniforms for chuprasis.
Haversacks for *khalásis*.
1 Hand-book of General Instructions.
1 of each of the Hand-books on Trigonometrical, Topographical and Revenue surveys.
3 Shortrede's log sines and tangents.
3 Chambers' logs.

2 Auxiliary tables.
Traverse tables (Boileau's, Shortrede's, or Gurden's), if traversing required.
1 Nautical almanac.
Star charts.
1 Hints to travellers in 2 Volumes.
Synoptical Volumes of Great Trigonometrical surveys.
Pamphlets of Great Trigonometrical spirit level heights.
1 Civil Service Regulations.
1 Civil Account Code.
1 Quarterly Civil List of Province.
1 Gazetteer of Province.
Postal, Telegraph, and Railway Guides.
1 Catalogue of Maps.
1 Rules and Regulations of Mathematical Instrument Department, and Catalogue of instruments.
1 Moore's Family Medicines.
1 6-inch transit theodolite, and stand.
Spare 5-inch theodolites, if traversing needed.
3 Planetables with waterproof covers, and stands.
3 Sight rules in deal boxes.
3 Survey umbrellas.
3 Rectangular magnetic compasses.
3 Pairs of binoculars.
3 Clinometers.
3 Chains 100 feet, with sets of arrows.
(A much larger number of spare chains 100 feet, and 63 feet if much traversing is needed).
2 Tapes, metallic or steel.
1 Box of Mathematical instruments, 1st sort.
2 Boxes of Mathematical instruments, 2nd sort.
2 Gunter's scales.
2 Beam compasses.
3 6-inch heliotropes in boxes with or without stands.
2 Graticule plates.
3 Straight edges, 33 inches.
1 Circular brass protractor.
1 Box French curves.
2 Planimeters.
1 Pantagraph.
1 Aneroid Barometer.
1 Chronometer.
1 Pair of magnetising bars.
2 Reading glasses, 3½ inches diameter.
1 Maximum thermometer.
1 Minimum thermometer.
2 Sets of Marquois scales.
2 Sets of plotting scales.
2 Parallel rulers on rollers.
3 Sets of set squares.
1 Bull's eye lamp.
1 Referring lamp.
12 Height indicators on cardboard.
12 Engine divided scales of feet, on cardboard.
2 Tracing glasses in frame, and covering lid.
Type, type-holders, drawing pins, etc., etc.

For each Camp Officer.

1 6-inch vernier theodolite, with complete vertical circle, and stand.
1 Planetable with waterproof cover and stand.
1 Survey umbrella.
1 Sight rule in deal box.
3 Chains 100 feet, with sets of arrows.
1 Tape, metallic or steel.
1 Clinometer.
1 Pair of binoculars.
2 Rectangular magnetic compasses.
1 Box of Mathematical instruments.
1 Gunter's scale.
1 Beam compass.
3 6-inch heliotropes.
1 Reading glass, 3½ inches diameter.
1 Set Marquois scales.
1 Set Plotting scales.
1 Parallel ruler on rollers.
1 Set of set squares.
3 Height indicators on cardboard.
3 Engine divided scales of feet on cardboard.
1 Shortrede's logs.
1 Chambers' logs.
1 Auxiliary table.
Traverse tables if needed.
1 Box of colours, and brushes.
1 Small treasure chest.
Light deal boxes, or camel trunks.

Tin tubes, tin lined cases, or portfolios.
1 District Officer's chest of medicines.
Stationery, Professional and Office Forms, etc.

For each Planetabler.

1 Planetable with waterproof cover and stand.
1 Survey umbrella.
1 Chain 100 feet with sets of arrows, if necessary.
1 Pair of Binoculars.
1 Sight rule in deal box.
1 Rectangular magnetic compass.
1 Clinometer.
1 Height indicator, or engine divided scale of feet on cardboard.
Village book.
Card of symbols and boundaries.
Forms for computing clinometer heights.
Rough note book.
Hold-all.
1 Box of colours, and brushes.
Stationery, Office forms, etc.
Bamboos, and flags.
Tin box of medicines.

For each Triangulator.

1 6-inch vernier theodolite, with complete vertical circle, and stand, or 8-inch micrometer, when 1st class secondary work is needed.
1 Planetable with waterproof cover and stand.
1 Survey umbrella.
1 Sight rule in deal box.
1 Rectangular magnetic compass.
1 Pair of binoculars.
1 Tape, metallic, or steel.
1 Box of Mathematical instruments.
8 to 12·6-inch heliotropes with or without stands.
1 Shortrede's logs.
1 Chambers' logs.
1 Auxiliary tables.
Light deal boxes with padlocks, or mule trunks.
Tin tubes.
1 District Officer's medicine chest, Angle books, tracing cloth, stationery professional and office forms, drawing pins, etc.
1 Box of colours, and brushes.
1 Observatory tent when necessary.

For each Traverser.

1 5-inch theodolite with stand.
2 66-feet chains and sets of arrows.
2 100-feet do. do.
1 Tape, metallic or steel.
1 Subtense bar, and stand, when necessary.
1 Planetable complete, sight rule and compass, when necessary.
1 Survey umbrella.
1 Pair of binoculars.
1 Heliotrope, if necessary.
2 Chisels.
1 Hammer.
1 Hold-all.
Bamboos, and flags.
Field books, stationery, office forms, etc.
Tin box of medicines.

This does not pretend to be a complete list of all that can be wanted by a topographical party, but is merely to serve as a guide to an executive officer to assist him in drawing up his indents.

Division of field work.

8. The work of a topographical party in the field may conveniently be divided into two classes, *viz.*, (i) triangulation (including previous reconnaissance) or traversing, or both, and (ii) plane-tabling. The general control of the operations is vested in the officer in charge of the party. It is his duty to so apportion the work among his subordinates as to secure the maximum outturn of thoroughly reliable work at a minimum cost. This is usually best attained by dividing up the party into camps, each under a senior assistant.

Junior Provincial Officers should not be placed in charge of camps, or on supervising work of any kind till they have done at least two field seasons plane-tabling, and one triangulating. C. O. No. 84 (Prof.), dated 8th July 1897.

An assistant in charge of a camp can supervise about 6 planetablers working on the 1-inch scale, 8 on the 2-inch scale, and from 10 to 12 on the 4-inch scale.

A tindal and 4 *khalásis* are sufficient for a planetabler's squad when work can be carried on by interpolation, and 3 additional men when chaining is necessary.

A traverser requires about 8 to 10 men, whilst a triangulation squad should consist of from 20 to 25 *khalásis*.

Miscellaneous duties of officer in charge.

9. The officer in charge should take a leading share in every part of the duties in the field and recess. He should be constantly inspecting the work of each camp, and instructing his subordinates in the use of instruments, in drawing and in mapping. No pains should be spared in training newly-joined assistants in the theory, as well as in the practical use of the theodolite and the planetable.

He should see that his subordinates are properly provided with instruments, stationery, medicines, and camp equipment, and furnished with ample data on which to base their work, together with full instructions (written, if necessary) as to the locality, method of procedure, and quantity of work expected of them; also that they keep up a sufficient amount of carriage to move daily, or march at a moment's notice, on which condition only the daily travelling allowance can be claimed; and that they are fully capable of performing their work in the field. He should keep his assistants duly informed of the various circular orders as they are issued. He should satisfy himself that they study their hand-books, and keep them up to date, and he should examine them every month during the recess, to ensure their keeping up a sound knowledge of their profession.

Health of establishment.

10. The officer in charge of a party should be most careful of the preservation of the health of his establishment. He must see that each detached party is supplied with medicines which are suitable and sufficient for its wants, and also that written directions as to their use, in English or the vernacular, as may be necessary, accompany the medicines. He should, therefore, before taking the field, obtain from the Medical Store Department, a sufficient supply of medicines on an indent, prepared by the Hospital Assistant, and countersigned by the Civil Surgeon. When no Hospital Assistant is attached to a party, it is well to indent for boxes of prepared medicines, the larger boxes known as "District Officers' chests" being served out to the Provincial Officers, and the smaller "tin medicine boxes" to the subordinates. All serious cases of illness should

be at once reported to the Head-Quarter camp, and when there is no Hospital Assistant, the patient should be sent for treatment to the nearest Civil Hospital or Dispensary. These medicine chests should be returned to store every year to be refilled, in time for the next field season. Useful medical hints will be found in Moore's Family Medicines, Hints to Travellers, and in the Hand-book of General Instructions.

Duties of officers in charge of camps.

11. A camp officer is entirely responsible for the work entrusted to him. Except for the few hours he has to attend to the examination of bills and returns from his subordinates, prior to their despatch to the officer in charge of the party, and the distribution of their pay, he should be constantly marching about, and visiting the planetablers, checking their work, helping them out of difficulties, and training the junior members of the party. He should be a man of tact and resource, and of active habits, punctual in the submission of accounts and returns, and methodical in all matters connected with the management of his camp.

Accuracy and fidelity of field work.

12. It cannot be too strongly impressed on all members of the Department, that every consideration should give way to the one great and paramount object of turning out good work, which may be thoroughly relied on by the public, and which will be found on examination in the field to be as accurate as it appears to be on paper. The public service requires the maximum amount of work of the best description; it expects quantity as well as quality; but quantity without quality is of very questionable value; the outturn should, therefore, on no account be permitted to exceed what can be accomplished with an appropriate degree of fidelity. The surveyor should resist all temptation to gain fictitious credit by departing from the strict line of duty. It may be difficult for him to refrain from injudicious haste when he knows that some of his brother surveyors are working with greater rapidity than himself, and are likely to gain more credit than himself, because they happen to have a greater show of work, but his duties appertain to his own work only, and if he is careful to make it as good as possible, it will always be a credit to him, and to the Department.

Officers to forfeit pay if their work has to be revised.

13. Officers who, after having been sufficiently trained, submit field work that requires to be revised, render themselves liable to forfeiture of pay during the time occupied in revision.

Penalty for falsification of records.

14. Any person who may submit documents, maps, or plans for record containing intentional errors, should be prosecuted by the officer in charge of the party to which the individual belongs, under sections 167 and 218 of the Penal Code.

Prevention of oppression of villagers.

15. Officers in the field must do all in their power to prevent any oppression of the villagers by their native establishment or their servants; they will report at once to the officer in charge of the party any circumstance of this nature coming under their notice.

Gratuitous labour, except when the civil officer states that it can be legally enforced for line clearing on their own village boundaries, is in no case to be demanded from *zamindars*, or landholders. If they are kindly and considerately dealt with, they will be found, as they generally have been, willing and ready to lend assistance whenever necessary.

Subordinates are granted certain concessions in the way of travelling allowance, in order that they may be in a position to provide themselves with tents and camp equipment and maintain them, they are therefore prohibited from demanding accommodation in houses in the area under survey. It is the duty of every officer to pay for all supplies received by himself and to see that his subordinates also pay for any they receive.

In certain districts water, grass, and firewood are supplied gratis, but this cannot be enforced, and must be looked upon as an act of courtesy and hospitality.

Presents or gratuities prohibited.

16. Surveyors, sub-surveyors, or others who can be proved to have received on any pretence whatsoever, any present or gratuity from the inhabitants or authorities of villages in which they may have been, or are employed, or from their subordinates, will be summarily dismissed and proscribed. They are also liable to be sent for trial by the civil powers.

Native States.

17. Executive officers working in Native States should insist on their own subordinates and followers paying for every article supplied to them, at the rates furnished by the *vakils*. Should it be found that the surveyors and assistants have cause for complaint, a representation will be made by the officer in charge to the Political Officer of the State. It is a good plan to make each *vakil* with a detached subordinate, send in a report to the officer in charge every fortnight, stating whether the assistant with whom he is detached has, or has not, paid for all supplies procured for his camp. Any omissions can then be speedily attended to, and the reports act as valuable refutations against any subsequent statements of the *vakils*, sometimes made to screen themselves.

Trespassing, and sporting prohibitions.

18. Officers and subordinates of the Department indulging in sport are warned— G. I. O. No. 238, dated 15th October 1895.

(1) Against trespassing on standing crops without the consent of the owners.

(2) Against shooting pea-fowl, or other birds or animals, which are looked upon as sacred in the vicinity of villages, or habitations.

(3) Against shooting domestic animals, such as dogs or pigs.

(4) Generally against shooting or fishing in the immediate neighbourhood of villages, temples, or mosques.

Guarding stores.

19. Stores and public property should not be kept in a closed tent, with a single sentry outside; for such an arrangement is unsafe, and unfair to the man on guard. The most secure method of guarding property is to collect it in an open spot, from which the sentry can have a clear view on all sides; the articles should be raised above the influence of damp ground, and of white ants, by means of wooden trestles, stones, or bricks. Delicate instruments liable to injury from exposure can be guarded securely, if placed in a *shuldári*, or open *pál*. When the strength of the guard is insufficient for furnishing a double night sentry, the *khalásis* of the establishment must take their turn on such duty.

The care of Government property.

20. All Government property should be stored in a masonry building, whenever practicable. When left at "*khamáls*" or "godowns," proper arrangements should be made for its safe custody. Every precaution should be taken against damage to, or loss of, Government property by theft, fire in tents or godowns, and in transit by post, boat, or rail.

C. O. No. 164 (Adm.), dated 4th November 1898.

Warning to sub-surveyors on promotion to permanent service.

21. Sub-surveyors are warned that should they, on promotion to the permanent establishment, slacken their energies and diminish their outturn, their pay will be promptly and substantially reduced.

Ditto.

Duties of surveyors, etc., in the field.

22. The duties of a surveyor or sub-surveyor in the field are to triangulate, traverse, or plane-table, and they are on no account to be employed by executive officers on office duties, as assistant writers, etc., except on very exceptional occasions, and then merely as a temporary measure.

Cartiage of survey instruments in the field.

23. It should be specially noted and impressed on all assistants and subordinates, that survey instruments, such as theodolites, levels, plane-tables, etc., should, except in very exceptional circumstances, always be carried by the *khalásis* and not on carts, mules or other animals. Should it be unavoidable to carry theodolites or other delicate instruments in carts, a layer of branches placed under the boxes, will be found to be an excellent substitute for springs, and prevent injury from jolting.

Duration of field season.

24. The field season should last about 6 months, but the date of commencing survey operations varies in different parts of India. In malarious tracts, little benefit is gained by commencing field work before the middle of December, and in Rajputana, Sind, parts of the Punjab, and the United Provinces, out-of-door work becomes almost impossible for Europeans after April. In Burma little in the way of triangulation or reconnaissance can be done during March and April, owing to the dense smoke haze due to jungle fires which obscure all distant points. The period of a field season varies with local climatic conditions, and has nothing to do with the survey programme which is merely an approximate estimate of a season's outturn; if a party completes its programme before the estimated time, it should take up additional work.

Executive officers must apply to their administrative officer for orders as to the dates of commencing field work at least a month before the proposed date for taking the field. Similarly executive officers must apply for permission to retire from the field, and withdraw their establishments at least one month before the proposed date of return to recess quarters. With the application full particulars of the area completed and remaining to complete the season's programme should be sent. At the same time a statement on form O·65 should be submitted showing the proposed *recess* strength of the native establishment of the party. An executive officer should on no account, unless by special sanction, return to recess-quarters until all the field work has been tested, the instruments cleaned and properly stowed away in the field depôt, and the accounts of the field establishment adjusted.

Disposal of field establishment not required during the recess.

25. At the close of a field season, the sub-surveyors whose services are not required for recess duties, should be granted departmental, or recess leave by the officer in charge of the party on pay not exceeding half their salaries. All inefficient *khalásis* should be discharged, and departmental leave certificates on form O·65, with, or without pay, should only be granted to those whose services are again required next field season. Tindals, heliotropers, and others who have done conspicuously well for at least 5 years' service, may be granted such leave pay during recess, not exceeding half their salaries, as the officer in charge may deem expedient. Re. 1 for every 5 years' service is a fair rate of leave pay to grant them.

Maintenance of maps and charts in the offices of topographical parties and drawing offices.

Circular Order No. 216 (Adm.), dated 27th April 1904.

26. Officers in charge of topographical parties, and drawing offices, are required to keep one copy of the latest edition of every published topographical and district map, triangulation and traverse chart extant, of the Province in which they are working, (whether such

maps are in standard sheet form or not), carefully stored in an almirah, and arranged in drawers holding 50 maps each, with the sheet numbers 1 to 50, 51 to 100, etc., etc., painted outside. The standard sheet number should be stamped on the right hand lower margin of each map, where it can be readily seen on pulling out the drawer, and the maps returned daily to their proper places in the almirah after use. They should be correctly coloured and kept for reference and not for ordinary office use.

Officers in charge should consider it a duty to make themselves thoroughly conversant with the history, and quality of each one of these maps, noting all information on these points in ink on the backs of the maps. They will thus be enabled to report at any moment to their administrative officers, as to the needs of the Province in which they are serving, in the matter of topographical maps, and to point out where new surveys are required, and over what areas a revision or supplementary survey will suffice, also what maps are in a fragmentary state, and require joining together to form complete standard sheets, and the amount and nature of the work necessary to effect this.

To aid them in attaining this knowledge and for ready reference, they should prepare index maps, and also keep up a register giving, as far as possible, all the requisite information. It is also desirable that they should acquire a general knowledge of the history and quality of all revenue surveys that have been conducted in the Province, whether by Imperial or Local Agency, so as to be able to judge whether the material thus available, can be made use of in the compilation of the standard topographical maps.

They should take every opportunity, when in, or going to or from, the field, of roughly examining the work in any of the sheets previously surveyed through which they pass, so as to get as correct an idea as possible of future requirements, and whenever possible, should survey and record on the maps any new roads or railroads, etc., that may have been made since publication, so that should a new edition or stock of any sheet be required, the new work may be shown on it without delay.

Officers in charge of Forest parties should in like manner keep up a complete set of Forest maps of the Province in which they are working.

These orders are also applicable to Burma parties, but in a modified form. Burma is for survey purposes divided into certain areas bounded by the limits of certain standard sheets, and officers in charge of parties should confine themselves with regard to these orders to the portion of the country falling within their particular zone and in their case where 1-inch work has not been carried out, they should treat in a similar way the ¼-inch reconnaissance maps.

Chapter II.

Triangulation, and its Computation.

Triangulation, the basis of topographical surveying.

27. The only safe basis for topographical operations is beyond all question a system of accurate triangulation, whereby undue accumulation of error is precluded in the extension of the work and at the same time limits are set to the intrusion of error in the internal details. For topographical purposes, all "Principal" and "Secondary" data of the Great Trigonometrical Survey, must be considered errorless, but "intersected points" fixed by long rays for temporary topographical purposes should be rejected as soon as the same points have been well fixed by triangulation from near stations by topographical parties. In the case, however, where a heliotrope has been put over a mark on the intersected point, and observations have been taken from two or more principal stations, those intersected points should also be considered errorless. There are few parts of India in which its work has not penetrated, and wherever its stations are found, the initial elements required for commencing a survey are available, *viz.*, the latitude, longitude, and height above sea level of a fixed point, a base of ascertained length, and an initial azimuth or true direction of the meridian. As plane-tabling and traversing both depend on the triangulation which has to be previously computed, it will generally happen that the whole strength of a party will, for the first year, be employed on reconnaissance and triangulation only; in this case careful arrangements must be made that the work of each observer joins properly on to that of his neighbour, and that the same stations on the common flank are used by both.

Triangulation, to whom entrusted.

28. Triangulation is generally entrusted to Imperial and Provincial officers after their first or second field season, but it is always advisable to train a certain number of the senior sub-surveyors in a party to triangulate, especially in difficult and forest-clad countries where it is easier for a native to get about than a European, as he has less baggage to take with him. Moreover, triangulation is essentially a process which proves itself in the subsequent computations, and requires but little supervision in the field. It is essential that the person who undertakes triangulation for topographical purposes should have had a good previous training in plane-tabling, for it must be borne in mind that the object of the triangulation is to provide points such as will enable the plane-tabler who follows, to sketch the country accurately and well.

29. The G. T. triangles, when they exist, should be first broken down into triangles of about 8 to 20 miles to the side, according to the nature of the country, and subsequently into still smaller ones, if a sufficient number of "intersected points" cannot be otherwise obtained. The triangles should be as "well conditioned" as possible; that is to say, their angles should neither be too obtuse, nor too acute. The names by which the various classes of triangles are distinguished are as follows: (i) Principal, (ii) G. T. secondary, (iii) First class secondary, (iv) Minor, (v) Tertiary. Of these the first two are dealt with in the Trigonometrical Handbook. The third, *viz.*, "First class secondary" work is very similar to "G. T. secondary," but is distinguished by the fact that it is done by a topographical party, generally with a high class vernier, or small microscope theodolite. Both of these classes of secondary triangulation are moreover usually laid out in the form of a series, as distinct from a net work of triangles. "First class secondary" series are generally run as connecting links between G. T. series which are widely separated, or in extensions over areas where no G. T. work exists. In either case a superior instrument and observer are necessary for this class of work which must be executed with particular care.

Classes of triangles.

All ground not included in the G. T. or "First class secondary" triangulation must be covered with a net work of "Minor" triangles having long sides, which are in turn broken up when necessary into "Tertiary" short-sided triangles, the latter being laid out solely for the purpose of fixing intersected points. By far the greater portion of the triangulation done in a topographical party, consists of "Minor" and "Tertiary" triangles only, but it must be borne in mind that such work is suitable only in moderate sized areas, which are bounded by work falling under the first three classes, and wherever the areas are very large, or extension work forms part of the programme of a topographical party, it is advisable to lay out a "First class secondary" series of triangles before the net work is commenced.

30. Trigonometrical points are either "stations of observation" where a theodolite is set up, or "intersected points" which are unvisited and fixed by two or more rays from stations of observation. The size of the triangles and the number of fixed points per square mile must depend on the scale of survey, the nature of the country, and state of the atmosphere at different times of the year. The larger the triangles, the greater the rapidity of covering the ground, and the simpler the computations. All consideration of scale may, however, be got over by regulating the number of points to be given on *a certain area of the paper* on which the final survey is made

Number of fixed points required.

instead of on a certain area of ground. A good estimate is one fixed point on the average to each six square inches of paper.

Construction of stations.

31. It is indispensable, in order to get the best results from a theodolite, that it should be placed on a perfectly stable foundation; and a certain amount of building is frequently necessary to ensure this. The ordinary procedure is to build with bricks (or stone) set in mortar, a central pillar two or three feet in height according to requirements, and just large enough to accommodate the theodolite stand, say two feet in diameter. In the centre of this, on its upper surface, a heavy stone is let in, on which is engraved a circle about three inches in diameter, with a central dot to mark the exact site of the station. Around this pillar, but not touching it, is built a rough masonry platform of stones and mud, on which the observer stands when at work: the space between the pillar and platform, which may be about two inches wide, is filled in with loose grass or sand. The stations are generally built by a *tindal* during the time that the reconnaissance is in progress, so as to be ready for use when the angular measurements begin, and at the same time *khalásis* are sent out with instructions to fix up signals on various conspicuous points previously selected by the triangulator. This is the usual method where building is necessary, but in "Minor" triangulation this is very rarely the case, and stations are placed on solid rock, the roofs of buildings, or merely on the ground surface. In the first two cases, it will suffice to engrave the circle and dot *in situ*, but otherwise it should be done on a large stone subsequently embedded in the ground. On black cotton soil, or in other circumstances where the ground is very unsteady, an excellent temporary support for the theodolite may be made by driving deep into the soil three large tent pegs or stakes, on which the legs of the stand will rest.

In flat country where there is much low jungle, it is often convenient to carry a tall braced tripod on which the usual stand of the theodolite is placed. This tripod is surrounded by a detached outer tripod which carries a platform for the observer. If these tripods are well designed and well constructed, there is no difficulty in raising the telescope of the theodolite to a height of 15 feet above the ground.

Preservation of stations.

32. The elaborate precautions taken for the preservation of the principal stations of the Great Trigonometrical Survey are superfluous in the case of topographical work, and it will suffice if a pile of stones or earth is heaped over the site of the station. The topographical surveyor must, however, when making use of the principal G. T. stations, be careful to leave them properly protected according to the rules given below:—

(a) *Hollow towers of paka masonry*:—Stop all cracks; close the trap-door; block up the windows, and the doors in the basement; and should the roof have fallen in, shape the *débris* in the form of a cone on the basement floor.

(*b*) *Solid towers of kacha masonry with central paka solid pillar* :—Cover over summit of structure with a large pile of mud sloped away to carry off the rainfall.

(*c*) *Solid towers of kacha masonry with central paka perforated pillar* :—Protect summit of structure as in (*b*); and close the passages to the basement floor with earth and stones.

(*d*) *Low platforms of kacha materials with central paka solid pillar* :—Repair platform if necessary; and pile up a pyramid of earth and stones over pillar and platform.

(*e*) *Paka perforated pillars without platforms* :—Close the passages to the basement floor; and prevent water lodging round about the pillar.

(*f*) *Paka pyramidal pillars* :—Cover over with earth and stones as in (*d*).

Remove all vegetation from the pillars and platforms, and clear the space round them.

C. O. No. 97 (Prof.), dated 4th February 1902.
C. O. No. 115 (Prof.), dated 23rd June 1904.

All G. T. stations are under the custody of local officials, who are responsible for their upkeep, but to further ensure their preservation, executive officers are directed to repair all such as fall within the area under survey during a field season, action to be taken at once without further reference. The cost of such repairs will be defrayed from the contingent grant of the party, under the budget head "Building survey stations," and if the expenditure thus incurred exceeds the budget allotment, a further grant will be made to meet it. If the repairs are of such a nature that they cannot be carried out by local labour, an executive officer should at once call the attention of the local authorities to the condition of the station, and request that the repairs may be executed, and reported to the Superintendent, Trigonometrical Surveys. At the close of the field season, executive officers will submit to the Superintendent, Trigonometrical Surveys, through their administrative officers, a return on form P. 80 reporting the condition of all G. T. stations falling in the area surveyed, and the action taken, and cost of all repairs. They should at the same time report, whenever possible, whether the necessary repairs of stations which were brought to the notice of the local authorities in previous years, have been carried out, or not.

Reconnaissance Chart, and its use.

33. Before commencing the actual observation of the angles of the triangles, a previous reconnaissance with the plane-table is necessary, by which the most advantageous positions for the stations are chosen, and points selected for the erection of temporary signals, such as poles, flags, etc., where natural objects are wanting. In skilled hands this rough

reconnaissance may become a very fair approximate map of the country, and will well repay a large amount of care and thought bestowed upon it. The identification of the so-called "intersected points," when observed from two or more stations, depends largely on the clearness and accuracy of this preliminary work: moreover, the selection of "well-conditioned" triangles is much facilitated by it, and it is of use in many less obvious ways which a surveyor soon learns to appreciate.

A field chart of triangulation should be projected so as to include the area allotted to the triangulator, and all previously ascertained trigonometrical points therein that may be available, plotted thereon, the Great Trigonometrical points and rays being inked up in red and the topographical points in black. A scale ¼ of that of the detail survey will generally be found suitable.

In selecting points to be fixed, the triangulator must imagine himself in the position of the detail surveyor about to survey the ground in question, and such points must be chosen as will facilitate the plane-tabling. A triangulator is too apt to fix points on the hills to the exclusion of those in the valleys, whereas if the valleys are narrow and confined, points with heights, low down in the valleys, are of the utmost importance to a plane-tabler. In the Himalayas, points can sometimes be fixed down slopes and in positions where intersection is impossible, by means of the bar-subtense method described in paragraph 68 *et seq.* This will give points with quite sufficient accuracy for plane-tabling purposes up to distances of 1½ to 2 miles.

In commencing his reconnaissance, the triangulator, accompanied by several of his *khalásis* who will subsequently have to pole the points, should first visit a fixed trigonometrical station forming one end of his initial base, examining the ground as he goes, for suitable points to be used as intersected points. He should interpolate his position on the plane-table as opportunity offers, by means of such points as he has plotted, so as to take rays to, and fix the position of, intersected points which, if necessary, should be there and then poled by sending men off to put them up on hills or trees. On reaching the station, he should search carefully for such points on high ground as appear suitable for stations of observation, getting cross rays to them and so approximately fixing their position as soon as he can. He should then make his way to the other end of the base, cutting in, poling where necessary, and naming or numbering intersected points as he advances. From the second station he will be able to fix approximately the positions of his forward stations of observation. He should then march towards one or other of these, fixing and poling suitable intersected points *en route* as before. The new station should be visited, its position carefully fixed, and the site prepared when necessary, the mark-stone being cut and imbedded, and orders issued for the felling of trees, etc., in the direction of the rays required. After a little practice good *khalásis* can be entrusted with the preparation of the sites, after they have been visited by the triangulator, and the necessary work determined on. When no forest exists, this work is of the simplest; a little levelling of the ground and the placing of a mark-stone with pole and brush supported by a cairn of stones is all that is required. It cannot, however, be too much insisted on, that the pole must be most carefully placed vertical and central over the mark-stone. If *khalásis* see that their officer is always very careful about this point, they soon get into the habit of very careful centering; this is most essential as the accuracy of one's work is entirely dependent on the faithfulness with which they centre the poles or heliotropes, and there is no check on it.

When a wooded hill is cleared, in order to make a site for a station, a conspicuous tree should be left standing somewhere near the station. In selecting such a tree take care that it is not so placed that its shadow will fall on the station and so interfere with the heliotroper there. Such a tree will be of far more use to the plane-tabler than the pole and brush on the station itself.

The whole ground is thus gone over, the officer marching from place to place as best suits the lie of the country, always keeping a careful plane-table reconnaissance of the work, choosing suitable points for intersection, and marking them by poling where necessary. The chart should be kept up to date, stations of observation and intersected points being inked in with large and small circles, and their names or numbers entered in ink. The lines connecting stations which are intervisible should, however, be left in pencil till the observations have been taken. It is generally necessary to keep a descriptive list of all intersected points fixed on the chart, as this much facilitates their subsequent identification. This may be done on the margin of the chart or in a note book.

Care should be taken to avoid covering the board with a mass of pencil rays to doubtful intersected points, which will only confuse the triangulator when he commences to observe. The intersected points selected should be definitely fixed, and named or numbered, and tentative pencil work cleared off the chart. In this way when the officer has reached the further limit of the area allotted to him, he should have been all over the ground, and selected all his stations of observation and intersected points, all marked in their proper positions and named on the chart; he will then be ready to go back over the work taking the observations. The observer will however generally find it advisable to devote a little labour to the chart before beginning to observe, with the object of avoiding unnecessary work afterwards. It will usually contain many redundant rays, and possibly some superfluous stations, but by distinguishing the different classes of triangles by different grades of pencil lines, such rays as are unnecessary can be detected and cut out. This preliminary scrutiny will largely reduce the work particularly at many of the "Tertiary" stations which (as will be seen in paragraph 42) are places selected solely with the object of giving extra rays to intersected points, when the view obtainable from the "Minor" stations does not suffice for this purpose.

Without a preliminary reconnaissance, such as has been described above, it is impossible to carry out a successful triangulation.

On commencing to observe at any station, a triangulator has only to fix his plane-table truly in position, and write down in his angle book the list of stations and intersected points to be observed. By laying his plane-table rule on the line to any point, a careful search with a telescope or pair of binoculars will enable him to identify the object, if it is in view.

As soon as reciprocal rays have been observed between stations of observation, ink up the lines on the chart joining the stations with lines of varying thickness according to the "class" of triangles, and then go over the chart with the angle book, and ink in the rays from the observing stations to each intersected point, inking up, for clearness' sake, only the last ½ inch of the line nearest the intersected point. A cross mark should be drawn across the line where a vertical angle has been observed. At the close of the field season, this chart should be in such a state, that any officer conversant with such proceedings, would be able to lay out from it, the computations.

In forest parties, such charts if neatly prepared, are bound up with the computations of a season's work.

Signals.

34. Signals are of two kinds, luminous and opaque. The former consists of heliotropes for use by day, and lamps for night work: lamps are very rarely employed in triangulation for topographical work, whereas heliotropes are in constant use. The *khalásis* employed on heliotroping have to be carefully instructed to move from station to station in a certain order when they get their "*jawab*," *i.e.*, when they are no longer required at a particular station, and delays owing to cloudy weather and misunderstandings are apt to occur even with carefully trained men. A very useful opaque signal is that known as the pole and brush. This may be erected either by heaping up a pile of stones 5 or 6 feet in height around it, or by tying it on the top of a tree. A pole and brush of this description should always be erected over every station of observation after it is built, and heliotropers should be instructed always to put it up carefully over the mark stone in cloudy weather, and also before they quit a station. A rough coat of white wash over the pile of stones will enable it to be seen much more readily against a dark background. When a tree is poled, it is very necessary to have a mark, such as a triangle cut

deeply into its stem for the purpose of future identification, or else to heap a pile of stones round its base. Another very good form of opaque signal is made of thin laths of bamboo worked into the shape of a deep basket. Two of these are joined together mouth to mouth and fastened on to a pole running lengthwise through them. The pole is supported by three other poles with forked ends leaning against it, and firmly fixed in the ground, the intervening spaces between the supports being interlaced with split bamboos. This signal when new is very clearly visible at long distances. There is no better signal than a single tree or bush left standing on a hill top from which all contiguous jungle has been removed.

Small pyramidal tents may under certain circumstances form good signals, especially when looking down from a hill upon a plain below, but they are not often employed. Flags are very useful in forest clad countries, and are easily recognised against a background of foliage where any other sort of opaque signal would be invisible. They are, however, apt to be stolen, and in calm weather are sometimes difficult to recognise. For "intersected points," natural objects should be used as much as possible ; not only are they permanent, but they are sure to be identified by the plane-tabler when at work. Isolated trees, village temples and pagodas, etc., etc., make excellent points, and for 1 inch work it is rarely necessary to pole or flag them. Rays taken either to the stem, or apparent centre of a tree are sufficient, provided there can be no doubt in the mind of the plane-tabler as to which tree amongst others has been intersected.

Heliotropes, and their uses described.

35. A heliotrope (called also heliostat) consists of a plane circular mirror, so mounted on a small tripod or three foot screws as to be movable on two axes, one vertical and the other horizontal, whose directions pass accurately through the centre of the mirror, at which point a small hole, about $\frac{1}{10}$ of an inch in diameter, is drilled through the glass. Each heliotrope is usually accompanied by a small sight-vane, consisting of an aperture in a board with two cross wires spanning it: failing this, a leaden weight (or even a lump of clay) of 2 or 3 lbs., can be used into which is inserted vertically a straw or very thin slip of wood, on which a ring of thread is tied loosely so as to be movable up and down at pleasure. This latter arrangement can be made by the *khalási* on the spot, and is preferable on the score of simplicity. Heliotropes may be used either mounted on a folding wooden tripod, or on the tops of their own boxes. The second plan is recommended for use in all cases, except where the station is surrounded by bushes or long grass, and such places will be noted by the triangulator when carrying out his reconnaissance. Using the box as a support has advantages, in that it minimises the uncertainty as to the height of the signal, reduces the apparatus to be

carried and enables the *khalási* to sit to his work, in which position he is more likely to keep his alignment properly and continuously. It is an advantage to use only one size and pattern of heliotrope in each party, as the "height of object" can then in most instances be entered by the observer at the time of observing, and a common source of error in deducing the height of stations will be thus avoided. If tripods are used, a good plan is to give each heliotroper a plumb line with knots at intervals of one foot, with instructions to set the centre of the mirror a definite number of feet, say 4 above the mark. If this is impossible owing to the position of the mark stone, the height of the mirror above the mark should be roughly measured, by the *khalási* who is quite capable of measuring to the nearest ¼ of a foot.

The process of aligning a heliotrope, or so placing it that the sun's rays are reflected in any desired direction, is very simple, and soon learned by ordinary *khalásis*. It is carried out as follows:—The sight-vane is carefully centered over the station mark, and the heliotrope placed about two feet from it, facing the point on which it is to be aligned, in such a manner that the *khalási* can see both the sight-vane and the distant mark through the hole at the centre of the heliotrope. By moving the heliotrope slightly, the distant mark, the cross wires of the sight-vane, and the hole in the mirror, are brought into the same straight line. The mirror should now be turned towards the sun, by means of its motion on the two axes (the tripod remaining fixed), in such a direction that the image of the hole, which is a small black speck in the middle of the bright reflection of the mirror, falls on the cross wires of the sight-vane. An observer at the distant mark will then see the sun reflected in the mirror. Some observers prefer centering the heliotrope itself, instead of the sight-vane, over the station mark. The latter method is simplest when the heliotrope is used on a tripod, but the former is the most accurate method of centering when the box is used as a support.

When the sun is near the horizon, its rays may fall so obliquely on either the observer's or the heliotroper's mirror, that the signal is seen with difficulty: this may, in skilful hands, be remedied by double reflection. The method, however, requires a second heliotrope, and is a little too complicated for the ordinary native, but may often be adopted by an observer at the close of a day's work, when he wishes to give a "*jawab*" to a heliotroper.

In order to get good work from heliotropers it is essential to drill them carefully at the beginning of each field season before commencing work, when the method of signalling by double reflection might also be taught.

It is advisable to send two men out in charge of each heliotrope, partly because the *khalási*, whose duty it is to show the signal nearly all day, requires assistance in cooking, etc., and partly because the second man, who is generally untrained, has thus a good opportunity of becoming practically acquainted with heliotrope work, whilst in case of sickness, the presence of a second *khalási* is imperative.

Management of heliotropers.

36. The routine of heliotroping is necessarily made simple in order to be within the comprehension of the uneducated men who are employed on it, and consists of a few readily understood signals as follows:—When the observer wishes to observe a distant station heliotrope, he, with his own heliotrope (which may be 12 inches in diameter with advantage) flashes continuously on that point, until the signaller has adjusted his heliotrope, and shows a steady light; he then ceases flashing, and the signaller is required to keep his light fixed throughout the whole day. If he gets careless, a few flashes are again sent to him, by which he understands that he is to see carefully to the adjustment of his heliotrope, as it has probably got off the line owing to the motion of the sun. When the observations to any station are completed, the heliotroper may be dismissed, or given his "*jawab*" as it is commonly called, as follows:—The observer, having in the regular way obtained a good steady light from the heliotroper, fixes his own heliotrope *steadily* upon him (*i.e.*, not flashing). The heliotroper seeing this suddenly extinguishes his light, the observer immediately follows suit; the heliotroper again shows a steady light, the observer does the same; the heliotroper extinguishes his, the observer does likewise; and this process is repeated three times till the heliotroper is satisfied of the observer's intention; he then gives a few flickers with his heliotrope to signify that he understands the signal, dismantles his heliotrope, sets up the pole and brush over the station mark with stones or earth piled around it, and proceeds either to the observer's camp, or to the next station allotted to him, according to orders previously received. There is another method of giving the "*jawab*," *viz.*, to display two heliotropes thirty or forty yards apart, in answer to which the heliotroper extinguishes his light three successive times as before. In some topographical parties it is customary to give a partial "*jawab*," consisting of one reciprocal extinction, by which the heliotroper is to understand that his work for *that day only* is over; but thisi s liable to be mistaken, and cannot be recommended except with experienced and well-trained heliotropers.

Before despatching the heliotropers to their stations, a triangulator should draw up a sort of programme, giving each heliotroper a list of the stations in consecutive order from which he is to signal. If this programme is carefully made out, and the heliotropers are thoroughly instructed as to their movements from station to station, much trouble will be avoided, and very few mistakes should occur.

At short distances even a 6-inch heliotrope will be too bright to observe with precision, and its light must be partly reduced; this may be done by fitting on the diaphragm with which most heliotropes are provided, thus limiting the exposed part of the mirror's diameter to 2 or 2½ inches, but a more convenient method is to have a piece of muslin or black crepe stretched on a little slip of bamboo bent round into the shape of a tennis bat held by a *khalási* in front of the object-glass of the telescope of a theodolite. A card-board cap, with muslin stretched over the aperture, will answer the same purpose.

Theodolites.

37. The best instrument for running long series of "First class secondary" triangulation is undoubtedly the 6-inch or 8-inch microscope theodolite by Messrs. Troughton and Simms, both of which are fitted with powerful telescopes, but for all "Minor" and "Tertiary" triangulation a good 6-inch vernier instrument will suffice. The modern 6-inch theodolites are very handy and portable instruments, with simple adjustments, and in the hands of skilled observers, capable of giving results more than good enough for any topographical work. The average triangular error for a season's work with the microscope class of instruments should certainly not exceed 2″ to 4″ according to the precautions adopted if luminous signals are used. A memorandum on modern theodolites by Capt. Turner, R.E., is given in the Appendix where the adjustments of these instruments are fully described.

Centering of theodolites, and signals.

38. The observer will of course take the greatest care in centering his theodolite exactly over the station mark, but he should remember that all his care will be thrown away, unless he can succeed in impressing on his signallers the necessity for equal care in centering the heliotropes, etc.; and he will do well to make a show of extreme scrupulousness on this point whenever setting up his instrument, even where accuracy is not imperative, in order to cultivate this habit among his *khalásis*.

Observatory requirements, and procedure.

39. It is indispensable for good observing that proper shelter from wind, sun or rain should be provided for the theodolite, and the officer in charge of the party is responsible that a suitable observatory tent or umbrella accompanies each triangulating party. An observatory tent should invariably be used for "First class Secondary" work.

When possible the observer should be given the services of a recorder, as this will add greatly to the speed and comfort of the work, and to some extent also, to its accuracy, for the recorder's business is to take out the means of the vernier readings and angles whilst the work proceeds, and to call the observer's attention to any discrepancies.

On completing all rounds to stations the observer should at once scrutinize the results, and when large differences appear, the doubtful measures should be repeated before doing other work. If this important precaution is omitted, errors will often subsequently be found when there is no means of rectifying them.*

Use of reconnaissance chart when observing.

40. Before commencing work with the theodolite, the observer should orientate the plane-table on which his reconnaissance chart is mounted in a convenient position, and read out (or enter in his book if he has no recorder), the names of the stations to which he has decided to observe rays, proceeding from his selected zero station in the direction of the hands of a watch, *and closing with the zero station.* The best point to select for the zero station is that which is most likely to be clearly visible all day. He will usually have to observe both "Minor" and "Tertiary" rays, and as the former are observed on more zeros than the latter, he may either observe them in two groups, or may omit the "Tertiary" rays from the list of stations prepared for alternate zeros. The former is the best plan, and should be adopted, except when either class of ray is limited to a very small number, or when time is of great importance. After completing observations to all stations, reference is again made to the plane-table, and commencing *with the same zero station* if visible, the names or numbers of all the intersected points are written down in the order in which they will enter the field of view when revolving the telescope from left to right, *the zero station again closing the list.*

Definition of terms used in observing.

41. A "swing" is a continuous motion of the telescope round the circle, beginning and ending with the zero station. It may be made in either direction, *i.e.*, either clockwise or counter-clockwise.

A "measure" is the number of degrees, minutes and seconds contained in an angle. Each angle must be measured more than once, as a single measure is not free from error.

A "setting" is the division on the limb at which vernier A is clamped on beginning a round of observations.

The "zero" includes a pair of settings on different faces 180° apart. Thus $\frac{\text{F. L. } 0^\circ}{\text{F. R. } 180^\circ}$ is counted as one zero.

* After a short experience in the field, the observer will know what to expect in the matter of agreement between measures on each zero and must then lay down a criterion for his own guidance. Instruments and conditions vary so much that no hard-and-fast rule is possible, but when using a modern 6-inch vernier theodolite, all measures of the same angle should fall within 20″ or 25″, provided the signals are clearly visible. With microscope theodolites the range will be much smaller.

Measures which do not comply with the adopted criterion must be repeated at once.

42. The number of measures to be made of each angle depends chiefly on the class of the work in hand, and the following table will furnish a useful guide—

Measurement of horizontal angles.

Class of triangle.	Number of measures of each angle.
First class secondary*	16
Minor	8
Tertiary	4
Intersected points	2

The number of zeros depends on the class of instrument used, and is based on the following considerations:—

(1) Each measure should be independent, and unbiassed.

(2) Each measure should, if possible, be made on a different part of the arc.

(3) On each zero, the measures made must be balanced in respect of the direction of the "swing," and "change of face."

When using a "vernier" instrument, if two measures in contrary directions are made on each face, the first condition cannot be complied with, as it is impossible to avoid a certain bias in favour of the measures first recorded, many of which will unavoidably be recalled to the observer's mind by the position of the verniers when read on the return "swing." Hence it follows that with a "vernier" instrument, no more than two measures should be made on each zero, the first swinging clockwise on one face, and the second swing counter-clockwise on the other face.

If the instrument has only two verniers, this procedure will not satisfy the second consideration, and from his point of view it would seem better, when working with this class of instrument, to take only one measure on each "setting," reversing conditions, as to direction of "swing" and "face," on every fresh "setting" used. This, however, is objectionable in other ways, and in this case it is therefore best to disregard the second consideration.

A "microscope" theodolite possesses the advantage that there can be no appreciable bias in the readings under any circumstances, so that the first condition is satisfied even when repeating a round of angles with reversed "swing." As moreover these instruments are usually very carefully divided, there is no particular reason for multiplying largely the number of zeros, and it is therefore best to take four measures per zero, and keep the number of zeros, small. †

* Any officer who has to do "First class secondary" work is recommended to refer to the chapter on Triangulation in the Hand-book of the G. T. Branch, where the precautions necessary for highly accurate work are entered into.

† As regards repeating discordant measures, see paragraph 39 and footnote.

The following table has been based on the above arguments and is recommended for universal adoption :—

Class of triangle.	Number of measures of each angle.	Number of zeros.		Setting of zeros.			
		Vernier theod :	Microscope theod :	2 Vernier theod :	3 Vernier theod :	5 Vernier theod :	2 Microscope theod :
First class & secondary.	16	8	4	See below (*a*).	See below (*c*).	See below (*d*).	See below (*b*)
Minor . .	8	4	2	See below (*b*).	See below (*e*).	Not used	L 0° R 270° R 180° L 90°
Tertiary . .	4	2	1	L 0 R 270° R 180° L 90°	L 0 R 240° R 180° L 60°	Not used	L 0° R 180°
Intersected points.	2	1	1	...	...	...	...

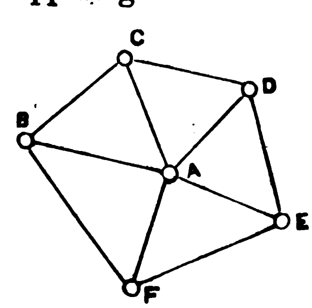
	1	2	3	4	5	6	7	8
(*a*)	L 0° . R 180° .	R 202½° L 22½°	L 45° R 225°	R 247½° L 67½°	L 90° R 270°	R 292½° L 112½°	L 135° R 315°	R 337½° L 157½°

(*b*) The 1st, 3rd, 5th and 7th zeros under (*a*).

	1	2	3	4	5	6	7	8
(*c*)	L 0° . R 180° .	R 187½° L 7½°	L 15° R 195°	R 202½° L 22½°	L 30° R 210°	R 217½° L 37½°	L 45° R 225°	R 232½° L 52½°
(*d*)	L 0° . R 180° .	R 184½° L 4½°	L 9° R 189°	R 193½° L 13½°	L 18° R 198°	R 202½° L 22½°	L 27° R 207°	R 211½° L 31½°

(*e*) The 1st, 3rd, 5th and 7th zeros under (*c*).

The angles at a station are taken thus :—Supposing the observer to be at *A*, and the signals at *B*, *C*, *D*, *E*, *F* are all visible, the instrument is carefully levelled and clamped at 0°, the lower plate being unclamped. The instrument is then turned round in azimuth so that some station, *B* for instance, reads 0° or zero on vernier A ; *B* is then called the zero station. Suppose the telescope to be brought up from the left hand of *B*, and turned gently, so that *B* may enter the field of view, and come near the centre



wire, but not pass over it; the lower plate must then be clamped, and the bisection of *B* completed by using the slow-motion screw. All the verniers are now read, and the recorder enters the readings in a fair legible hand in the angle book. The observer should then look again into the telescope to see that *B* remains bisected. If found correct the upper plate is to be gently unclamped and the telescope moved by means of its supports towards *C*, care being taken not to overshoot it. The clamping, bisecting and reading is done as before, and similarly also for *D*, *E* and *F*. The "swing" is then continued and the zero-station *B* is again observed. This completes one set of observations. A comparison of this reading with that previously obtained will test the stability of the instrument. A complete round of observations is thus obtained at "setting" F. L. O.°, by a continuous motion or "swing" from left to right. Now, after overshooting the station *B*, the telescope is brought back by a continuous motion from right to left, to each station in succession, and the readings recorded in a similar manner. This will give a second round of observations at "setting" F. L. O°. Now "change face" by turning the telescope through 180° in a vertical plane, and round 180° in azimuth, so that if the face of the vertical circle were previously to the left hand, it will now be to the right hand; clamp station *B* at 180°, and proceed as before, taking two rounds of observations, the motion or "swing" of the instrument being in one round, continuous from left to right, and in the other from right to left. This is called "setting" F. R. 180°, the former position being "setting" F. L. O°.

When only two measures per zero are made, *i.e.*, one on each face, the procedure is as follows: swing from station to station clockwise, then reverse face and swing back in the contrary direction.

All three angles of each triangle should be observed no matter what the class of triangle may be. In "Tertiary" work this is not so essential but the frequent omission of the third angle in "Minor" triangles is a certain indication of slovenliness, and should always be so regarded.

When observing at a *G. T.* station, always be careful to have a heliotrope at an adjacent *G. T.* station, and observe it in your round of angles, to enable you to deduce your triangles from *G. T.* bases.

When it is found, while observing, that a certain portion of the ground is commanded from two stations only, it will very often be found feasible to select a "Tertiary" station of observation from which a third ray can be obtained to the intersected points in this area. To do this choose a convenient station from which two of the previously chosen stations of observation are visible, such that they will subtend a suitable angle at the new station. Take your round of angles to the intersected points and observe carefully the angle between the two stations. Leave a conspicuous mark at the "Tertiary" station, and when either or both of the two original stations are visited, include the "Tertiary" station in the round of angles. The angle taken at the "Tertiary" station, and that observed at one of the other two stations, will be sufficient if carefully taken to fix the new station, as it is merely required to get checking rays to the intersected points. Such a "Tertiary" station should be chosen judiciously, so as to observe at it while on the way to one of the main stations, in order not to entail going back to one of them to fix it.

In observing intersected points, it is necessary that at least one, (but preferably more than one) station should be observed with them in the same round, and it is essential to commence and finish with a station as a check on any movement of the instrument during the round. Intersected points should have a short description or sketch attached to them in the column of remarks of the angle book, to assist in subsequent identification, and to ensure the same part of the object being observed in all cases. It is a rule not to be departed from, except for very urgent reasons, that intersected points must be fixed by three rays. When two only are used, a large number of points are almost always lost owing to misidentification.

If intersected points are not poled, they should be well defined natural objects. To take several readings to an ill-defined object on the chance of one of the readings working out in the computations, is a waste of time in the field, and entails useless labour in recess, for even if the point eventually works out, it is sure to be of no value to a plane-tabler, who will fail to identify it.

When a wooded hill has been cleared and a single tree left standing near a station, a reading of the horizontal circle on one face should be taken to it from the station and entered in the angle book under the head of "Station tree" and the distance from the station to it should be measured and recorded in the column of remarks.

The magnetic variation having to be determined for entry on the maps, the theodolite must be set in the magnetic meridian at each station of observation, by means of the needle, and the reading recorded in conjunction with the reading of one of the surrounding stations. The angle derived from these two readings when applied to the computed azimuth of the station will give the magnetic variation.

Satellite stations.

43. It may occasionally happen that the observer has, through inadvertence intersected, when observing, not the exact station itself, but a point quite close to it: on the other hand it is occasionally necessary, in order to avoid intervening obstacles, to place the theodolite a short distance from the mark for some particular ray. In such cases all that the observer has to do in the field, is to enter carefully in the angle book the

circumstances of the case, giving the distance of the "satellite station," as it is commonly called, and its direction referred to one or other of the distant stations. The computation of the correction to be introduced is then a very simple matter of plane trigonometry, and is generally postponed till the calculations are taken in hand during the recess.

Measurement of vertical angles.

44. Vertical angles to all stations distant more than 4 or 5 miles, should be measured at about the time of minimum refraction, *i.e.*, between 1-45 P.M. and 3-45 P.M., and always with at least one "change of face:" for intersected points the time is of less consequence, and so long as the observations are not made in the early morning or late evening hours, the observer may use his own discretion about infringing the rule. If vertical angles are observed at an hour very different from that of minimum refraction, it is desirable to observe some station at the same time: the reason for this is, that the height of the station being known, the observer is enabled to compute the refraction at the time of observation, by means of the vertical angle then taken to it. For stations the observations should be reciprocal, because the effect of refraction is not only thereby eliminated, but because they furnish the coefficient of refraction to be employed in reducing single, *i.e.*, non-reciprocal, vertical measurements.

The heights of the instrument and signal above the station platform must always be recorded in the angle book; and in observing vertical angles to intersected points, the particular part of the object intersected should be noted, as well as its height above the ground level.

The level attached to the vertical arc must always be read and recorded, when observing heights of stations, but in the case of intersected points, it will suffice to keep the bubble near the centre of its run, and neglect the level correction. A note as to the nature of the graduation of this level must be given on the first page of the vertical angle book, as the rules for reducing the correction vary according to the method used, *vide* paragraph 47. The scale value of the level should also be entered with a note as to when, and how it was derived. Levels being very sensitive thermometers, care must be taken not to influence them by breathing on them, or by too near an approach of the body.

The practice of observing both horizontal and vertical angles simultaneously, by putting the intersection of the wires on the object and reading both sets of verniers, should never be permitted when observing to stations. Not only is the intersection liable to be less accurate, but the extra delay in observing the horizontal round and the extra handling of the instrument, which is necessary, are very liable to cause a shifting of the instrument, vitiating the horizontal angles.

In observing heights to signals placed on trees in forest-clad hills, it is advisable to observe both the top and the base of the tree when visible, for the height of the top of a tree is more useful to a plane-tabler in taking clinometer heights than the base, whilst the ground level is required for insertion on the fair maps, and needed by the plane-tabler to regulate his contours. The foot of a tree being frequently invisible from some stations, the height of the tree above ground level should be determined by the *khalási* who erects the signals by means of a string and plummet, or subsequently by the plane-tabler employed on the detail survey.

Vertical angles to intersected points should always be observed on both faces. It is a slovenly and bad method to merely take them on one face, and note the index error of the vertical circle.

Horizontal angle books.

45. It is most essential, in order to avoid errors and loss of time, that the angle books, in which the measurements made by the theodolite are recorded, should be systematically and clearly kept up. All entries must be made in ink on the spot, and no erasures are permitted. The following abbreviations are recommended for adoption in the angle books and computations :—

H.S.	for	hill station of the Great Trigonometrical Survey.
T.S.	,,	tower ,, ,, ,, ,,
h.s.	,,	hill station of "First class secondary," "Minor," and "Tertiary" triangulation.
v.s.	,,	village station of "First class secondary," "Minor," and "Tertiary" triangulation.
t.p.	,,	tree pole.
v.t.p.	,,	,, near village.
h.t.p.	,,	hill tree pole.
t.f.	,,	tree flag.
temp.	,,	temple.
Hel.	,,	heliotrope.

For all regular topographical triangulation, separate angle books should be used for horizontal and vertical angles. The condensed angle book P. 40 is only designed for astronomical and transfrontier work where the saving of weight is of importance. Duplicate angle books are not required.

The name of the station of observation should be entered in Roman letters, or full round hand. Names of stations to which rays are to be observed should be similarly written in full for the first round, and given distinguishing numbers or letters. The second round is written in reverse order, using the numbers only, and for the sake of brevity, these numbers may be used for all subsequent rounds recorded. A clear space of one or two lines should be left between each round of angles; also a blank page left for the abstract, before commencing to write out the intersected points.

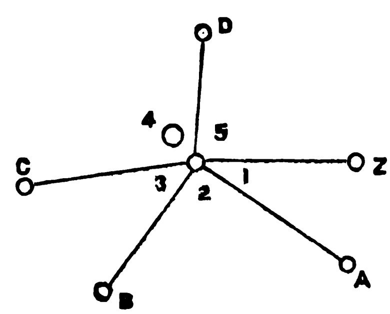
The stations of observation must be very carefully described, so that any one subsequently wishing to make use of them may have no difficulty in finding and identifying the marks. The directions and distances of the neighbouring villages should be given, and the local name of the spot, if any exists, also the best means of getting to the station, and the name of the village in whose lands it is situated, together with the name of the district, the distance and bearing of the mark tree, and any other information likely to prove useful in the future. This description must be written in the angle book at the end of the observations appertaining to that station, in a clear legible hand, special care being taken to write proper names in a good round style, or even to print them.

C. O. No. 40 (Prof.), dated 16th October 1884.

Taking out the "means," and "abstracts" of horizontal angles.

46. On returning to camp, the recorder will go through his work again, and at the earliest opportunity the observer will re-check all means, and angles, and prepare an abstract, which will subsequently be checked, and signed by the recorder. There are various methods of making out the abstract, but the following seems the best and should be generally adopted by topographical parties.

In the figure, O is the station of observation, and Z the zero station. Each round gives one measure of each of the angles ZOA, AOB, BOC, COD, and DOZ, *i.e.*, of 5 angles which, in the following example, are given imaginary values. The first step is to find the mean values of each angle as follows :—



Means of angles.

Zero.	1	2	3	4	5
	30°·3′	89°·21′	65°·47′	35°·36′	89°·10′
L 0° . . .	15″	55″	7″	59″	27″
R 180° . . .	18″	43″	13″	67″	35″
L 45° . . .	13″	51″	10″	64″	40″
R 225° . . .	30″	67″	19″	73″	39″
L 90° . . .	25″	56″	15″	80″	21″
R 270° . . .	17″	59″	27″	69″	28″
L 135° . . .	23″	50″	21″	65″	38″
R 315° . . .	19″	49″	17″	60″	30″
Sums .	160″	430″	129″	537″	258″
Means .	20″	54″	16″	67″	32″

Then follows an abstract—

Abstract of "Minor" angles.

Name of station.	Angle.	Correction.	Corrected angle.	Abstract.
Z	...	...	0° 0′ 0″	0° 0′ 0″
A	30° 3′ 20″	—1″	30° 3′ 19″	30° 3′ 19″
B	89° 21′ 54″	—2″	89° 21′ 52″	119° 25′ 11″
C	65° 47′ 16″	—2″	65° 47′ 14″	185° 12′ 25″
D	85° 37′ 07″	—2″	85° 37′ 05″	270° 49′ 30″
Z	89° 10′ 32″	—2″	89° 10′ 30″	360° 00′ 00″
Sum .	360° 00′ 09″	—9″	360° 00′ 00″	...

This form should be used for "Tertiary" rays also, and it may be noted that whole seconds only are entered in the tables of means, and abstracts. The correction applied in the abstract, to make the sum of all the angles = 360°, may be made equal for each angle, or roughly proportional to the size of the angle. The latter is perhaps the better method, but either will do. "First class secondary" work should be dealt with as laid down in the Trigonometrical Hand-book, to which reference should be made. When both "Minor" and "Tertiary" rays are observed, two separate abstracts will have to be made, *the same zero station being used in both.* The abstract of the intersected points should be made on the right hand side of the page on which the angles are recorded, and in doing this, it will suffice to take the mean of the first and last readings of the zero station, and correct all the angles, by applying to each, the difference between the mean value and 0°.

Vertical angle books, level corrections.

47. In filling up the columns in a vertical angle book, the only point calling for notice is the level correction. The readings of each end of the level are registered in two columns marked "object-end" and "eye-end." The dislevelment must in all cases be calculated separately, for each observed object, from the readings of the level taken during the observations to it. Some levels being graduated from the centre outwards, and others continuously from end to end, different rules for correcting the observed angles for dislevelment are necessary in the two cases.

(1) *For levels graduated from the centre outwards,* the rule is as follows:—Calling the readings of the object-end + and those of the eye-end —, the algebraical sum of the whole of the level readings is to be divided by the number of readings, each end reading being counted as an independent observation. The quotient will be the level correction in terms of the level scale, which, multiplied by the angular value of one division of the scale, will give the angular correction to be applied with its resulting sign to elevations, and with reverse sign to depressions.

Expressed by a formula the correction is as follows :—

Let $\Sigma(O)$ and $\Sigma(E)$ be the sums of the readings of the object and eye-ends respectively, both being considered positive, d the value of one division of the level scale in seconds, and n the total number of level readings, including both object and eye-end readings;
then

$$\text{level correction} = \frac{\Sigma(O) - \Sigma(E)}{n} \times d;$$

this correction is to be applied with its resulting sign to elevations, and with reverse sign to depressions.

(2) *For levels graduated from one end to the other*, the formula is as follows :—

$$\text{level correction} = \frac{\pm \Sigma(O_R + E_R) \mp \Sigma(O_L + E_L)}{n} \times d,$$

where $\Sigma(O_R + E_R)$ and $\Sigma(O_L + E_L)$ signify the sums of the object and eye-end readings on face right and face left respectively, d the value of one division of the level scale in seconds, and n the number of level readings, each end reading being considered an independent observation. The $\frac{\text{upper}}{\text{lower}}$ signs will give the correction with its resulting sign to be applied to $\frac{\text{depression}}{\text{elevation}}$ if the graduation reads from the *object-end towards the eye-end* when the instrument is face right, and to $\frac{\text{elevation}}{\text{depression}}$ if the graduation reads in the *reverse order* on the same face.

48. There are several methods by which the value of the divisions of the level scale can be ascertained. The best is by means of a "bubble-tester," an instrument of very simple construction. It consists essentially of a bar or frame-work, on to which the level is firmly fixed by contrivances for the purpose, and admitting of being raised or depressed at one end by a screw of known pitch. A graduated disc is attached to the head of the screw, on which is read off the change of elevation of the bar caused by turning the screw; and hence by a comparison of this change with the divisions that the bubble passes over, a value of each division is arrived at. An instrument of this kind is available only at the Calcutta or Dehra offices.

Methods of ascertaining the value of the level scale.

The value may also be ascertained by affixing the level to the frame of the vertical circle (or making it ride parallel to the telescope), and then taking readings of the verniers on the vertical arc in two positions of the bubble, whence by comparing the number of the divisions of the level scale traversed by the bubble, with the corresponding angular motion of the vertical circle as read by the verniers, the value of one division is arrived at by simple proportion. At least fifty separate observations should be made; they should not all be taken at the same time, but under as great a range of temperature and circumstances as possible, with various lengths of run, and at different parts of the vertical circle, taking special care to avoid allowing the bubble to approach too near the end of the scale on the one hand, and on the other, avoiding small runs. In applying a level to a vertical circle for the purpose of measuring the value of its scale, the best plan is to fix on the bars, or on the telescope, two V's of wax, in which the level can be made to sit firmly, taking care to secure it from accident by tying it on. The level should be carefully cross-levelled, so that it may occupy the same position under trial, as when in actual use. If there be no cross-level attached, one may be fixed on temporarily with wax, before dismantling the level; but if means are not available for this purpose, then, before taking the level off for trial, mark with pen and ink on the glass the outline of the bubble. This approximate cross-levelling, however rough, is far better than trusting to chance.

There is yet another mode of determining the value of the divisions of the level scale, applicable to levels of azimuthal instruments, which does not necessitate the detaching of the level. It is performed as follows:—Bring the object or eye-end of the telescope plumb over a foot-screw. Turn the stand with the instrument so set, till the telescope is directed to some natural object close by. Now level the instrument. It is clear that, if the screw under the telescope end be raised or depressed, the amount of dislevelment so occasioned may be measured both by the verniers of the vertical circle and by the level, whence a comparison of the two measures gives at once the value sought.

C. O. No. 40 (Prof.), dated 16th October 1884.

Completion of angle books.

49. It is most desirable that the abstract of horizontal and vertical angles, and all other details of the angle books, including paging and indexing, should be written up, examined and signed *during the field season*, as the work progresses; but if for any reason this has not been possible, it should be taken in hand the first thing on return to recess-quarters, before any of the computations are begun. Most scrupulous attention must be paid to neatness and methodical arrangement of all records and computations. Good handwriting, and freedom from blots, erasures, and interlineations, are essential.

Arrangement of triangles for computation.

50. All computations of "First class Secondary," "Minor," and "Tertiary" triangles must be done in duplicate by two independent computers who should use different sets of tables, and each copy must be signed by both computers. The order in which the names of the stations of each triangle are entered should always be round in the same direction as the motion in the hands of a watch, so that any one standing at the first station, and facing in the direction of the other two, should have the second one towards his left hand, and the

third towards his right;* the distance between the first and second stations forming the given base. The filling up of the form is too simple to require detailed explanation.

"First class Secondary" triangles are computed on Form P. 13. The triangular error is divided equally between each of the three angles of every triangle; it is equal to the difference between the sum of the observed angles and 180°, + spherical excess, with the proper sign. The angles observed, as well as the corrections, and the angles for computation, should be retained to the nearest tenth of a second: the length of sides in feet should be taken out to tenths, and in miles to thousandths.

The "Minor" and "Tertiary" triangles are computed on Form P. 14 to which the above remarks also apply, with the exception that the spherical excess is not computed, and the angles are entered to the nearest second only. *No "deduced" or "supplementary" angle should ever be entered in the column of "observed" angles.* The lengths of sides in feet should be taken out to units, and in miles to thousandths. It often happens that the mean side derived from two triangles is not the side required for extension. In this case the triangle should be recomputed from the mean base, and the new value of the required side so found, is that which should be used for extending the computations. *The arrangement of the "Minor" triangles so as to get the best results in computing, is a matter requiring much judgment, and should usually be done by the officer in charge of the party.*

The "Intersected points" are computed on Form P. 15; in these the third angle is always unobserved, and its value is supplementary, *i.e.*, it is obtained by taking the sum of the first two angles from 180°. The majority of these points should be fixed by observations from at least three stations, otherwise there is no reliable check on their identification. If, however, the *height* of an intersected point is observed from two stations, the accordance of the two results furnishes a test, though not a very rigorous one, that the same point is observed from both: the test is the more reliable, the steeper the rays to the point observed. If a point P be observed from three stations A, B, C, two triangles A B P and B C P may be computed, giving a double value of the side B P, the agreement of which will furnish a test of the accuracy of the work. In such cases it is useless to compute (as has sometimes been done) the triangle A C P, no new information being obtained thereby. The lengths of sides in feet should be computed to units and in miles to thousandths. Five places of logarithms are sufficient for the computation of intersected points.

* This rule ensures the correct plotting of the points, if laid down by distance only.

It is not necessary to compute intersected points in duplicate, the agreement of the common sides and common heights, and the computation of the co-ordinates from two stations being sufficient check on the accuracy of the work.

The computations of points found wrong by the plane-tablers, should be examined, and if the error be due to want of identification by the triangulator, they should be expunged from the angle books, computations, and triangulation chart.

Limits of errors of triangulation.

51. Average linear errors of "First class Secondary" triangulation should be less than 3 inches per mile, and triangular errors less than 4 seconds. In "Minor" and "Tertiary" triangles these errors should not exceed 6 inches and 10 seconds, respectively, if luminous signals are used: for intersected points, the linear error will largely depend on the kind of object intersected; if it be a pole, or tree stem, or temple, or other well-defined object, the error should average perhaps about 1 foot per mile.

Method of deducing linear errors of triangulation.

52. In deducing the linear errors of the triangulation, the mean of all the values of the same side is to be taken as the correct value, and the differences between that mean and each separate value, will be the linear errors in each case, which are to be used in calculating the general mean linear error for each class of triangles. There is a more direct method of deducing the same thing from the log sides only, which, though not rigorously correct in theory, is probably more accurate in practice, owing to the feet being given only to the nearest tenth. The method is as follows:—Take the mean of the logarithms to represent the correct logarithm of the side, subtract each logarithm from this mean; take the mean of the differences, and treating it as a whole number, divide by 68*; the result is the linear error in inches per mile. Thus suppose the three logarithmic values of a side to be 4·8149322, 4·8147443, and 4·8147559: the mean is 4·8148108. The differences between this and each of the logarithms are ·0001214, ·0000665 and ·0000549, the mean of the three being ·0000809, then the average linear error in inches per mile will be $\frac{809}{68} = 11{\cdot}9$.

Computation of latitudes, longitudes, and azimuths.

53. The computation of latitudes, longitudes and reverse azimuths should be next undertaken. The forms used are P. 16 for "First class Secondary" stations, P. 17 for "Minor" and "Tertiary" stations, and P. 18 for "Intersected points." They differ only in the extent to which the computation is carried. The first two are

* More exactly this is 68·54.

explained at considerable length, with examples, at pages 14 to 18 of the third Edition of the Auxiliary Tables: it is important to note that the angles for computation, increased by ⅓ of the spherical excess, commonly called *spherical angles*, must be used in this computation for "First class Secondary" stations: for "Minor" and "Tertiary" stations, and intersected points, the difference between the angles for computation, and the spherical angles is immaterial, and the former may be used. Form P. 18 is merely an abbreviated Form of P. 17, and suffices for intersected points. In Forms P. 16, and P. 17, the computer should be guided by the examples as to the number of decimal places to be retained; in Form P. 18, λ and L require only one place.

Synopsis of latitudes, longitudes, azimuths and sides.

54. The latitudes, longitudes, azimuths and sides contained in the foregoing computations must now be entered in the synopsis P. 24. Care should be taken that every side which has been computed be entered, and that no side should appear twice; that where mean values are obtainable, they should be entered, and that the numbers of the triangles from which the values have been obtained, be recorded in the appropriate column. The height contained in the last column is calculated subsequently. This compilation will then be a complete synopsis of bases, the values of which will correspond with those given on the charts of triangulation to be described hereafter. The synopsis should be filled up step by step, and not left till the latitudes and longitudes are completed. As the triangles are computed, the computers should enter the values obtained. This prevents any chance of a side being entered twice, and ensures the mean value being adopted, when required as a base for computing fresh triangles. Much time is wasted in looking back through the triangle sheets for a base, if the synopsis is not kept up *pari passu* with the computations.

Miscellaneous computations.

55. Before passing on to the computation of heights, it will be as well to mention here three other forms of computation which are occasionally required. The first is the calculation of the length of the third side of a triangle when the angle opposite to it, and the two sides including that angle, are given. The form for this is P. 25, in which AC and BC are the two known sides, including the known angle C, from which the value of AB has to be determined. To those who have an elementary knowledge of plane trigonometry, a detailed explanation of the working of this form is superfluous.

The second is the computation of the position of a station from observations to three known points on Form P. 26, the correct working of which may be gathered from the notes at the foot of it: and the third is the computation of the distance apart, and mutual azimuths of

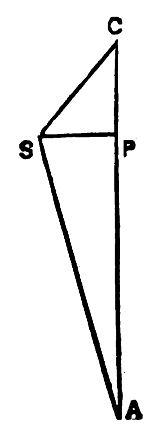
C. O. No. 20 (Prof.), dated 7th October 1881.

C.O. No. 30 (Prof.), dated 7th August 1883.

points, of which the latitudes and longitudes are known: for this purpose there are two forms, *viz.*, P. 27 and P. 28, the former for "First class Secondary" stations, and the latter for "Minor" and "Tertiary." The explanation of these computations will be found in the Auxiliary Tables.

Computation of satellite stations.

56. It has been remarked in paragraph 43, that it occasionally becomes necessary to use a so-called "satellite station." There are two cases which may occur, (1) that in which a satellite station is observed *to*, and (2) that in which a satellite station is observed *from*. The first generally arises from some object near the mark being accidentally observed instead of the mark itself, the mistake being discovered on visiting the station; or from the mark being so difficult to see, that some better defined object very close to it is purposely intersected in its stead. All that is necessary in this case is to measure carefully with a tape the distance between the satellite, and the true mark, and the angle at the latter point between the satellite and the distant station, from which the original observation was made. This angle need only be recorded to the nearest minute. The computation is as follows: In the annexed diagram let A be the station from which the satellite S was observed instead of the true mark C. Let CS=d, the angle SCA=a, SAC=θ, and the perpendicular SP from S upon AC=p, AC=a.



Then $p = d \sin a$, and $\tan \theta = \frac{p}{PA}$.

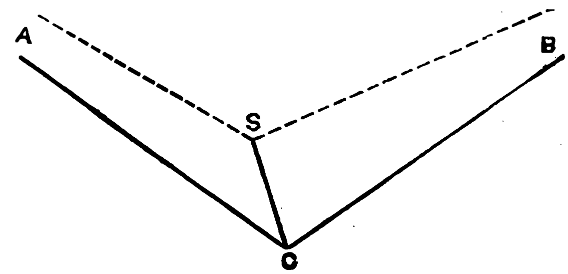
Now as SC is very small in comparison with AC, and the angle SAP also very small, we may put PA = AC, and $\tan \theta = \theta$ in seconds $\times \sin 1''$,

hence $$\theta'' = \frac{d \operatorname{cosec} 1'' \sin a}{a}.$$

The value of "a" may be computed with quite sufficient accuracy from any triangle in which that side occurs, using two observed angles only, the third being supplementary. Hence the correction to any angle, in which S has been observed instead of C, is $\frac{d \operatorname{cosec} 1'' \sin a}{a}$ with its proper sign.

The second case, *viz.*, that in which a satellite station is observed *from*, generally occurs from an obstacle hiding the view of some particular station which it is necessary to observe, and which can be avoided by shifting the instrument a few feet one way or the other. Let ABC be any triangle in which the angles BAC, ABC have been, or can be observed, but the angle ACB cannot be measured owing to an obstacle preventing the theodolite being set up at C. Suppose the theodolite to be moved to S, it is required to compute the correction to the observed angle

ASB in order to reduce it to ACB. Four cases may arise according to the position of S with regard to AC and BC. It may lie between them, as in the figure, or between AC and BC produced, or between AC produced and BC, or between AC produced and BC produced. With a little care however with regard to signs, one formula may be made applicable to all cases.



When the observer has set up his theodolite at S, he must first measure carefully with a tape the distance SC, and then having set the limb to read 0°, he must turn the telescope on C, and then revolving it from left to right, record the readings of A and B. This completes the observation. To compute it, the length of AC and BC must be first calculated by using two angles only of the triangle ABC. Let AC = b, BC = a, SC = d, the theodolite *reading* of A = β and of B = a.

Then it may be readily shown, as in the first case, that the magnitudes of the angles SAC, SBC, in seconds, apart from all consideration of signs, are :

$$\text{SAC} = \text{d cosec } 1'' \frac{\sin \beta}{\text{b}}, \ \text{SBC} = \text{d cosec } 1'' \frac{\sin a}{\text{a}},$$

and the total correction to the angle ASB becomes

$$-\text{ d cosec } 1'' \left\{ \frac{\text{sn } a}{\text{a}} - \frac{\text{si n}}{\text{b}} \right\}.$$

This formula will apply to any of the four positions of S specified above, if it is remembered that the sines of angles between 180° and 360° are negative, and the sines of a and β are treated in accordance with this property.

If three or more rays from S are to be considered, the same procedure can be extended to them, but such cases are of infrequent occurrence, and it is unnecessary to give further details.

57. The computation of heights of stations, is fully explained with numerical examples at pages 24 to 31 of the Auxiliary Tables, to which the reader is referred. The form used is P. 19, for "First class Secondary" stations; the heights should be retained to tenths of feet, and for other stations to units only. Refraction can only be computed in the cases where there are reciprocal observations between the stations. The coefficient of refraction should not be obtained from sides less than 10 miles, as errors in the heights of the instrument and signal have too great a proportional effect when the distances are shorter. Form P. 20 provides for the computation of heights of intersected points. In connection with this

Computation of heights.

C. O. No. 10 (Prof.), dated 14th June 1880.

C. O. No. 32. (Prof.), dated 19th October 1883.

form, Table XV of the Auxiliary Tables is required, the adopted refraction with which to enter the table being obtained from the computations in Form P. 19. If no refraction be forthcoming, it is usual to take it as $\frac{1}{16}$, or 0·07 of the contained arc.

C. O. No. 71 (Prof.), dated 6th March 1896.

Triangulation, and traverse charts.

58. As the first essential in arranging the records of a survey party is to have a means of supplying data of points fixed by the survey to those requiring them, the results of the triangulation or traversing of topographical parties are published in the form of a chart, bearing on it a printed list of the co-ordinate values of all stations and points included in it.

The following scales are to be adopted in preparing the charts :—

Scale of Original Survey.	Scale of Published Chart.
8 inches = 1 mile . .	½ inch = 1 mile ordinarily, to be increased to 1 inch = 1 mile if the sheet is greatly crowded.
4 inches = 1 " . .	
2 inches = 1 " . .	
1 inch = 1 " . .	¼ inch = 1 mile.
½ inch = 1 " . .	⅛ inch = 1 mile.
¼ inch = 1 " . .	
⅛ inch = 1 " . .	

The charts will in all cases be drawn on double the above scales for reduction to one-half.

The area comprised in each chart will be as follows :—

Scale of Publication of Chart.	Area comprised.
1 inch = 1 mile .	7½′ in latitude by 15′ in longitude.
½ inch = 1 " . .	15′ " by 30′ "
¼ inch = 1 " . .	30′ " by 1° "
⅛ inch = 1 " . .	1° " by 2° "

No data must be entered on the face of the chart. The names of the stations of observation should be typed on it: all intersected points and permanently marked traverse stations, such as the trijunctions of village boundaries and other objects which may be readily identified hereafter, must be numbered serially throughout each chart, commencing with the number 1 in the left upper corner, and numbering the points successively downwards as in the specimen chart circulated with the order quoted in the margin.

C. O. No. 68 (Prof.), dated 1st March 1900.

All trigonometrical and traverse stations and points must be shown by circles, principal stations of the G. T. Survey by larger circles; the rays between G. T. principal stations in broad heavy lines, "first class secondary" triangles in medium lines, and "minor" and "tertiary" triangles in fine lines; no rays to be drawn to intersected points.

Traverse lines connecting the permanently marked traverse stations should be drawn as thin as possible compatible with good photozincography, and the number of the traverse printed along them.

The border lines, typing, etc., should be in accordance with the specimen chart. The title of the chart must contain the sheet numbers, the name of the Province, and the season of survey.

With the chart must be submitted a list of data in manuscript, which is eventually set up in type at the Head-quarter Offices. This will comprise an alphabetical list of stations with their co-ordinates, rectangular or spherical, and heights, followed by a list of the intersected points and permanently marked traverse stations, the reference numbers on the chart being arranged serially, followed by the names of the intersected or traverse points with their co-ordinates and heights.

In the case of rectangular co-ordinates, the latitude and longitude of the origin must be prominently given. The chart will appear on the upper portion of the paper, and the data below as in the specimen.

Each chart must include, not only the triangulation and traversing done by a party, but all previous triangulation falling in the area of the chart. In order to ensure that nothing is omitted, executive officers should enquire at the Calcutta or Dehra Offices for information on the subject, and for the supply of the necessary data. Rough reconnaissance triangulation, which precedes or accompanies geographical surveys, and triangulation which is classed "confidential," are not to be entered on the chart. C. O. No. 71 (Prof.), dated 6th March 1896.

Where the triangulation of more than one party is entered on a chart, an extra column should be added to the tabular statement, following the column of heights, headed "series of triangulation," with reference letters indicating the series of triangulation from which the data are taken, and an explanatory note at foot. This information is required to enable the original data to be referred to at any time.

General Reports.

59. The original computations of a party are bound up in such a form as to make their contents readily available for reference. As far as possible, *the computations referring to each chart* will be bound up in two volumes, the first containing those most likely to be referred to. The contents of this volume will be as follows :— C. O. No. 71 (Prof.), dated 6th March 1896.

I.—Chart of triangulation with list of points and their co-ordinates and heights (as described above).

II.—Title page (Form $\frac{G.R.}{1}$)

III.—Table of contents (Form $\frac{G.R.}{3}$)

IV.—Index (Form $\frac{G.R.}{3}$)

V.—Introduction.

VI.—Description of the general construction of stations and marks erected for observation.

VII.—Synopsis of latitudes, longitudes, azimuths, and heights.

VIII.—The computations of "First class Secondary" triangles.

IX.—The computations of "Minor" and "Tertiary" triangles.

X.—Abstract of horizontal angles and azimuths or bearings (Form P. 6).

The above may be called the "General Report, Volume I."

The computations of triangles of intersected points, of latitudes and longitudes, of heights, traverses and all others not included in the General Report, Volume I, should be bound up in a separate volume, and submitted with the General Report, and called Volume II. Angle and field books appertaining to these computations should be submitted with the above volumes.

Intersected points observed from two stations only, and subsequently ascertained by the plane-tablers to be wrongly observed by the triangulator, should be deleted in the computations and angle books.

The title page should specify the Province of survey, the degree or degrees in latitude and longitude to which the report refers, and the years during which it was in progress.

The index must contain a list of the stations and intersected points arranged separately and alphabetically, their co-ordinates and heights, together with references to the sheets in which the points fall, and the pages on which the computations will be found. In the case of intersected points falling in a chart, but fixed wholly or partly by rays from stations outside, it will be sufficient to quote on the index, the charts and volumes in which the stations fall, which were used for fixing the position and height of the point. This will avoid much copying out of computation from adjoining volumes. Such an index, which is really an abstract, is always necessary for reference in a party, and it should be made out, and the co-ordinates filled in, as soon as the computations are completed, the pages being subsequently entered when the computations are bound up.

The introduction should give a full account of whatever may be necessary to enable the contents of the volumes to be readily understood. It should quote the fundamental elements on which the triangulation was based, specifying whence they were obtained, and whether from final or preliminary data of the Great Trigonometrical Survey, whether traversing has been added to the triangulation, and rectangular co-ordinates employed as well as spherical; in which case it should give the latitude and longitude of the adopted origin; also full information regarding any spirit-levelling which is incorporated with the operations.

It should also give a sufficient description of the physical geography of the country comprised within the area, stating whether it is level or hilly, smooth or rugged, open or forest-clad, in order to explain any peculiarities of the triangulation, and it should add any information which is likely to be serviceable to surveyors who may have occasion hereafter to visit the country, in order to re-survey any portion of it on a larger scale, as may occasionally be necessary for special purposes. Finally it should state the names of the persons by whom the work, within the area dealt with, has been chiefly performed.

The descriptions of the general construction of the stations, and of the signals at unvisited points, are intended to obviate the necessity of frequently repeating these details in the descriptions of the stations and points. A description of each class of structure should be given here, and numbered for reference.

When original triangulation computations have been bound in General Report volumes and their receipt acknowledged by the Calcutta Office, all duplicate copies of such computations may be destroyed. C. O. No. 109 (Prof.), dated 13th February 1904.

The above is the type of General Report which every officer should do his best to imitate, and, as far as possible, he should strictly comform to the above orders. In those cases where, owing to the scattered nature of the work or other reasons, it may become impracticable to wait until the whole area is completed, the volumes may, with the sanction of the administrative officer, be bound up and sent to the Calcutta Offices for record.

A small index map of the Province shewing the area to which the computations refer, coloured in red, should be pasted inside the cover of each volume, whilst an outside label should give the name of the Province, and standard sheet numbers.

Chapter III.*

Traversing and its Computation.

Considerations which render traverses necessary.

60. In a topographical party traverses are required for either or both of two reasons: (*a*) to provide mathematical data for the identification of boundaries, or (*b*) to provide points for the plane-tablers in flat forest tracts, where triangulation is impossible. The officer in charge should, in consultation with his administrative superior, decide when it is necessary to run traverses for the first of these purposes; but if it is settled that mathematical data for boundaries are unnecessary, traverses will be required only in country where frequent plane-table fixings by interpolation are impracticable. They should be considered a necessary evil rather than a regular means of supplementing inferior triangulation.

In tracts where a Revenue survey is being supplemented by a topographical survey, a great many traverse stations, such as village trijunctions will be found on the ground. These stations being generally connected with trigonometrical points, should be utilised as far as possible.

Brief description.

C. O. No. 113 (Prof.), dated 27th April 1904.

61. A traverse must start either from a triangulated point or from another traverse. As he proceeds from point to point, the traverser measures the distances by means of a chain or subtense bar, and the angles between the lines joining his stations by means of a theodolite. Generally speaking he should measure also the vertical angles between stations to provide data for computing their heights, as this information will be most valuable, except when the country traversed is almost flat. Errors in the angular measures tend to accumulate, and divert the traverse from its true direction, and to prevent this it is necessary to observe an azimuth by the sun or stars whenever a traverse includes a large number of stations. Errors in the linear measurements are inevitable and can only be kept within reasonable limits by the use of many precautions.

Angular measures.

62. (*a*)—Having carefully levelled and centred the theodolite over the mark, *the back station* is intersected using either tangent screw after both plates have been clamped, particular care being taken to clamp the lower plate

* This chapter embodies Captain Fraser's "Notes on traversing as practised in topographical parties," which are now out of print.

firmly: the horizontal and vertical readings are then taken and entered in the field book.

(*b*)—The upper plate is then released and the forward station intersected using the upper tangent screw, and the horizontal and vertical readings are again recorded.

(*c*)—Keeping the upper plate clamped, the lower plate is released, and the instrument turned again to *the back station,* intersecting by the *lower* tangent screw. As the reading of the arc is obviously not altered by so doing, it need not be read or recorded again, though it is advisable to glance at the vernier to see that no change has taken place.

(*d*)—Next release the upper plate, and, having again intersected the *forward* station with the upper tangent screw, record the third reading.*

(*e*)—Then by subtracting the first from the second reading, we get one measure of that angle which lies to the left of the observer when facing his forward station, and similarly, taking the second from the third, we get another independent measure of the same angle, from a different portion of the arc. These angles are taken out immediately after recording the third reading, and entered on the right hand side of the field book: if they do not agree within *1′ of arc,* a third independent measure is taken in a similar way, and entered above the others (*vide* specimen field book at the end of this chapter, ⊙ 2).

Remarks on angular measures.

63. The plates need not be set to any particular zero, either when starting work or at any other time. The theodolite compass is never required.

The back station must be intersected first, otherwise the supplement of the angle, described in paragraph (*e*) above, will be measured, and this being unnoted and unknown to the computer, the traverse will not prove. This mistake is not likely to occur if traversers are shown that there is a reason for first intersecting the back station

The vertical readings need not ordinarily be taken a second time.

The time occupied in taking the second measure is very small as compared with the total time required to centre and level the instrument, and if the above method be strictly carried out, it is quite impossible for any gross error to creep into the angular measurements: if therefore the angles do not prove, it can only be due to gross negligence on the part of the traverser.

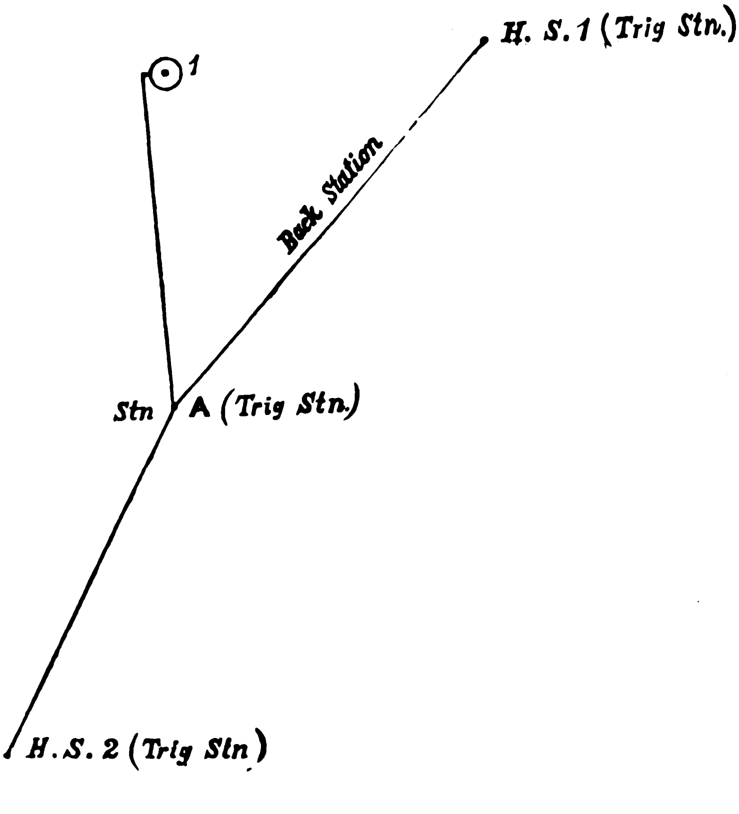
The instrument must be carefully centred over the station mark, an operation which is much facilitated by using the railway pattern of theodolite stand, which allows the whole instrument to be shifted

* In Revenue parties, instead of taking the third reading, the "supplement" angle is recorded. This takes a little longer, but it has the advantage of allowing the traverse to be "set up" from either end, and as a check, affords an absolutely independent reading of the angle being dealt with.

laterally on its stand, after the latter has been roughly centred and its legs firmly embedded in the ground. Also the staff must be accurately placed over the forward station or peg.

An error of 1 inch in the centering of the theodolite or the intersection of the mark will produce an angular error of nearly 5′ at a distance of one chain : consequently the smaller the distance between stations, the greater is the necessity for care both in centreing the instrument and staff, and also in making the intersection of the latter. When therefore the distant peg cannot be seen, the staff (of which a description is given later) must be held in a vertical position, and *the lowest visible portion of it* should be intersected.

At the first station of a traverse, there are usually three rays to be observed, *viz.*, the forward ray to ⊙ 1, and rays to two (or more) triangulated stations. In this case, *the back station* is that one nearest in angular distance, in the direction taken by the hands of a watch, to the forward station, as shown in the annexed diagram, where A is the starting point of the traverse, and H. S. 1, H. S. 2 are two of the triangulated points with which the traverse is connected.



When taking combined horizontal and vertical readings the proper order of procedure is as follows :—

(1)—Swing the instrument till the *bottom* of the staff is seen near the intersection of the cross webs in the telescope, and clamp the horizontal arc.

(2)—Intersect the peg or *lowest* visible portion of the staff with the middle portion of the vertical web by means of the slow motion screw on the horizontal plate.

(3)—Clamp the vertical circle and intersect the vane at the desired point with the horizontal web by turning the slow motion screw on the vertical arc.

With a good instrument this double clamping saves time and does not impair the accuracy of the results, but the observations may be taken in two parts if desired.

Linear measures.

64. Distances between stations are measured either directly, with a chain, or indirectly, by means of a sub-tense bar or a subsidiary triangle.

The first method is that most commonly used, and except in very bad ground gives better results than either of the others. Each traverser should be supplied with one chain 100 feet long, one chain 66 feet long, and one steel tape 100 feet long. The latter is to be used as the standard for checking the chains and *for this purpose only.* Two men are required for each chain, and the long chain should precede the shorter because it will go faster. The traverser will *accompany* the short chain (keeping his eye on the line taken by the long chain to prevent deviation), in terms of which all intermediate measures and off-sets are to be recorded in the field book. On arriving at the forward station the traverser first records the total distance in terms of the short chain, and on the line above, the distance given by the men with the long chain. Before doing anything else he reduces the measurements obtained in feet by the long chain to links (in pencil in the margin of his book) either by the use of tables, given at the end of this chapter, or by the rule of thumb method shown below—

First Example—

12·72 = recorded long chain measure.
6·36

19·08 (obtained by adding half).
·19 (Add the first two figures of the third line removed two places to the right.)

19·27 = reduced measure in short chains.

Second Example—

3·41 = recorded long chain measure.
1·705

5·115
·051

5·166 = reduced measure in short chains.

Assuming the chains and chaining free from error, this result must correspond exactly with the recorded short chain measure. In practice, however, the two measures will rarely agree exactly, but provided the difference does not exceed *one link for every five short chains*, the measures may be accepted. Thus in a line of 19·27 short chains, the long chain measurement would be accepted as correct if, when reduced, it come between 19·23 and 19·31. The maximum discrepancy should not exceed 12 links for any length of line. Whenever a larger difference occurs, the whole line must at once be remeasured by *both* chain squads the new measures being recorded above the old ones, which are then crossed out, and initialled.

The practice in Revenue parties is to allow a discrepancy of only one link in every ten short chains, but such accuracy is attainable only in very favourable country. However, the limits allowed in the last paragraph are ample, and if frequently exceeded by a careful worker, it is an indication that the subtense bar method should be given a trial.

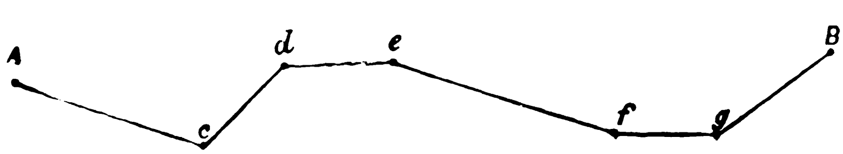
Remarks on chaining.

65. The most reliable men should be told off to the long chain, partly because they have to work independently in advance of the traverser, but chiefly because the distances used in the computations are *those derived from the long chain*. One of the chief sources of error lies in the pitching of the arrows, so that *cæteris paribus* the long chain must give more accurate results than the other. Thus the short chain should be considered merely as a check to prevent gross errors and the mean of the two results should never be used in computing. At first, no doubt, time will be lost in remeasuring lines, but after sending the men back a few times, they will become more careful, and the work will proceed as rapidly as if measured by a single chain only. This method of chaining requires more men than for a single chain and is therefore more expensive, but if conscientiously carried out gross errors are almost impossible.

The traverser must be informed that he, and not his chainmen, is directly responsible for the accuracy of the linear measurements, within the limits laid down.

On sloping ground all chain measurements have to be reduced to their horizontal equivalents. The correction applied depends on the vertical angle recorded and is taken from a table of corrections when the traverse is being computed.

In rough country cases like the following are not uncommon :—



A and B are adjoining stations of a traverse; the ground between them, though perfectly chainable, is uneven, so that the chained distance will not even approximately give the required distance A B.

This is merely a case of roughly obtaining the angle of the intervening slopes Ac, cd, ef, and gB, and showing the situation intelligibly in the field book by a diagram, *vide* specimen Field Book, stations 4 to 5. Taking the intermediate slopes by means of the theodolite, even roughly, will entail considerable loss of time and if such cases are likely to prove of frequent occurrence it would be well to provide the traverser with a simple hand clinometer for reading the slopes.

Checking chains.

66. The hard work to which they are put, soon causes chains to stretch or even break, so that when serving out old chains, the camp officer should not only adjust their length accurately, but must see that the 10 link metal tabs are attached at correct intervals, otherwise the terminal measures to stations will be incorrect, and proper agreement between the two chains will be impossible.

When in use, both chains must be checked *every day*, and their lengths recorded in the space provided for this purpose in the field book fly-leaf (*vide* specimen). Should the error of either chain exceed half an inch, it must be corrected by removing a short link* before commencing work. In this case the corrected length only is entered with the letter C affixed (*vide* specimen).

The best thing for checking the length of a chain is a steel tape but they are expensive and liable to rust and break unless carefully handled, so that it may be necessary on the score of economy to use a standard chain instead. But as the standard is itself liable to stretch, it will be necessary to provide each traverser with two standards, one of which will be sent in at stated intervals to the camp officer for adjustment, whilst the other is required for use.

Measuring by subsidiary triangles.

67. Occasionally an obstacle will prevent any kind of chaining between stations, and the traverser, if not provided with a subtense bar, may avoid the difficulty by laying out a base of suitable length on any level or evenly sloping piece of ground. One end of the base will coincide with the traverse station and its direction should be, as nearly as possible, perpendicular to the line whose measure is required.

In addition to making accurate measurements of the base itself, a satisfactory result can only be obtained if the following conditions are satisfied :—

(*a*) All three angles of the triangle must be measured.

* A pair of strong pliers is the most convenient tool for removing a link.

(*b*) The vertical angles along each side of the triangle must be recorded.

(*c*) The sum of the angles at each end of the base must not exceed 170°.

If however the ground does not permit of the third condition being satisfied, it becomes necessary to measure the angles of the triangle with great accuracy. and the traverser must then read all the horizontal verniers, and observe each angle on both faces as if he were doing triangulation proper. At the same time it is well to remember that if the triangle contains an angle of less than 5°, no amount of care will render the resulting measure a really reliable one.

Measurement of distances by bar-subtense method.

68. An admirable method of measuring the distances between traverse stations, especially if very far apart and separated by inaccessible or rugged ground, is that known in the Department as the "bar-subtense method" due to Colonel Tanner. In special cases the advantages of this system are incalculable, but it should not ordinarily be resorted to in open and level country, where the distances are short, as under such circumstances it cannot compete with the chain in accuracy. The principle of it is to measure, by a system of repetition on the horizontal circle of a theodolite, the angle subtended by a bar of known length placed horizontally and at right angles to the ray of which the length is required.

This method may also be used with advantage in dense jungle, where the undergrowth is a serious obstacle to dragging a chain, and where the distances between stations rarely exceed 5 chains. Satisfactory results have been obtained in the Burma Forests using a special subtense bar, in which the distances between discs were 5 feet and 3 feet respectively, and the number of repetitions of each angle ten. Up to 10 chains, 10 repetitions suffice; between 10 and 20 chains, 20 repetitions are necessary, and beyond 20 chains, the results are unreliable.

Description of subtense bar.

69. The new pattern bar is of teak and its total length is 11 feet. The vanes or discs are 8½ inches in diameter; they are painted red on one side and white on the other, in each case with a 3 inch black centre. They can be placed either 10 feet apart with their red faces showing or 8 feet apart with their white faces showing, but the fittings are such that other positions are not possible, so that the colour seen is a certain indication of the space observed. Attached to the bar is a sight rule (S S in the figure at end of chapter), which when clamped in position is perpendicular to its length.

The bar is mounted on an ordinary plane-table stand by a cup and ball socket, which allows 5° of play without shifting the legs. It is roughly levelled by eye, and finally adjusted by means of the thumb screws t, t, and the small level l let into its upper surface. When properly aligned and levelled, it is clamped in position by a bolt passing through the cup and tripod head.*

Method of using the subtense bar.

70. It has been found in practice that economy of time is effected by separating the angular measures of the traverse lines from the measures of the subtense bar, as their combination would involve carefully plumbing the bar over the station peg, whereas for the purposes of linear measurement it suffices to make this adjustment within one or two inches. The procedure is therefore as follows:—

(*a*) The surveyor, after finishing his operations at any station, removes his theodolite and *himself* erects the subtense bar, plumbing it approximately over the peg. He then aligns the sight rule on his forward station, levels the bar, and clamps it in position.

(*b*) On reaching the forward station, he erects his theodolite and takes the necessary observations to the subtense bar, the discs being 10 feet apart.

(*c*) He then signals to the *khalási* at the back station, who reverses the discs, and a fresh set of readings are taken at the 8 feet distance.

(*d*) After finishing with the bar he signals again: the bar is then removed and brought forward to him, whilst another *khalási* with the traverse staff takes his stand over the mark, and the surveyor completes the ordinary angular measures.

Method of measuring the subtended angle.

71. It is necessary to distinguish the right and left discs from one another when observing and this may be done by drilling the *khalási* at the bar to stand always immediately behind the left hand disc; but a better plan is to paint cross lines on both faces of this disc.

The operation involves the successive movement, by means of the tangent screws of alternate plates of the horizontal limb of the theodolite, and as it is important that it be completed without reaching the end of the run of either, each tangent screw should be set back to the commencement of its run before making an intersection. The lower plate is then clamped, and the disc at the left hand end of the bar is intersected by moving the upper plate, clamping and finishing the intersection with the tangent-screw. The limb is then read off and recorded, all the verniers being entered in the record. Now, by means

* In practice, it has been found that *tindals* are quite capable of levelling the bars by means of the level alone without using the thumb screws.

of the upper plate tangent-screw only, intersect the disc at the right end of the bar, and read off one vernier to give an approximate value of the subtended angle, which will be found useful as a check against gross errors. Next, with the lower plate tangent-screw, bring the telescope back and intersect the left disc, then with the upper plate screw intersect the right disc again, and repeat the process as often as necessary, keeping count of the number of repetitions, and finishing on the right disc. Finally read and record all the verniers, and divide the difference of the means of the first and last readings by the number of repetitions. This gives the value of the subtended angle, and a comparison with the approximate value obtained as explained above, will guard against gross errors, or against a wrong reckoning of the number of repetitions made.

With traversers there is always the possibility that the man may make only one measure of the angle and multiply this by ten to save himself trouble. It is largely to guard against this tendency that the observations are repeated with discs reversed at a different interval, and in addition, the agreement of the distances computed from the two positions will prevent gross errors and give a certain indication of the quality of the work.

If so many measures are made that the tangent-screws have not sufficient play to include them all, they must be unscrewed again, care being taken that the *lower* one is unscrewed while the *upper* plate remains clamped, and the *upper* one while the *lower* plate remains clamped. As however this is apt to introduce errors unless great care is taken, it is better when more than five repetitions are required, to arrive at the result by taking the desired number in groups of five, and to treat each group independently whilst observing.

The advantages of this system of repetition over a similar number of separate measures of the subtended angle, are that the error of reading the limb, which may, in a 6-inch theodolite, amount to as much as 10″, enters in the repetition system twice into each group of measures, whereas with separate measures the error occurs twice in each measure. The system is also very much quicker.

Computation of the distance.

72. Having thus obtained the value of the subtended angle, the distance corresponding may be either taken from a table * previously prepared, or computed on the spot by a table of natural cotangents, or a special scale may be prepared from which the distance may be taken off with dividers at once. The true distance in feet, or *d*, is $\frac{l}{2}\cot\frac{s}{2}$, where *l* is the length between the centres of the discs in feet

* Tables of distances corresponding to the angles subtended by 20, 10, 8, 5, and 3 feet bars have been prepared and can be obtained from the Surveyor General's Office, Calcutta.

and s is the subtended angle; but the formula $d = l \cot s$ is quite accurate enough and more convenient. The approximate formula $d = \frac{l}{s \sin 1''}$ is also practically accurate within the limits of observation and is the most convenient of all, as $\frac{l}{\sin 1''}$ may be taken as a constant, and then division by s in seconds is all that is necessary to give the distance without the aid of logarithms.* Thus if $l = 10$, $\frac{l}{\sin 1''} = 2062648$. Suppose the subtended angle is 20′ then $d = \frac{2062648}{20 \times 60} = 1{,}719$ feet.

Construction of a scale for laying off the distance

73. A scale from which the distance may be taken off directly with dividers may be thus constructed. Draw an indefinite straight line as base, and from one extremity set up the following distances in inches, 1·15, 1·19, 1·23, 1·27, 1·32, etc., up to 11·46, these being the natural cotangents to radius ·01 of the subtended angles 30′, 29′, 28′, etc., up to 3′, beyond which it is unnecessary to carry it. At the point 11·46 raise a perpendicular equal in length to $\frac{10 \times \cot 3'}{5280} = 2{\cdot}17$ inches and join the extremity of this perpendicular to the other end of the base, thus forming the hypothenuse of a right-angled triangle. Through all the points of division of the base, draw perpendiculars terminating in the hypothenuse; these perpendiculars represent the distances corresponding to the respective subtended angles. These dimensions are for the scale of one inch to a mile, but the principle is applicable, *mutatis mutandis,* to all scales.

Error caused by wrong alignment of the bar.

74. It is worth noticing that the error arising from a slight misdirection of the bar is much less than would at first sight be supposed. For if θ be the excess or defect from 90° of the bar's direction with the ray under measurement, the subtense angle measured becomes $l \cos \theta$ instead of l, and the resulting error in the distance is,

$$l \cot s - l \cos \theta \cot s = l \cot s \times \text{vers}\ \theta.$$

Now versine θ is about ·0001, for $\theta = 35'$, and therefore so long as the error in pointing does not exceed 35′—an almost impossible quantity, unless the bar be purposely misdirected—the error in measurement will not amount to $\frac{1}{10,000}$ part of the whole length, or about $\frac{1}{2}$ foot in a mile.

General remarks on subtense bar.

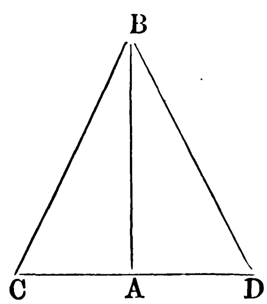
75. The number of repetitions of the subtended angle should clearly bear some relation to the size of that angle. The following table represents the

* The error introduced by using this approximate formula is less than $\frac{1}{10}$ of an inch per mile.

most recent practice in the Revenue branch, and will be found a useful guide.

Angle subtended by 10-foot bar.	Corresponding distance in chains.	Number of repetitions to be made.	
		10-foot bar.	8-foot bar.
52′ and over . .	0 to 10 . .	5	5
52′ to 35′ . .	10 to 15 . .	10	5
35′ to 26′ . .	15 to 20 . .	15	5
26′ to 17′ . .	20 to 30 . .	20	5
Under 17′ . .	Over 30 . .	Observe on double base.	

The figure below will show what is meant by observing on a double base



A B is the traverse line over 30 chains long whose length is required. Lay out, approximately at right angles, the bases A C and A D of suitable length, and measure them with the subtense bar placed at C and D. Then measure all the interior angles of the two triangles A B C and A B D and the distance A B can be computed.

The theodolite used for subtense work should preferably read to 10″; instruments of which the slow motion screws have a short run are not suitable for this kind of work.

It should be noted that a difference of level between the observer and the bar does not prejudice the deduced distance, since the fact of the theodolite, measuring angles on the plane of the horizon, makes automatically the necessary correction from the hypothenuse of the slope to its base. Thus the computed distances are horizontal distances, and must not be corrected for the slope of the ground. In setting up the traverse, the distances computed from the 10 feet interval will be used exclusively, as those from the shorter interval are obviously less reliable and are used merely as a check.

76. Allusion has already been made to the necessity (in all but flat countries) of measuring the vertical angles between stations. Besides giving data for the reduction of the chain measures to their horizontal equivalents, the heights of each traverse station may be obtained and used for contouring the ground.

Vertical angles.

To obtain a correct vertical reading three conditions must be satisfied—

First.—The instrument must be level, and the bubble of the level attached to the vertical verniers must occupy the centre of its run.

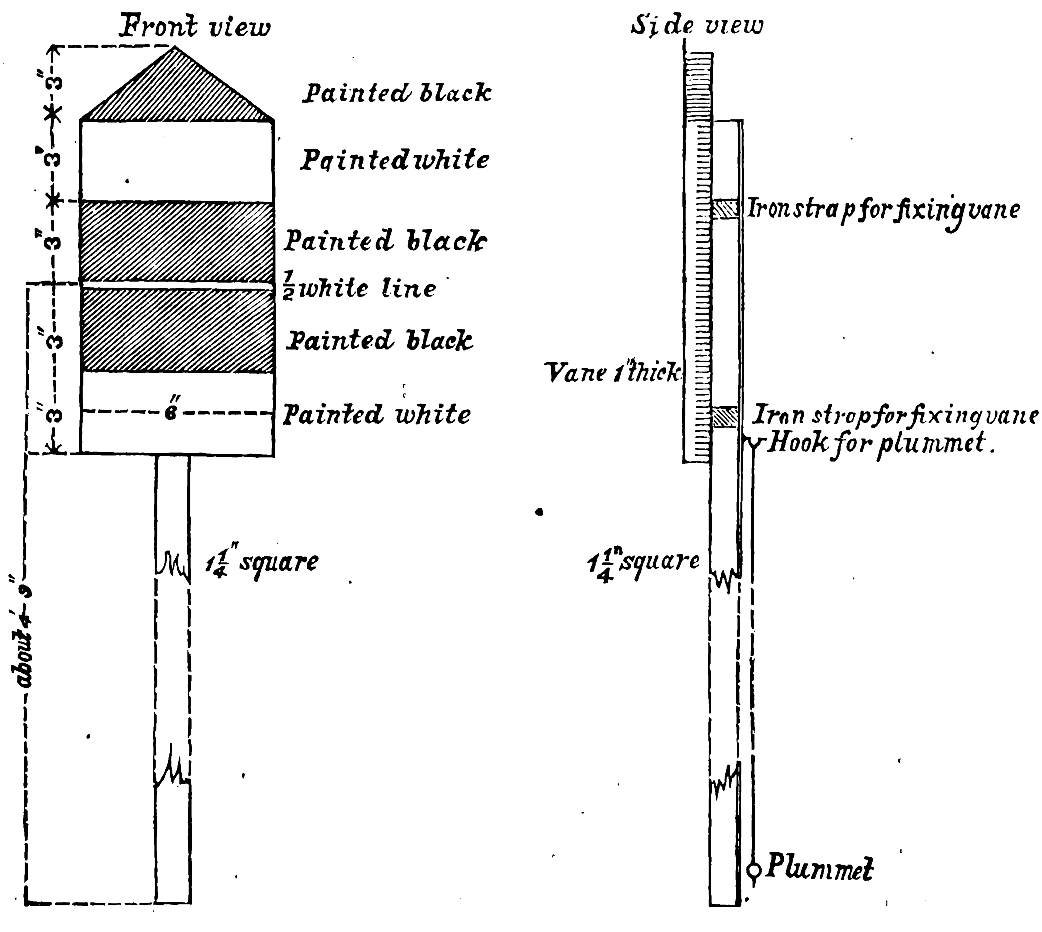
Second.—The line observed must be parallel to the line joining the station pegs.

Third.—The vertical collimation error of the instrument must be eliminated.

77. To satisfy the second condition the point observed to must be at a height above the peg equal to that of the telescope above the station mark.

The traverse staff.

This result can be attained by using the traverse staff, of which a dimensioned drawing is herewith given—



The staff should be painted white with a ½-inch black line running down the centre. A tapering iron spike should be accurately fixed to the bottom of the staff, and when possible, observations should be made to its finest visible point, and surveyors should be warned never to observe to anything except this point in short lines.

Each traverser should be supplied with 3 staves—one forward, one back, and one for the end of his base line when measurements by means of triangulation are necessary. At the commencement of the season, the traverser sets up his theodolite on level ground at a convenient working height to suit his stature, then measures the height of the telescope from the ground and adjusts the centre line on the vane to measure this height from the foot of the staff, either by altering the screws or by cutting a bit off the bottom. All his vanes must of course be similarly adjusted and he should then mark his name on them. He will then measure, by means of a spare plummet line, the height from the ground to the plummet hook of the theodolite, and make a large knot in the string to indicate this length, which may be called the "normal length."

Now suppose the instrument set up and level over the first station of a traverse and the forward staff in position over station 2, then, before making an intersection, measure with the spare plummet string the height from the station mark to the plummet hook of the instrument. The height so found must be either (1) x inches greater, (2) y inches less, or (3) exactly equal to the "normal length."

Then, in order to satisfy the second condition above laid down, obviously the vane must be intersected in the first case, x inches *above* the centre line, in the second case y inches *below* that line, and in the third case *on* that line.

The distance x or y on the string, above or below the knot, can be readily estimated by eye, or if preferred can be measured along a scale of inches cut on the legs of the theodolite: it is generally small and will rarely exceed 6″. The vane being printed in 3″ horizontal stripes of black and white, the intersection can always be made within an inch or less of the correct position by intersecting at a distance above or below the centre line of the vane equal to the distance indicated by the string, and this is sufficiently close for all practical purposes. Even in rough ground the vertical error will not exceed from one to two feet in a mile, provided the collimation error of the instrument is dealt with as described in the next paragraph.

Eliminating vertical collimation.

78. The error due to vertical collimation can only be eliminated by reversing face, and as this is not done when traversing, the instrument must be freed from this error by adjustment. Moreover, as the vertical reading is taken on one vernier only, it follows that the adjust-

ment for vertical collimation should be made with reference only to this vernier. After eliminating the vertical collimation error, it is immaterial whether observations are taken F. L. or F. R., but as the O. E. vernier on F. L. is the most convenient to read, and it is desirable that all observations should be taken under the same conditions, all traversers should be trained to *invariably work on F. L. with the object end vernier only.*

With regard to the error commonly known as vertical collimation error, it may here be noted that this error is really a combination of two errors, *viz.*, (1) the error due to the optical axis of the object glass passing above or below the horizontal web of the eye piece (*i.e.*, vertical collimation error proper), and (2) the index error of the vertical arc.

It is possible to eliminate each separately, but would serve no good purpose to do so, for as each error is alike in respect to its being eliminated by merely changing face, and they are, therefore, of the same nature, it is much simpler to consider one of them as being unadjustable, and to manipulate the other so that the sum of the two becomes *nil.* Practically the adjustment of the horizontal web should be considered fixed (though in some instruments means are provided for moving it), and the combined error is eliminated by adjusting the level attached to the vertical verniers, *vide* Appendix—(Memorandum on theodolites).

Errors permissible in vertical angles.

79. When the vertical collimation is *nil,* the forward and back vertical readings between each pair of stations should correspond in magnitude and differ only in sign. In practice there will generally be a difference in magnitude owing to the approximate methods used, but this is of no practical importance when within reasonable limits. When observing between two stations A and B, should the back vertical angle from B to A differ from the forward vertical angle from A to B (already recorded) by more than 5′, a second intersection must be made, and the reading entered in the book; if these two readings agree "*inter se,*" but differ largely from the angle recorded at the back station, the latter should be struck out and *the back station need not be revisited* (*vide* station 3, in Specimen Angle Book). In computing, the means of the observations recorded from A to B, and from B to A respectively should be employed.

Connecting traverses with triangulation.

80. It may sometimes happen that the triangulator has been able to lay out suitable traverse stations at intervals of a few miles, in which case the traverser's work is much simplified, but the fixing of many such stations undoubtedly retards the triangulator considerably; so that with experienced traversers, it is more economical to train each man to make his own starting and closing connections.

There are several methods of doing this, which will be described in order of preference—

(*a*)—*Interpolation from 3 or more triangulated points.*—When the triangulation is recent and the hill poles are standing the traverser selects a spot whence three or more well defined points are visible, erects his theodolite and observes a complete round of angles starting and closing with the *back* station. The last two rounds of angles should include his forward traverse station previously laid out.

Provided they are well fixed and defined, intersected points may be utilized for interpolation instead of, or in addition to, stations of observation.

This method is sufficiently accurate and is most expeditious and economical, but requires very careful supervision by the camp officer, who, on receipt of the field book, must see that suitable rays have been observed to admit of a satisfactory solution of the problem involved. This can readily be done by laying off the observed angles with the aid of a protractor on tracing paper, and so graphically determining the traverser's position on the chart. Should this position fall on or near to the circumference of the circle passing through the points observed to, one of these points must be visited by the traverser, and a round of angles observed.

(*b*)—*When only two triangulated stations are visible.*—In this case the starting or closing station of the traverse forms a single triangle when connected with the two visible points, and all three angles must be observed to prevent gross errors.

(*c*)—*When only one triangulated station is visible.*—The traverse may be closed or started by measuring a base line of suitable length and connecting each end of it with the triangulated point, provided that—

(1)—No angles of the triangle so formed shall be less than 10°.

(2)—All 3 angles of the triangle be observed.

(3) When observing at the triangulated point, another triangulated station or point be included in the round of angles to each end of the base, so that the bearing may be obtained from the triangulation. Failing this an astronomical azimuth must be observed.

A second or third trigonometrical point may often become visible by means of a moderate amount of line clearing; and this is greatly facilitated if the traverser, by keeping up his plane-table carefully, is able to determine from it, more or less correctly, the direction in which it is necessary to carry out the line clearing.

For all such work observations must be taken on *both faces*, and on one or more zeros according to the nature of the theodolite used. All the verniers both horizontal and vertical should be read, and the results recorded in a combined angle book (Form P. 40).

Starting or closing on an old traverse.

81. In order to properly identify the old mark, the adjoining stations on either side must be located. The distances to both must* be measured with both chains and a round of angles observed commencing and closing with the *back* station.

Field traverse chart.

82. To prevent confusion in the field and to facilitate the subsequent computation of the traverses it is always advisable to supply each traverser with a chart properly mounted on a plane-table. On it will be plotted all stations and properly fixed triangulated points, and all old traverses on which new work is to be based; the approximate directions of the new traverses required may also be shown with advantage when possible. In order to make proper use of the chart it is necessary to give every traverser a sufficient elementary training in the use of the plane-table to enable him to find his position on the board by interpolation and to plot his traverse work as he proceeds. In country covered with dense jungle, where traverses are numerous, this latter precaution is very necessary. In Burma it is the custom for each traverser to clear his own lines, and mark out the forest into blocks by means of traverses, and unless an accurate plane-table chart is kept up as the work proceeds, great confusion must ensue. This chart will be found most useful for finding the approximate latitudes and longitudes of the azimuth stations observed at.

Astronomical azimuths.

83. Whenever a traverse contains a large number of stations, astronomical azimuths must be observed at intervals so as to prevent an accumulation of angular errors. The interval between azimuth stations varies with local conditions, but as a rough guide they should average 25 to 30 stations apart: azimuths are only necessary where frequent connections with the triangulation are impracticable. Either the forward or back station must be used as the referring mark and observations may be taken to the stars or to the sun.

When stars are observed practically the only method used is that described on page 128, Chapter VI, which involves intersecting the star on the junction of the cross wires in the telescope. This method has the advantages of being accurate and of not needing the use of a watch, but it has a serious drawback, in the fact that it keeps the observer up after his day's work is done, and as his knowledge of stars is always limited, he will often have to do his azimuth work in the middle of the night in order to get those he knows. Consequently it is often preferable to observe to the sun and in so doing two methods are available.*

* In Revenue parties, stars are generally observed in preference to the sun.

The first consists in working by a similar method to that above alluded to, intersecting the sun's disc simultaneously on the horizontal and vertical wires. Supposing that the apparent upper and leading limbs were first observed on F. R. in the lower left quadrant formed by the cross wires, then before reversing face the apparent lower and following limbs will be observed in the upper right quadrant. Thus the mean of the two observations refers to the sun's centre at the junction of the cross wires and a similar pair of readings is then made on F. L. before again intersecting the R. M. The zero is then changed and another complete series of observations taken, the azimuths being computed independently so as to give a check on the work. This method is not capable of giving highly accurate results, because the eye cannot make simultaneous accurate intersections in different portions of the field of view. It is, however, amply good enough for traverse purposes, where a result accurate to one minute of arc is all that is aimed at. The sun's declination may sometimes be computed with sufficient accuracy by guessing the local time of the observation, but generally the time should be first computed from the vertical readings only. This method therefore also possesses the advantage of requiring no watch.

The second method consists in taking separate sets of observations, one of which will give the error of the watch used, whilst the other (when this error is known) will give the azimuth. The method of taking the time observation is described on page 125, Chapter VI, and the only point to note is, that the interval between the observations for time and azimuth must be short, for otherwise when a common watch is being used, the latter result may easily be vitiated by neglecting the rate of the watch, which may be large and will certainly be irregular. In the azimuth observation, the leading and following limbs of the sun are observed on the vertical wire only, and the time of each intersection noted. A similar pair of observations is then taken on the other face and the computation is done on Form P. 44B. This method will give accurate results, but it involves the use of a watch, and this adds to the expense of the traverser's equipment. As it also takes longer both to observe and to compute, it is less suitable for traverse purposes than the method first described.

Whether observations are taken to the sun or stars, it is necessary to test a traverser's capacity for azimuth work before sending him into the field. To obtain good results careful training and practice are equally necessary; two common sources of error are, (*a*) dislevelment of the body of the instrument, the error arising from which does not cancel out on changing face; and (*b*) looseness of the foot screws of the instrument.

When working to a pair of East and West stars, errors in the assumed latitude of the station of observation to a large extent cancel out in the mean result. But in the case of a single star, or of sun observations which are not thus balanced, the latitude must be known with considerable accuracy, and a well kept plane-table chart will be of much assistance.

Star charts in the Vernacular should be issued to all native traversers to enable them to identify the stars they observe.

84. A specimen field book on a reduced scale is shown at the end of this chapter from which the method of making entries may be seen. The following rules will be useful as a general guide :—

The field book.

(*a*)—All entries in the field book are to be made on the spot in ink or indelible pencil. A common lead pencil is on no account to be used.

(*b*)—No erasures whatever may be made in the field book. All figures corrected, or altered must be initialled.

(*c*)—*No second copy of the field book is to be made* for the sake of neatness, except by the special orders of the camp officer and the original will always be kept. Under exceptional circumstances the traverser might find himself forced to record in common pencil in order to avoid delay, in which case the record must not be touched afterwards in any way, a *copy* in ink being made as soon as possible.

(*d*)—Every traverse book will commence with a printed fly-leaf (*vide* specimen), and must be bound in brown paper to keep it clean. The traverser will himself fill in all items on this fly-leaf except the two at the top of the page.

(*e*)—As a general rule each traverse book will contain one traverse only, and should be despatched to the camp officer at once on the completion of the traverse.

(*f*)—On the first page a neat diagram must be made shewing the starting connection with the neighbouring triangulated points or traverses (*vide* specimen Field Book), and the mean values of the connecting angles entered as soon as they have been taken out. First draw the ray to the forward station up the centre of the paper, between the printed lines, and then holding the book so that this line points in its direction, draw rays, as nearly as possible as can be done by eye, in their actual position relatively to this line, to the different triangulated points and traverse stations with which it is intended to form a connection. Similarly a closing diagram must be made at the end of each traverse commencing with the back ray.

(*g*)—The cross lines above and below the chain measurements and the station number must not be omitted, as they greatly simplify the subsequent reading of the book by the computer (*vide* specimen).

(*h*)—A heavy line right across the page must be made at the conclusion of each day's work, and a new date entered above it when work is continued next day (*vide* specimen field book).

(*i*)—When recording the vertical readings, an arrow should be drawn as shown in the specimen, as this facilitates reading the book.

Checking the field book.

85. On receipt of the book, the camp officer should take the earliest possible opportunity to check the angles and measures throughout. If the two angular and linear measures at each station are in accordance, there can be very little doubt as to the subsequent closing of the traverse. Should this examination bring to light any gross error, the camp officer should order the traverser back to the station at which the error was discovered, where new measures must be taken. When examining the book, each figure must be ticked off in red ink, and all necessary corrections made and initialled in the same colour. The examiner will then sign and date the second entry on the fly-leaf "Field book checked by________"; the book should be rebound in brown paper if necessary, and the following notes made outside in red pencil:—

"Traverse No.______by R. F.________District________," with any remarks that may be necessary.

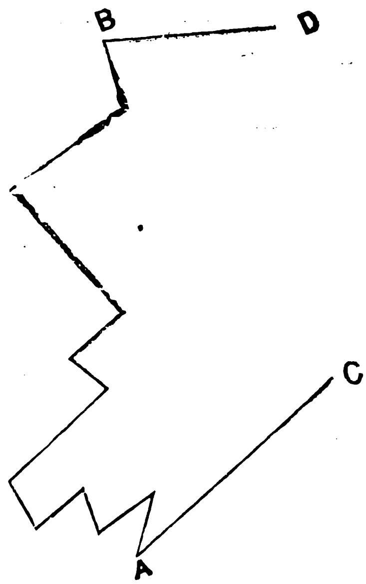
Marking of traverse stations.

86. *Every* traverse station must be marked as conspicuously as possible, for unless a plane-tabler can find two or more consecutive stations, he cannot properly identify his position or orientate his board. Every fifth station is usually distinguished by an extra large cairn of stones or by some special mark. When a peg is used as the station mark, a V shaped trench should be cut on either side of it, partly to indicate the exact position of the peg, and partly to show the directions of adjoining stations. In rocky ground when a ⊙ is used, the mark should be *cut* and not merely scratched on the surface, and if possible a small cairn of stones erected over it. Wherever forest pillars exist, stations should be selected as close as possible to them, and the actual position of the pillar recorded in the field book by an offset (*vide* specimen ⊙ 5). When pegs are used, they should be driven nearly flush with the ground, as both horizontal and vertical measures are referred to the top of the peg and not to the

ground itself. In Burma,* however, it is the custom to drive in stout posts to mark stations, and as the distances between them are short, it is necessary to drive a small iron pin into the top of each post, so as to define the point to which horizontal measures are taken. In this case, as the traverse staff is used only for vertical measures, it need not be provided with a plummet.

Computation of the data for starting and closing a traverse.

87. The procedure to be adopted will be best seen from the following example:—

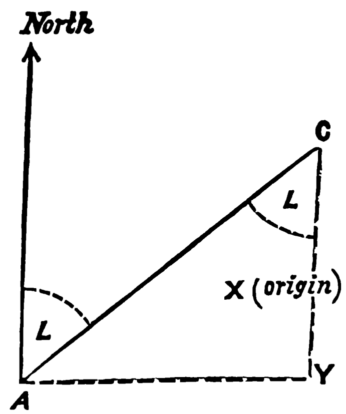


In the figure A and B are the starting and closing points respectively of a traverse, and A, B, C, and D are all points connected with the main triangulation. In order to compute the traverse, we require the rectangular co-ordinates of the points A and B, and the starting and closing bearings A C and B D respectively. If the triangulation data are in spherical co-ordinates, the rectangular co-ordinates of A and B with reference to the origin X (not shown in the diagram), are computed on Form P. 48. From the triangulation data, we can obtain either the azimuth of A to C, or of C to A, but probably not both. If the azimuth A to C is known, the bearing A C with reference to the origin X is found as follows:—compute the convergency at A with reference to the origin X by table XLIII of the Auxiliary Tables (*i.e.*, the convergency between the meridians passing through A and X respectively). Apply the angle so found with its proper sign ($\mp$ according as A is $\frac{E}{W}$ of X) to the azimuth of A to C, and the result is the bearing A C with reference to X.

* Sometimes numbered zinc tablets are affixed to three consecutive posts at intervals of about one mile, to assist in identification.

But if the azimuth C to A is known, the convergency at C with reference to X must be computed and applied to the azimuth to obtain the bearing C A, whence obviously the bearing A C = bearing C A $\pm$ 180°. (Note that if the distance A to C is sufficiently short, *i.e.*, does not exceed 1 mile for latitudes of 25° or less, we may consider the azimuth A to C = azimuth C to A $\pm$ 180°, with sufficient accuracy for traverse purposes where the bearing A C is required only to the nearest minute). The bearing B D is similarly found, and we then have all the required data for computing the traverse.

An alternative method of obtaining the bearing between any two points A and C whose spherical co-ordinates are known is given below and will often be found useful—



Compute the rectangular co-ordinates of A and C with reference to origin X on Form P. 48. Then C Y and A Y are the differences in Northing and Southing and in Easting and Westing between the two points. The bearing A C is the angle N A C = A C Y whose tangent is $\frac{AY}{CY}$, whence the bearing is at once obtained by a very simple computation.

Bearings and azimuths distinguished.

88. All traverses are computed from *bearings* and when the triangulation data are in spherical co-ordinates, the bearings are derived either from the azimuths taken from the triangulation, or from observed azimuths, by computing the convergency as above explained. But when the triangulation is computed in rectangular co-ordinates, we get from it *bearings* and not azimuths, and so avoid the above computation, except in the case of observed azimuths. In fact bearings may be said to have the same relation to azimuths, that rectangular co-ordinates have to spherical co-ordinates, *i.e.*, they refer to a local selected origin and not to a system of co-ordinates having the centre of the earth as its origin and applicable all over the world.

Selection of origin.

89. When the triangulation of the country, in which traverse operations are being carried on, has been computed in terms of rectangular co-ordi-

nates, all traverses will be referred to the origins used for the triangulation, which are usually at the centres of each or alternate square degrees. But if spherical co-ordinates have been adopted, we may either select an origin for the traverses centrally situated with regard to the area under survey, or we may consider the starting point of each traverse as its origin, and so have as many origins as there are traverses: the first alternative is the one usually chosen, as the second has obvious disadvantages except where traverses are of rare occurrence.

With regard to the area over which the system of rectangular co-ordinates can be applied with accuracy, Circular Order No. 113 (Professional), dated 3rd May 1904, should be consulted. The following paragraphs extracted therefrom give the conclusions arrived at:

"The result is therefore arrived at, that within these very wide limits, *viz.*, 3° on each side of the origin, traverses starting from origins 6 degrees apart and passing through the same point should give practically identical spherical co-ordinates for the position of that point. In practice however the values are seldom identical, the discrepancy being due to faulty measurements either angular or linear or both. The only remedy for this is frequent connection with well fixed trigonometrical points, and if there are not sufficient points available, supplementary triangulation must be carried out, or special main traverses must be run through the country starting from, and ending on points fixed by triangulation, and all other traverses should be based on these.

The fact that a traverse or circuit closes correctly on its starting point is no criterion of its accuracy, as its length may be quite erroneous.

It is not intended by the foregoing actually to advocate the extension of traverse work for 3° on each side of an origin: but to explain that rectangular co-ordinates can be safely used for such distances. As however the greater the distance, the greater the error likely to arise in the traverse, it may be laid down that, as a general rule, a traverse should not be carried more than about 1° on each side of the origin.

Within such limits, it is immaterial whether the bearing of one point from another is got directly from the rectangular co-ordinates, or by transferring these latter into spherical co-ordinates, computing the azimuth and applying the convergency: the results should be practically identical. If however two triangulated points fall in the neighbourhood of the traverse operations, their mutual azimuths should be referred to the traverse bearings in order to obtain a check on the accuracy of the latter.

The system formerly in use, of making the centre of each degree sheet the origin for that square degree is convenient for the purpose of tabulating the rectangular co-ordinates of corners of standard sheets, but has no other advantages. On the other hand, practically all revenue surveys are conducted district by district, and in many cases a district runs into three or more degree sheets. If the centre of each degree sheet were to be its origin, several origins would be required for the traverses of each district, and this would entail much additional computation when the traverses overstepped the graticule lines separating the different degrees. As no extra accuracy is gained by this constant shift of origin, it seems advisable to adhere to the system at present in use of taking a suitable one for each district or area to be surveyed near its centre, selecting for it the intersection of a meridian and parallel representing a round number of degrees and minutes."

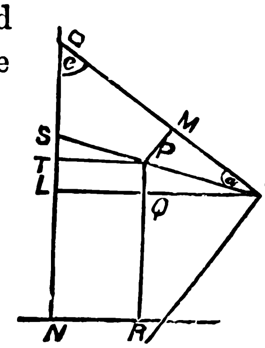
Projecting from different origins.

90. In projecting points near the margins of plane-table sections it frequently becomes necessary to plot them by co-ordinates from the origin of a neighbouring sheet, and not from that of the sheet in which they are situated. The formula by which this is done is as follows :—

Let O be the old origin, and N the new, and let the co-ordinates of O, with reference to N, be $\zeta = OL$, $\eta = NL$; and let c be the convergency of the meridians.

Let P be any other point whose co-ordinates require transformation.

Let the co-ordinates of P with respect to the origin O be



$X = PM$, $Y = OM$, and let PT and PR be drawn perpendiculars to the meridian and parallel at N.

Let PR cut OL in Q, and let $PQ = y$, $OQ = x$, and $OP = D$

Then if α is the angle POM

$$\tan \alpha = \frac{PM}{OM} = \frac{X}{Y}$$

$$\text{and } D = Y \sec \alpha$$

Now if A is the angle OSN, we have $A = \alpha + c$,

so that angle OPQ = angle OSN = A

Therefore $y = OP \text{ Cos } OPQ = D \text{ Cos } A$,

and $x = PQ \tan OPQ = y \tan A$,

or $= OP \sin OPQ = D \sin A$.

Finally

The perpendicular co-ordinate of P from $N = PT = OL - OQ$

$= \zeta - y \tan A$. or $\zeta - D \sin A$.

The meridional co-ordinate of P from $N = NT = NL + PQ = \eta + y$.

The above is a special case, but in Form P. 54(*a*), on which the computation should be carried out, provision has been made to meet every case.

The linear quantities in these equations must all be expressed in the same unit, but it is immaterial whether this be feet, links, yards, or any other unit. When a continuous traverse runs from one degree into another, the co-ordinates of its stations may be all computed from the origin of the degree in which it starts unless it encroaches far into a neighbouring degree, in which case the part falling into each of the degrees should be referred to the centre of that one as origin.

If however there are many points requiring conversion, it will be found much more simple to plot them graphically. To effect this, squares are ruled on a piece of tracing cloth and numbered with reference to the origin in terms of which the points are; the necessary points and spherical graticule of the adjoining plane-table are then plotted thereon. The tracing cloth is then laid on the new plane-table section, so that the common spherical graticule lines coincide, and the points are pricked off from the tracing paper to the plane-table section.

It may also sometimes be convenient to project outside the marginal graticule of a plane-table, squares in terms of a neighbouring origin.

Setting up traverses.

91. As far as possible all important traverses should be set up and computed in duplicate, in which case one copy will be worked with traverse tables, and the other by computing on Form P. 60, which need not be kept as a record. Checking computations, instead of working them in duplicate, is a makeshift which is only justifiable when dealing with minor traverses on which fresh work will not be based. All work on P. 47 (computations of the co-ordinates of traverse stations) is to be written at once in ink, except under the columns "Meridian" and "Perpendicular," which must necessarily be first entered up in pencil. The common practice of working in pencil, and subsequently inking up is bad from every point of view, and must be absolutely prohibited. The heading of Form P. 47 must always be fully filled in: after the words "Traverse Stations," enter the serial number of the traverse, the name of the traverser, and the district. The latitude and longitude of the origin, and the points of departure and closing must also be written clearly on the first page of each traverse. These entries are very generally omitted, and the omission causes much trouble whenever it is subsequently necessary to refer to the traverse computations for data.

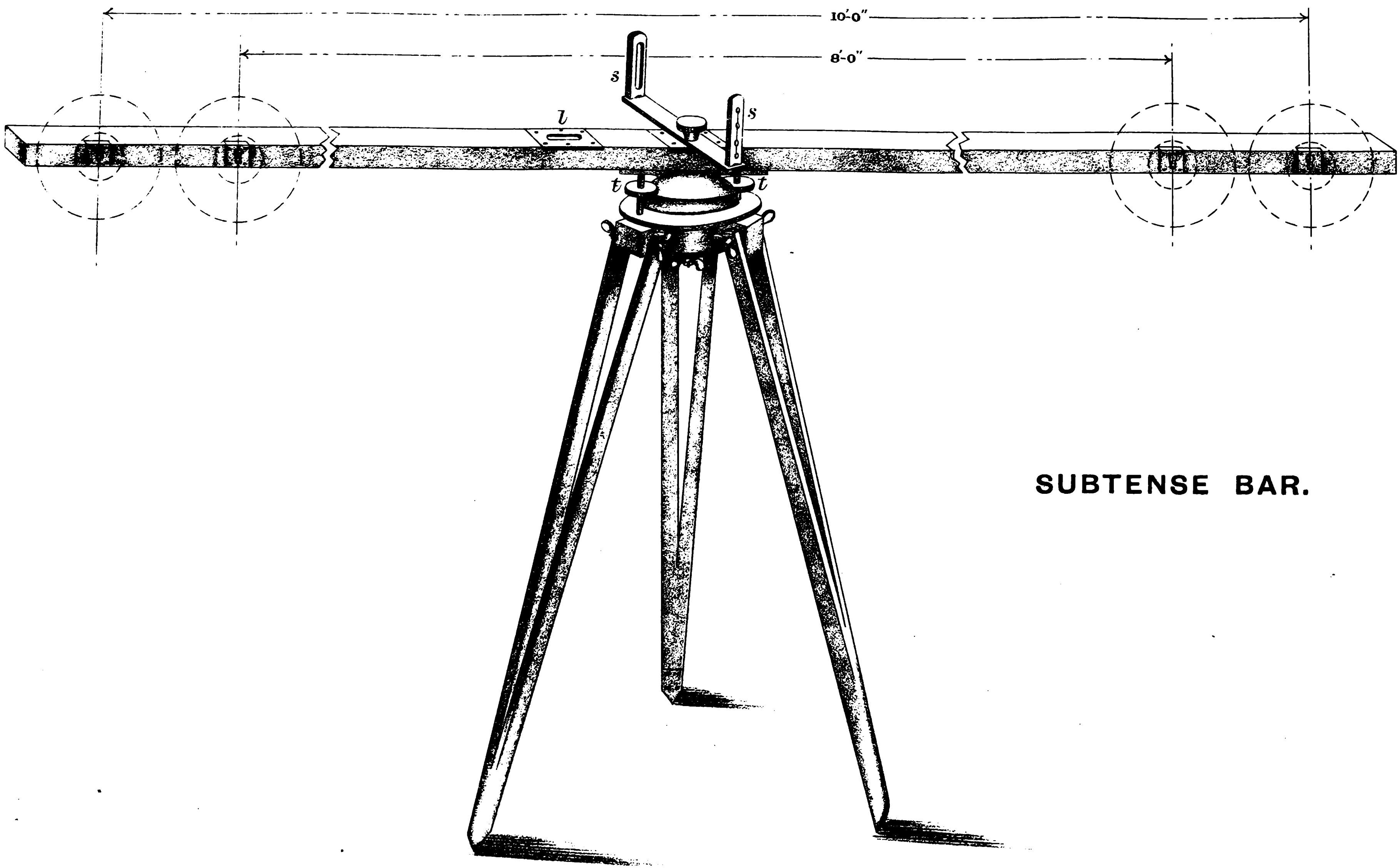
Special "Tables for Computing Traverse Heights" have been printed and may be obtained from the Superintendent, Trigonometrical Surveys, Dehra Dun.

In dealing with a large network of traverses, the adjustment of the errors at the junctions requires considerable care, and forms a complicated problem which must be dealt with by the officer in charge with the whole of the data before him. Very frequently, however, individual traverses have to be used before the whole network is complete, and its adjustment would then generally be abandoned unless of sufficient importance to justify the labour involves in re-computing the whole, or portion of the work.

Theodolites for traverse work.

92. When making over an instrument to a traverser, it is the duty of the camp officer to examine it carefully and see that it is in an easy running condition, that its stand is rigid, and that the three foot-screws do not shake in their bearings, a very common cause of error. The body level should be adjusted to the centre of its run, and the vertical collimation error very carefully eliminated. As soon as the traverser has taken over the instrument, he becomes personally responsible for it. Unless he has been specially trained to the work of cleaning instruments, he is on no account to take it to pieces should it show signs of working stiffly, but should send it at once to the camp officer for adjustment. He should entrust the carriage of the instrument, when at work, to the steadiest of his *khalásis*, and must use his discretion as to whether it should be carried on its tripod or in its box, being guided by the nature of the ground, and always remembering that *he* himself and not the *khalási*, is responsible for its safety. As a rule the best theodolite for traverse purposes is a 5-inch with incomplete vertical arc, and probably the best pattern is that made by Messrs. Cooke & Sons, whose instruments of this class are light, strong, capable of being rigidly clamped with ease and read to 30″. It is a great mistake to entrust the ordinary traverser with a 6″ or 7″ theodolite of high class, reading perhaps to 10″, except when distances are measured by the subtense bar.

The traverser is usually very careless and ignorant, and even were he not, the rough use to which a traverse theodolite is put in the field would very soon ruin a delicate instrument, and the heavier it is the more likely is it to suffer injury from constant portage. Attention may again be called to the immense advantage for traverse work of the railway pattern tripod, which can now be obtained on indent from the Mathematical Instrument Office.



SUBTENSE BAR.

Fly Leaf.

Serial Number

Field Book checked by . ...

on

Statement of Chain Measurements
at beginning of each day's work

Date	66′ chain	100′ chain	Remarks
21·9	66 · 0⅛ C	100 · 0¼ C	
22·9	66 · 0⅜	100 · 0⅜	
23·9	65 · 11⅞ C	100 · 0 · C	

Total Length of traverse .... chains + ... triangles

Theodolite No. 176 by Cooke

Name of point on which closed

Name of point from which commenced T. S. 7.

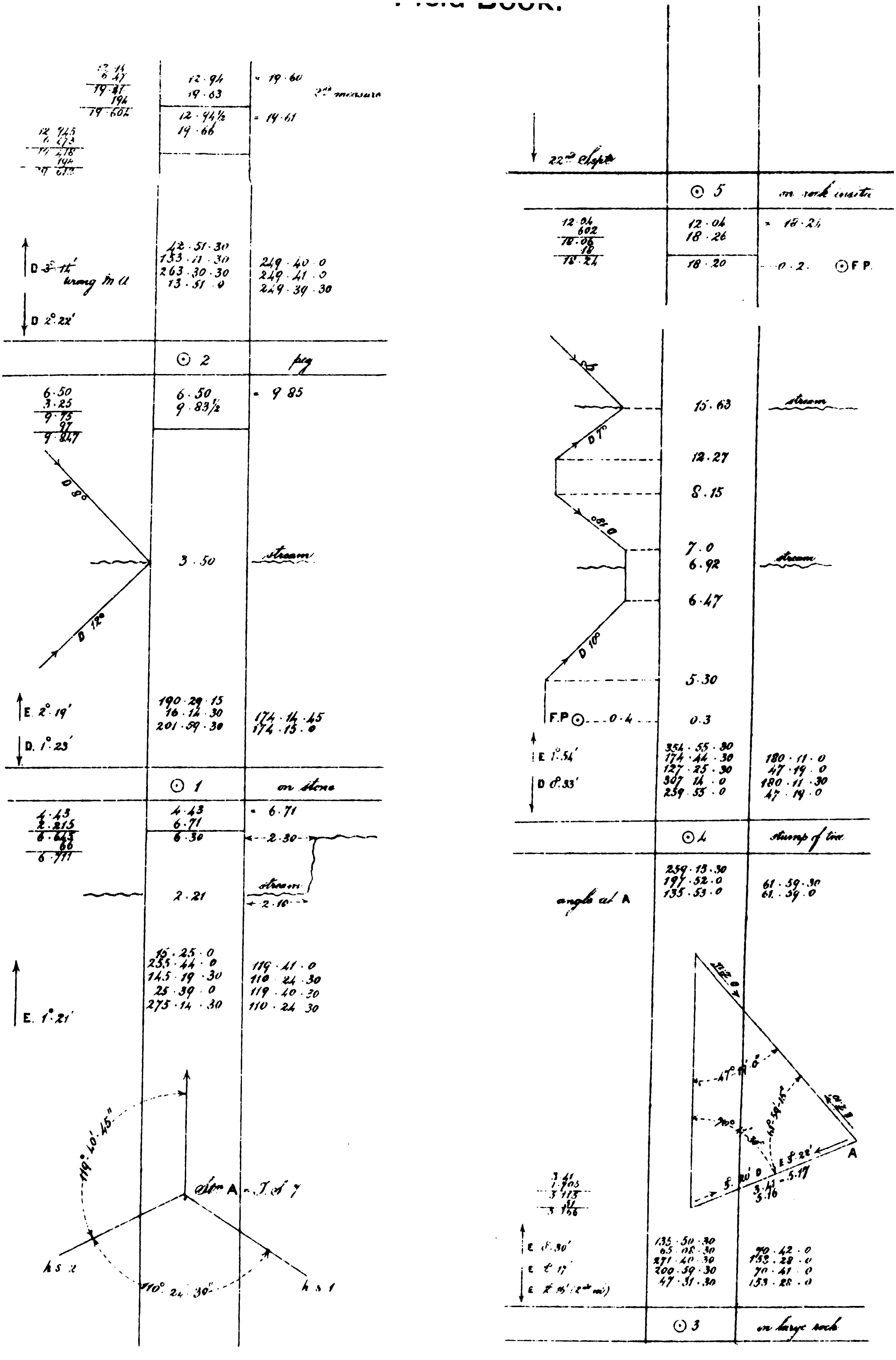
District Salem

Name of Reserve Gundakul R. F.

Finished

Commenced 21st Septr 1897

Traverse No. 3 by Mahomed Ali



2nd measure
D 2° 22′
wrong in A
⊙ 2
peg
6·50
9·83½
= 9·85
D 8°
3·50
stream
D 12°
190·29·15
16·14·30
201·59·30
174·14·45
174·15·0
E. 2° 19′
D. 1° 23′
⊙ 1
on stone
4·43
6·71
= 6·71
6·30
2·30
2·21
stream
2·10
15·25·0
235·44·0
145·19·30
25·39·0
275·14·30
119·41·0
110·24·30
119·40·30
110·24·30
E. 1° 21′
119° 40′ 45″
110° 24′ 30″
Stn A
h s 2
h s 1
22nd chain
⊙ 5
on rock
12·04
18·26
= 18·24
18·20
0·2
⊙ F P.
15·63
stream
D 7°
12·27
8·15
D 10°
7·0
6·92
6·47
D 10°
5·30
F.P ⊙
0·4
0·3
354·55·30
174·44·30
127·25·30
307·14·0
259·53·0
180·11·0
47·19·0
180·11·30
47·19·0
E 1° 54′
D 8° 33′
⊙ 4
stump of tree
259·13·30
197·52·0
135·53·0
61·59·30
61·59·0
angle at A
47·19·0
70°
61°59′15″
E 8° 22′
A
D
5·17
3·41
3·16
135·50·30
65·08·30
271·40·30
200·59·30
47·31·30
70·42·0
153·28·0
70·41·0
153·28·0
⊙ 3
on large rock

0 Chain.	1 Chain.	2 Chains.	3 Chains.	4 Chains.	5 Chains.	6 Chains.	7 Chains.	8 Chains.	9 Chains.	Links and Dec. of Links.
Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	
0	66	132	198	264	330	396	462	528	594	00·0
1	67	133	199	265	331	397	463	529	595	01·5
2	68	134	200	266	332	398	464	530	596	03·0
3	69	135	201	267	333	399	465	531	597	04·5
4	70	136	202	268	334	400	466	532	598	06·0
5	71	137	203	269	335	401	467	533	599	07·6
6	72	138	204	270	336	402	468	534	600	09·1
7	73	139	205	271	337	403	469	535	601	10·6
8	74	140	206	272	338	404	470	536	602	12·1
9	75	141	207	273	339	405	471	537	603	13·6
10	76	142	208	274	340	406	472	538	604	15·1
11	77	143	209	275	341	407	473	539	605	16·7
12	78	144	210	276	342	408	474	540	606	18·2
13	79	145	211	277	343	409	475	541	607	19·7
14	80	146	212	278	344	410	476	542	608	21·2
15	81	147	213	279	345	411	477	543	609	22·7
16	82	148	214	280	346	412	478	544	610	24·2
17	83	149	215	281	347	413	479	545	611	25·8
18	84	150	216	282	348	414	480	546	612	27·3
19	85	151	217	283	349	415	481	547	613	28·8
20	86	152	218	284	350	416	482	548	614	30·3
21	87	153	219	285	351	417	483	549	615	31·8
22	88	154	220	286	352	418	484	550	616	33·3
23	89	155	221	287	353	419	485	551	617	34·8
24	90	156	222	288	354	420	486	552	618	36·4
25	91	157	223	289	355	421	487	553	619	37·9
26	92	158	224	290	356	422	488	554	620	39·4
27	93	159	225	291	357	423	489	555	621	40·9
28	94	160	226	292	358	424	490	556	622	42·4
29	95	161	227	293	359	425	491	557	623	43·9
30	96	162	228	294	360	426	492	558	624	45·4
31	97	163	229	295	361	427	493	559	625	47·0
32	98	164	230	296	362	428	494	560	626	48·5
33	99	165	231	297	363	429	495	561	627	50·0
34	100	166	232	298	364	430	496	562	628	51·5
35	101	167	233	299	365	431	497	563	629	53·0
36	102	168	234	300	366	432	498	564	630	54·5
37	103	169	235	301	367	433	499	565	631	56·1
38	104	170	236	302	368	434	500	566	632	57·6
39	105	171	237	303	369	435	501	567	633	59·1
40	106	172	238	304	370	436	502	568	634	60·6
41	107	173	239	305	371	437	503	569	635	62·1
42	108	174	240	306	372	438	504	570	636	63·6
43	109	175	241	307	373	439	505	571	637	65·2
44	110	176	242	308	374	440	506	572	638	66·7
45	111	177	243	309	375	441	507	573	639	68·2
46	112	178	244	310	376	442	508	574	640	69·7
47	113	179	245	311	377	443	509	575	641	71·2
48	114	180	246	312	378	444	510	576	642	72·7
49	115	181	247	313	379	445	511	577	643	74·2
50	116	182	248	314	380	446	512	578	644	75·8
51	117	183	249	315	381	447	513	579	645	77·3
52	118	184	250	316	382	448	514	580	646	78·8
53	119	185	251	317	383	449	515	581	647	80·3
54	120	186	252	318	384	450	516	582	648	81·8
55	121	187	253	319	385	451	517	583	649	83·3
56	122	188	254	320	386	452	518	584	650	84·8
57	123	189	255	321	387	453	519	585	651	86·4
58	124	190	256	322	388	454	520	586	652	87·9
59	125	191	257	323	389	455	521	587	653	89·4
60	126	192	258	324	390	456	522	588	654	90·9
61	127	193	259	325	391	457	523	589	655	92·4
62	128	194	260	326	392	458	524	590	656	93·9
63	129	195	261	327	393	459	525	591	657	95·4
64	130	196	262	328	394	460	526	592	658	97·0
65	131	197	263	329	395	461	527	593	659	98·5
66	132	198	264	330	396	462	528	594	660	100·0

CONVERSION OF FEET INTO CHAINS.

The feet are given in the body of the table, their equivalent chains in the top and the links and decimals of links in the extreme right hand column. The decimal parts are taken out as whole numbers, removing the decimal point in the equivalent as many places as it is removed in the original.

Example: 416·9 feet to chains.
416 feet = 6 chains 30·2 lks.
·9 feet = 1·35 ,,

416·9 feet = 6 chains 31·55 lks.

CONVERSION TABLE.

100 ft. Long } *Chain to* { *66 ft. Short* } *Chain.*

Long chains and links.	Short chains and links.	Long chains and links.	Short chains and links.	Long chains and links.	Short chains and links.
					Ch. Lks.
1	1·52	34	51·51	67	1·02
2	3·03	35	53·03	68	1·03
3	4·55	36	54·54	69	1·05
4	6·06	37	56·06	70	1·06
5	7·58	38	57·57	71	1·08
6	9·09	39	59·09	72	1·09
7	10·61	40	60·60	73	1·11
8	12·12	41	62·12	74	1·12
9	13·64	42	63·63	75	1·14
10	15·15	43	65·15	76	1·15
11	16·67	44	66·66	77	1·17
12	18·18	45	68·18	78	1·18
13	19·70	46	69·69	79	1·20
14	21·21	47	71·21	80	1·21
15	22·73	48	72·72	81	1·23
16	24·24	49	74·24	82	1·24
17	25·76	50	75·75	83	1·26
18	27·27	51	77·27	84	1·27
19	28·79	52	78·78	85	1·29
20	30·30	53	80·30	86	1·30
21	31·82	54	81·81	87	1·32
22	33·33	55	83·33	88	1·33
23	34·85	56	84·84	89	1·35
24	36·36	57	86·36	90	1·36
25	37·88	58	87·87	91	1·38
26	39·39	59	89·39	92	1·39
27	40·91	60	90·90	93	1·41
28	42·42	61	92·42	94	1·42
29	43·94	62	93·93	95	1·44
30	45·45	63	95·45	96	1·45
31	46·97	64	96·96	97	1·47
32	48·48	65	98·48	98	1·48
33	50·00	66	100·00	99	1·50
				100	1·52

Chapter IV.

Plane-Tabling.

93. The detailed delineation of ground by topographical survey parties in India is effected almost exclusively by the use of the plane-table, an instrument which for this purpose far excels all others in convenience, accuracy, and rapidity, and one with which every surveyor should be thoroughly acquainted. It works to the greatest advantage in open and hilly country, and to the least in flat jungly tracts.

General remarks on the plane-table.

The plane-table and stand are so well known as to need no description, but there is a point about the sight-rule which should be noted. In the eye sight three or four small holes should be drilled at intervals along the fine cut which forms the sight, as it is very difficult to see objects through this cut. When the elevation or depression of an object to be intersected is more than can be embraced by the five inches of the sights, the intersection can be effected by stretching a thread tightly from the object-slit to the eye-slit on the top of the brass supports, and so contrived that it shall lie in the plane passing through the two slits. The eye slit and the thread of the object-sight must be in a plane perpendicular to the plane of the ruler. The edge of the ruler should be parallel to the junction of the plane of the ruler, and that of the eye-slit and thread of the object sight. This latter condition however is not absolutely necessary provided, the same sight-rule be used for the whole of the work on any one plane-table, and of that sight-rule, the same edge, either right or left, be invariably used for 'setting', and drawing rays. This practice will eliminate any error due to faulty construction of the instrument.

94. To "mount" a plane-table, a sheet of good drawing paper must be thoroughly wetted, care being taken that if wetted with a sponge, the surface should not be injured by too heavy rubbing. The sheet when thoroughly expanded, should be rolled up and laid aside till wanted, not being allowed to dry meanwhile. A piece of fine longcloth, large enough to overlap the board two or three inches all round, is next thoroughly washed free from dirt and starch, and while wet, laid flat on the board previously damped with the sponge. Very thin paste is then laid on the cloth and rubbed in, and the overlap secured under the board with strong paste. The paper, still damp, is now laid flat on the cloth, and

Mounting a plane-table.

pressed down (not rubbed), working from the centre outwards, and the edges secured with strong paste to the under surface of the board. The paper, when thus mounted, should not be allowed to dry too quickly. Care must be taken to mount the paper right side uppermost; this, in the case of drawing paper, can be known by looking through the paper for the "water mark". The side on which this reads correctly is the proper side of the paper to use.

When surveys are based principally on traverse data, hand-made paper, with 1, 1½, or 2½-inch squares printed in blue to facilitate the plotting of points, is generally used in the Department. Sheets of this paper mounted on cloth, can be obtained on indent from the Calcutta Office, the form number being P. 70. To mount one of these sheets, it is sufficient to slightly damp the cloth on the back, and lay it on the plane-table, and then paste the overlapping cloth under the edges of the board. The use of this paper enables all the points to be plotted, and checked in recess before taking the field, and in supplementary survey operations is invaluable.

Dimensions of plane-table sections.

95. Plane-table sections, or field sheets, on the scale of 1-inch to the mile, should occupy 15′ of latitude, and 15′ of longitude. The sections are then sub-divided into 5′ divisions, and the trigonometrical stations and points plotted thereon by co-ordinates, and tested by distances. For surveys on scales larger than 1-inch = 1 mile, the plane-table section should embrace a corresponding amount, proportional to the scale. Printed scales of latitude and longitude, suitable for all parts of India, can be obtained from the Calcutta Office on application, though it is frequently advantageous to draw the scales in the margin of a field sheet.

Definition of a "graticule," and determination of its position on a plane-table section.

96. A "graticule" is a four-sided figure contained by parallels of latitude, and meridians of longitude. The plane-table itself is considerably larger than the graticule to be plotted on it; this is necessary to enable the surveyor to plot a certain number of trigonometrical points outside his work, thereby ensuring greater accuracy of fixing towards the edges of the section; and the section or graticule should be so placed on the board as to include the most useful of these. The best way of doing this is to cut out a sheet of tracing paper of the exact size that the plane-table would be when reduced to the same scale as the reconnoissance chart of triangulation. This piece of paper is laid on the chart, and shifted about over the allotted section so as to embrace the best outside points,* the graticule is then outlined on the

* It is often extremely convenient to have one well-defined, very distant point, such as a sharp hill peak, to work with.

tracing paper in pencil. Measurements from the corners of this outline to the points where the lower parallel of latitude of the section produced cuts the edge of the board will now enable the surveyor to place this line in its proper position, and then by similar means, to find a point on it corresponding to the lower corners of the graticule. In placing the section on the board as described above, it is not at all necessary that its edges should be parallel to those of the table, but they should nowhere be so close as to leave less than 1½ inch margin.

Projection of a graticule.

97. Two modes of projecting the graticule of sheets are in use in the Survey Department. The first by means of the lengths of the sides and diagonals of certain geographical sections, as given in Auxiliary Tables XXXI and XXXII, which are for use when a survey is being carried out by triangulation, and the position of all points have been computed by spherical co-ordinates.

The second mode of projection is the more convenient when a survey is based on traverses, and when the positions of the stations are fixed by rectangular co-ordinates parallel, and perpendicular, to the meridian of origin. The latitude and longitude of the origin being known, Auxiliary Tables XXVI to XXVIII enable the rectangular co-ordinates of the corners of the graticule sheets to be computed and plotted. Table XLII, which gives the rectangular co-ordinates in chains of ⅛ degree squares referred to the centre of a degree as origin, will be found useful whenever the centre of a degree has been adopted as the origin of a survey whose operations are based on rectangular co-ordinates.

By spherical co-ordinates.—In this mode of projection the lower parallel of latitude is first laid off with beam compasses, and then, from either extremity, the distances on the meridian; these latter lines are then intersected by diagonals from the extremities, fixing the two north corners of the graticule. If the distance between them is now found correct by the table, the whole graticule may be assumed to be right. Graticule and sub-division lines must then be inked up in fine lines up to the edge of the board, and their co-ordinate values entered also near the edge of the board in black. When several field sections have to be projected along the same parallels of latitude, much time will be saved by projecting the graticules on a sheet of stout paper, and pricking the corners through on to the mounted sheet.

By rectangular co-ordinates.—Where the projection has to be made in rectangular co-ordinates, the procedure is as follows. After locating the lower parallel of latitude and one corner of the graticule as described in paragraph 96, the rectangular co-ordinates of this corner, as found either from table XLII, or by previous computation on Form P. 48

are noted. Assume these to be W 2002·14, and N 978·23, and suppose that the scale of survey is 2 inches to a mile. On this scale it would be convenient to lay out squares of 80 chains or 2 inches, starting from the origin, so that the co-ordinate lines nearest to the corner of the graticule will be those bearing the numbers W 2000, and N 960. Now take with the dividers a distance equal to 18 chains, and lay this off below the pencil line already drawn on the board, to show the approximate position of the lower parallel of latitude. Through this point draw a line parallel to the existing line and mark it N 960. In a similar manner, lay out to the east of the graticule corner a distance of 2 chains, and draw a line through this point exactly at right angles to the N 960 line: this will be marked W 2000. Then, starting from these two lines, draw in blue colour, a series of 2-inch squares covering the whole board, and number them in blue near the margins.

This is a tedious operation and is much facilitated by using specially prepared rectangular metal plates, the sides of which are perforated at regular intervals with holes just large enough to admit the point of a needle; such plates are known as "Rectangular co-ordinate plates" and may be obtained on indent in various sizes from the Mathematical Instrument Office. Even with the use of a special plate, the labour of ruling up boards is considerable, and may be avoided by using the blue-lined paper (P. 70) mounted on cloth referred to in paragraph 94. It is clear, however, that if this paper is used, the graticule cannot always be placed to the best advantage as explained in paragraph 96, because the blue-lined paper must necessarily be mounted square on the board, and the advantages sometimes obtainable by slewing the lines must be sacrificed.

As soon as the squares have been drawn and numbered, the four corners of the graticule are carefully plotted, after which the lengths of the sides should be tested with beam compasses from Tables XXXI to XLI. The graticule is then subdivided, inked in with fine black lines and the values of the spherical co-ordinates are marked in black ink near the margins of the board. In this case, therefore, a net work of rectangular co-ordinates precedes the graticule, and provides the basis on which it is projected.

Plotting points on field sections.

98. When all data are given in spherical co-ordinates, points are plotted by means of cardboard diagonal scales of latitude and longitude, and checked by distances; it is, however, always advisable to construct suitable scales on the sheet itself so that the plotting of points may be checked in the field from the data given in the surveyor's field note book.

In the case of rectangular co-ordinates, no ambiguity can arise as regards points which fall within the limits of the area allotted to the origin of survey. When it is necessary to plot adjacent points and traverses computed from another origin, reference should be made to Chapter III, paragraph 90, where the various methods of doing this are explained.

Checking and inking in points.

99. All trigonometrical and traverse points must be plotted by one man and when complete, carefully tested by another, and both should then sign their names on the " Record slip " which should now be pasted on the field section. As a check on the plotting, trigonometrical points should also be checked by their distances, as obtained from the computations.

The plotted points are then inked up, great trigonometrical stations and intersected points in red circles, other trigonometrical points in black, and traverse stations in blue; trigonometrical stations of observation being shown by two concentric circles.

The trigonometrical points will then be given serial numbers, and a reference table neatly drawn near the margin of the sheet giving the reference number, name and height of each point, care being taken to note whether the heights represent the top of an object or the ground level. When a height represents the top of an object, the height of the object above the ground will be measured by the plane-tabler, and entered in a column provided for the purpose in the reference table.

Field note book, and record slip.

100. Each plane-tabler should be supplied at the commencement of a field season, with a rough note-book in which he should copy the co-ordinates, and heights of every point and its plane-table reference number. This note-book should also contain a list of all the instruments, camp equipment, and stationery served out to him at the commencement of a field season; it will also be of use to him in many other ways in jotting down notes of any description whilst at work.

The following information should appear on every field section either typed on the field section outside the margin, or on slips of bank-post paper pasted on, before the section is given out to the surveyor.

These record slips on Form P. 79 can now be obtained on indent from the Calcutta Office.

RECORD SLIP FOR FIELD SECTIONS.

Projection by..

Do., examined by..

Plotting by...

Do., examined by...

Surveyed by..

Commenced...

Finished..

No. of working days...

No. of plane-table fixings..

No. of clinometric heights..

Contoured by..

Area surveyed.......................................sq. miles......................

Tested by...

Length of *purtal* or test lines..

No. of test *in situ* fixings..

Edges adjusted by..

....Camp Offr.

in ch. No. Party

C. O. No. 43 (Prof.), dated 4th March 1885.

"Setting" a plane-table at a known station.

101. In the following instructions for plane-tabling, it is assumed that the reader has passed through the essential parts of the course laid down in the order marginally noted, and is so far conversant with the theory of the instrument as to be fit for actual work in the field.

When commencing work, the surveyor should set up his plane-table on a prominent hill station, or well-fixed trigonometrical point situated in as commanding a position as possible, placing it level, and nearly over the station mark. He should then truly orientate his board, by placing his ruler so that its edge passes through the point at which he is standing, and the most distant visible point plotted on his board, and turning the table bodily round in azimuth until the true distant point is intersected by the sight-rule. This is commonly called "setting" the plane-table. He should next test the accuracy of every trigonometrical point on his board, by laying his sight-rule in their direction in succession; if any are found to be wrong, the plotting of them should be examined and corrected if necessary, by reference to the data in his note-book.

He should now place the compass in its box, on some convenient part of the table outside the graticule, and shift it till the needle reads 0°, and then mark on his board with a firm pencil line the edge of the box. This position of the box should always be used subsequently for all ground nearly in the same meridian as that of the station at which the compass was set up. To guard against rough usage and damage, it is usual to instruct a sub-surveyor not to take his compass out of its box, care being taken to securely wedge it, so that it cannot shift its position in the box.

"Setting" by the back ray.

102. He should next draw rays to any forward points which he considers suitable to visit for the purpose of sketching. These rays should be produced, and their extremities marked on both edges of the table. On arrival at the forward point, he will place himself accurately on the ray from the last station, and will "set" his board by laying his ruler on the ray, and turning it round with the board until it intersects the last station. This is termed "setting by the back ray", and there is no better method of placing the table in true azimuth. It is quite independent of abnormal compass variations, but it is essential that the same edge of the sight-rule be always used. Rays now drawn from any other *near* trigonometrical points, if possible on both sides of the setting ray so as to intersect it, and preferably as nearly at right angles as possible, accurately determine the position of the surveyor.

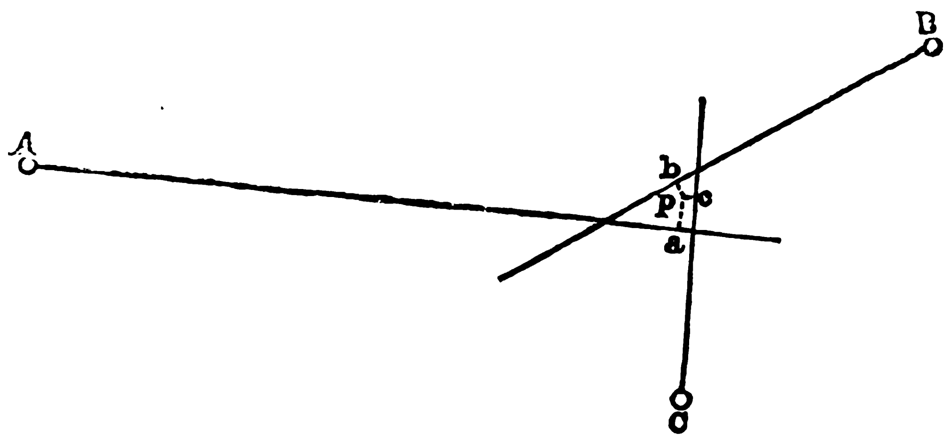
"Setting" by interpolation.

103. The other method of setting up the table is by interpolation, and there are several cases constantly occurring in practice. A table may be set by compass, and the required position ascertained by interpolation from two trigonometrical points, or it may be set, and the position ascertained by interpolation from three points without a compass (with certain exceptions), but in the first of these cases, there is, and in the second there may be (unless the position of the plane-table falls within a triangle formed by connecting the three points), no test of accuracy: in the first any abnormal magnetic variation vitiates the setting, especially if the two points are at a considerable distance; and in the second if the circle drawn through the three points passes through or near the surveyor's position, the setting becomes very ambiguous and unsatisfactory. Hence the plane-tabler should, if possible, fix or interpolate himself by four points at least, and should consider the compass as merely a convenient accessory for obtaining a first approximation, relying only upon triangulated or well fixed points for verification.

In interpolation, the surveyor should set up the plane-table at the desired spot, fixing it as level as possible. The compass should then be placed accurately on the line previously drawn to indicate the magnetic meridian, as previously described, and the plane-table turned round in azimuth until the needle points to 0°, and then clamped. Three trigonometrical points should then be selected from which to interpolate the position. The points should be as near as possible, and chosen so that the observer is inside the triangle formed by joining the three points. The ruler is then laid on each point in succession, and lines are drawn along its edge. If the plane-table has been set up accurately in azimuth, the three rays will intersect in a point, which is the required position. More frequently, however, the intersections form a small triangle of error, in which case it is necessary to determine the true position.

First, taking the case where the observer's position is inside the triangle formed by joining the trigonometrical points. In this case the true position will be within the small triangle of error formed by the intersection of the rays. It will also occupy such a position that its perpendicular distance from each ray will be in proportion to the distance of the observer's position from the respective trigonometrical points.

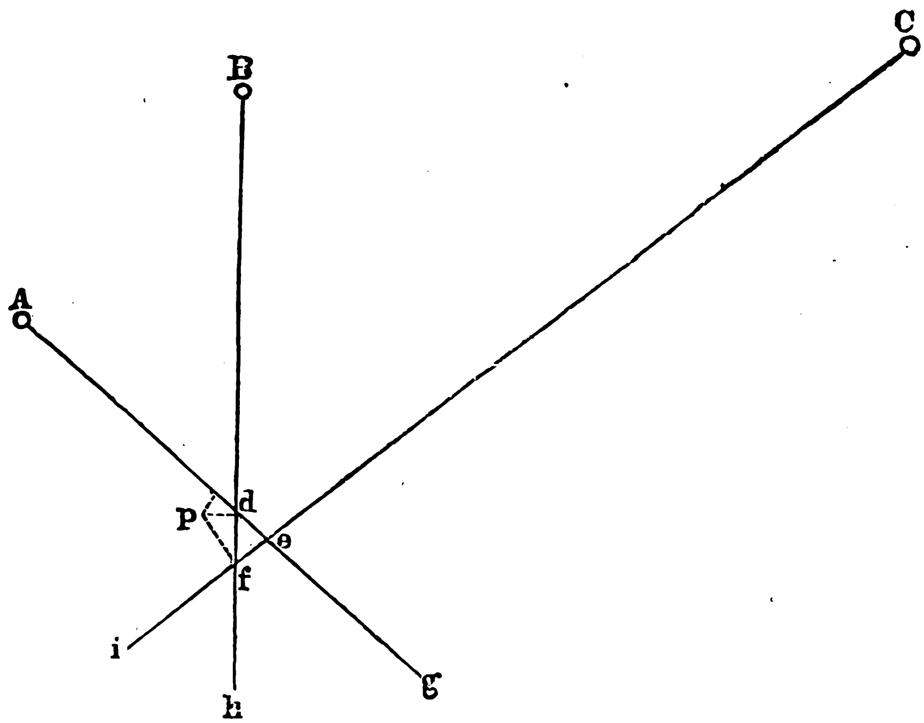
Thus in figure 1, p will be the correct position, the perpendicular distances p a, p b, p c being proportional respectively to p A, p B, p C.



Secondly, in the case where the observer has been forced to use three trigonometrical points so placed that his position lies outside the triangle formed by joining them. In this case the point will lie outside the triangle of error.

The same condition holds, *i.e.*, that the distances of the point from the rays will be proportionate to the distances of the respective trigonometrical points; but there is another condition which must be satisfied the point must be so situated that all the rays have to move in the same direction round their respective trigonometrical points in order to reach it, when the table is turned in azimuth.

Taking the second condition first, a glance at fig. 2 will show that there are only two possible positions of the fixing which fulfil it, *i.e.*, in the space C e g where all the rays would have to swing to the right or in the space A d f i, where they would all have to swing to the left.



Now the first condition of the relative distances will decide which position is the correct one. It will be seen that there is no point in C e g which fulfils this condition, but in the space A d f i there is one point p, the perpendicular distances from which on to the rays A g, B h, and C i are proportional to the distances A p, B p, and C p. With a little practice, the position of this point can be estimated most accurately. Having determined the approximate position of the point, lay the ruler over it and the *most distant* visible trigonometrical point on the board, and turn the board in azimuth till that point is intersected, and clamp it. The interpolation should then be repeated, when if the point has been properly chosen, the rays will intersect on it; if any small error still remains, the process should be repeated. The rule of setting in azimuth by a distant point is one which should always be borne in mind, as the effects of errors in laying the rule over the points, and in the accuracy of the assumed position, are much minimized.

There is one ambiguous case, in which the observer is situated on or near the circumference of a circle passing through the three trigonometrical points. In this case no accurate determination of the position is possible, and if the observer cannot get a fourth trigonometrical point which lies well clear of the circle, he must perforce trust to his compass for setting, and fix the position by any two of the points giving a suitable angle.

In "revision" surveys where "tracing" or blue prints are used, it is essential to interpolate by points, or topographical detail in the immediate vicinity of the spot where the plane-table is set up, and not by distant trigonometrical points, for all maps are slightly distorted in printing, and the relative positions of trigonometrical points cannot be depended on for the purpose of interpolation.

In hilly ground, and in large scale surveys, the necessity of setting up the plane-table level cannot be too strongly insisted upon. When some of the trigonometrical points are situated high above the observer, and some on a level, or below him, a small inclination of the plane-table will throw out the position of the fixing very considerably. In such cases the clinometer spirit-level can be used to level the plane-table, or a pencil may be dropped lengthways on to the plane-table a few times, and the direction in which it tends to roll noted.

Setting a plane-table on unstable ground.

104. In muddy and marshy places, a firm footing may sometimes be obtained for the plane-table by driving in wooden pegs flush with the surface of the ground for each leg to rest on, and in sandy soil a certain amount of stability can be effected by inserting each leg of the plane-table stand into a square or circular piece of wood, with a hole drilled through its centre, to allow it to travel a foot or so up the leg.

Plane-table sketching.

105. The surveyor, having obtained his position on the table by one or other of the above methods, proceeds to draw rays to all objects, such as peaks, spurs, ravines, villages, etc. He next proceeds to some other commanding station, where he again fixes his position, and again intersects the same objects, thus establishing their position on the board. The positions given by intersections of not less than 60° may be assumed to be correct; but when the intersections are more acute, only approximate, and they must be again intersected from some other more favourable station. Generally the position of any object should not be considered as finally determined until tested by at least three rays intersecting at favourable angles.

In hilly country, it is best to commence work from the tops of the hills, and work downwards rather than *vice versâ*, as, not only is the extent of country visible from high ground, over which rays to detail can be drawn, much greater than from the valleys, thereby necessitating the setting up of the plane-table fewer times to complete the survey of a given area; but from high ground, the different topographical features assume a far truer relative value than they ever will, when looked at from below. There is also the further advantage in working from high ground, rather than from below, that when making a fixing from which a comparatively extended view is obtainable, the chances of seeing the number of trigonometrically fixed points necessary for a good plane-table fixing, are greater than they would be were the fixing made on low ground. For much the same reasons it is always best to survey a slope, as far as possible, from two or more fixings high up on an opposite hill, rather than from those on the slope itself. There will of course always be the necessity of making fixings on the low ground, and on the slopes under survey, in order to survey detail which it has been impossible to obtain from the higher, and more distant fixings, but their number will be comparatively few and their attainment, owing to the number of good plane-table points, which will already have been fixed in their neighbourhood, a matter of comparative ease.

Another point which it is worth while remembering is the importance in regular work, of guarding against the tendency to waste time by drawing rays to distant objects whose position will be more easily fixed later on, by shorter rays. The drawing of an excessive number of rays from one fixing leads to confusion on the plane-table, and occupies time which would be more usefully employed in making a second plane-table fixing elsewhere, and again drawing a moderate number of rays from that. This does not apply to reconnaissance survey, or survey carried out during military operations in a hostile country, where the freedom of movement of the surveyor will always be restricted, and it is consequently of the utmost importance to get all detail fixed, even approximately, whenever and wherever the opportunity may offer.

The following hints on sketching and filling in the ground, abstracted from a Memorandum by the late Colonel D. G. Robinson, R.E., will be found useful :—

As soon as the surveyor has set his table at Station *I* and tested his points, he is ready to commence sketching. With this object he draws rays from his station to all the remarkable points, such as peaks, houses, trees, etc., around him, and within a reasonable distance; and estimating the distance, assigns an approximate position to them on his plane-table; he also draws rays to the junctions and turns of the different water-courses, and of spurs, knolls, etc., in his immediate vicinity, and sketches in (lightly) the ground by eye contours. This completed, he should move off to some distant commanding point (2 miles at least from his first station), set up his table, and fix himself (as previously directed). He should then draw rays to all the remarkable objects to which he drew rays from his first station. The intersections of the new and old rays fix the positions of all the objects thus laid down, more or less correctly, according as the angles of intersection are good or bad. The positions given by the intersections if not less than 60° may be assumed to be correct, but when the intersections are sharper, only as approximate. These points now become of great assistance; they cover a good area and enable the surveyor to judge pretty correctly the positions of all objects that fall within them or near them. He next draws rays to the spurs, water-courses, and other physical features in his immediate vicinity, and sketches these features lightly in pencil. He then works back towards Station *I*, putting up his table at intervals of from 200 yards to half a mile, according as the ground is more or less intricate or difficult to see. From each station he draws rays as before; and fixes the positions of the junctions of the watercourses, ends of spurs, knolls, etc., to which he previously drew rays, and he then sketches that part of the ground. In this way he works back past Station *I*, always taking rays to remarkable objects and keeping approximate work in advance of his final work. He should never consider any position determined until it has been tested by at least three rays intersecting at not less than a right angle. When a surveyor gets into a position where he cannot fix himself for want of trigonometrical data, he may use any point which has been laid down by not less than three rays from trigonometrical points, provided these intersections be at not less than a right angle, or his position does not fall outside the *triangle* of rays of intersection. To secure a number of such subsidiary points, the surveyor should always work along the ridges before descending into the lower ground. He will also find it much easier to sketch with the sun in his front, for if the sun be behind him, no shadows are thrown on the features he is looking at, all look like one continuous mass; but if he has the sun in front of him, objects stand out in strong light and shade, every ravine and turn of a ravine may be detected at once, and it is far easier to pick out or recognise the prominent points.

He will also find it a great advantage to traverse by zigzag (like triangulation) in circuits through the country when the physical formation permits of it. The blank areas thus circumscribed are always filled in much easier, and the zigzag process affords better intersections than can be obtained by working on straight lines.

The amount of detail to be shewn will depend upon the scale. On a small scale villages are shown by circles, on an inch scale they may be laid down by tangents to their edges, the tangents being drawn from so long a distance as to give nearly the correct area of the village, but on the 6-inch scale the streets and houses should be shewn. On the 1-inch scale, it is also usual to shew all the different areas, such as cultivation, various kinds of jungle, swamps, etc. The different minor features and the lay of the strata can generally also be shewn, but on the ½-inch and ¼-inch scales it will be generally sufficient to shew all ridges and spurs, without reference to their respective slopes. It is a great mistake to attempt to shew too much, as it only tends to confusion. Furthermore many objects, such as precipices, roads, wells, temples, and such like small objects, which would, if drawn to scale, be represented by almost invisible fine lines or points, must be exaggerated on the map, in order that they may draw sufficient attention and receive their true value. Much more might be written to meet the various contingencies of ground and position a surveyor may meet with, but without a few lessons and a little practice in the field, it is almost hopeless to attempt to make a good topographer, and when once the surveyor has acquired a little practical knowledge, his own wits will always suggest to him the means of overcoming a difficulty.

Traversing with the plane-table.

106. When surveying in forest-clad countries where clearances are rare and distant views seldom obtainable, it is evident that the method of plane-tabling above described is not possible. If the ground is flat in addition to being jungle-covered, recourse must be had to traversing with a chain and setting the plane-table up at each station "by the back ray" as explained in paragraph 102. Where the undergrowth

is heavy, iron chains are apt to catch in the jungle and break when dragged through it, and in consequence, the work is much impeded. A chain made of "lead line" rope, well stretched and tarred, will glide through a forest like a snake. One end should be formed into a loop to aid the man in dragging it and small strips of leather let in between the strands at 10 feet or 10 link intervals for the odd measurements. The length of the rope chain should be tested daily both before and after work with a standard iron chain or steel tape in camp, but it has been found in practice that a well seasoned rope does not alter much in length, and wears well—Canes well dried may sometimes be used with advantage in countries where they abound.

In thick jungle, where only short lines can be obtained, and there is not much detail, quicker and better work can be done by setting up the plane-table only at alternate stations, using the compass to set the table, *provided the magnetic variation is constant.*

In filling in topographical detail by traversing in a densely jungle-covered country, it will be found that it is frequently quite impossible to see the forward flag-man even when only 2 or 3 chains away. Clearing is impossible owing to the delay and expense: it has been found however that very fair work can be done by judging of the direction of the forward station by sound; any tapping noise made by the forward man can be located with quite sufficient precision up to a distance of 4 or 5 chains. A looking-glass is most useful flashed by the forward flagman in the direction of the surveyor as it can generally be seen through apparently very dense jungle; the back flagman should also be provided with one.

In surveying tidal creeks, where the banks are fringed with mangroves, it is generally impossible to set up a plane-table. A good plan is to go up the creek with the flood tide with two boats, and survey down with the ebb, the distances being obtained by means of a long rope with large corks attached at chain intervals to float it, and the angles with a prismatic compass, suspended in gimbals. The survey can then be plotted separately on a piece of paper, and transferred to the plane-table.

Number of fixings per square mile, and manner of showing them on a plane-table.

107. In easy ground, free from jungle, four or five fixings per square mile should be sufficient to enable a practised plane-tabler to show all necessary detail on the scale of 1 inch = 1 mile: in more intricate country eight to twelve may be necessary. In the case of larger scales or with inexperienced workmen, the numbers must be increased in proportion. Plane-table fixings by interpolation are to be marked on the sections by small red crosses, and points fixed by intersection but not visited, by small red circles. When there is a paucity of trigonometrical points, a surveyor should go over the ground, and

supplement them by so-called "plane-table points," which have been well tested by three or more rays. When a surveyor has to resort to plane-table traversing, traverse stations should be indicated by dots, connected by thin broken lines in blue.

Details to be shown on the field section.

108. On the 1-inch scale any natural feature, such as a ravine or water-course, less than $\frac{1}{8}$ of a mile in length, cannot well be shown; and if the country be intricate and full of detail, water-courses less than $\frac{1}{4}$th of a mile in length cannot easily be represented without creating confusion. Ravines and intricate ground or hills of irregular formation are generally of little value, and do not demand such precision and minuteness of detail as more valuable land. In such wild tracts it is sufficient that the prominent features of the ground be distinctly shown; in this case water-courses of $\frac{1}{4}$th of a mile would hardly attract attention.

It is customary to show by dotted lines such items as can, for cogent reasons, be only approximately surveyed. It is very necessary to pay attention to this rule, otherwise the surveyor may very possibly be blamed for bringing in incorrect work in country which he does not profess to have accurately surveyed, but merely sketched in roughly: and moreover users of the map might be misled if no clue existed as to what professed to be accurate, and what merely approximate, in the details shown. It must, however, be understood that recourse to dotted water-courses, etc., should only be had when the necessities of the case *really* demand it, and not merely as a means of avoiding a difficult piece of plane-tabling.

All symbols should be shown strictly in accordance with the specimen of conventional signs in use in the Department. *Bunds* of tanks, embankments, scarps, dykes, and banks of streams and rivers should have their relative heights in feet given here and there, as, 40r.—

All the villages, rivers, etc., on a field section must be serially numbered by the plane-tabler, and a reference table with the names of each, made in the margin of the section. This reference table should be compared, and agree, with the lists of names in the village field books.

Style of drawing.

109. Plane-table sections must in the first instance be drawn with pen and Indian-ink only; except in reconnaissance work, washes of colour for delineating hills, are not used.

The choice of delineating ground by the horizontal, or by the vertical, method of hill shading is not ordinarily left to the discretion of an executive officer, but it is as well that he should know the general arguments in favour of either system. For sketching in the field, the horizontal system is by far the most suitable, but for fair maps, the vertical system has its advantages. It is chiefly a question of scale; the horizontal system best suits scales of 1-inch to the mile and over, and the vertical system all scales below that limit. For fair maps of reconnaissance work, exploration and geographical surveys, the vertical system or brush work is in many ways preferable. If horizontal contours are used, there is a strong tendency for roads and streams to become confused with the contours, to the great detriment of the map; vertical shading lends itself with considerable facility to the delineation of billy ground only approximately surveyed, but fails somewhat where it is required to show up the minuter details of hills. For all engineering projects, such as road-making, railways, etc., the superiority of horizontal contours is unquestioned.

The introduction of the "Survey of India" pattern clinometer has brought about a much needed reform in the hill drawing of standard maps, inasmuch as it is now possible with its help, to insert on them approximate eye contours at fixed vertical intervals apart. Before its introduction, hills were delineated by what were termed "hachures," a method which led to much false drawing, and unequal representation of ground. Thus a surveyor working in one plane-table might exaggerate his hills, whilst his neighbour working on an adjoining plane-table under-estimated their relative size and importance, the result being, a want of symmetry and truthfulness, and a general unevenness of style in the finished standard map. For a discussion on so called "scales of shades," giving the number and thickness of "hachures" for any given slope, the reader is referred to the order marginally noted. On the other hand, the delineation of hilly ground by a method of approximate eye contours, aided by clinometric heights, not only effects a faithful representation of its inequalities and slopes, but produces uniformity of style, ties the surveyor down to a system, and thus prevents his running riot over the ground with his topography, and finally considerably enhances the value of the resultant map as a guide to any future engineering projects, or military operations. Relief, if necessary, can be obtained by thickening the contours where the slopes are steep, and the contours close to each other.

C. O. No. 15 (Prof.), dated 16th November 1880.

It must however always be borne in mind, that contours thus obtained with the aid of clinometric observations are only "approximate," and not "absolute," and a note to that effect should appear at the foot of every fair map.

Twelve and a half feet vertical intervals will generally be found suitable in surveys on the 8-inch scale, 25 feet intervals on the 4-inch scale and 50 feet on 2-inch and 1-inch surveys. In the Himalayas, and other very steep hilly tracts, it will be found necessary to draw the contours at 100 feet vertical intervals apart for 1-inch surveys, but the vertical interval

G 2

of contours on any one standard sheet or map, should be the same throughout. On scales larger than the 1-inch, it is customary to distinguish every 250 on 500 feet contour from the intermediate contours by colour, or by the quality of line, for ease of reckoning up heights.

In parties in which large numbers of not very highly skilled native plane-tablers are employed, it has been found advantageous to entrust them with only the outlines of the detail survey, omitting the contours and sketching of the ground. The assistant in charge of the section subsequently inserts the contours on these plane-table sheets, thus ensuring the double object of accurate contouring, and a thorough examination of the section in the field; advantages which are cheaply gained at the sacrifice only of the small extra time required to go twice over the same ground.

C. O. No. 26 (Prof.), dated 8th February 1883.

Description of "Survey of India" clinometer, and its use.

110. The instrument, of which a drawing and description are given in the order marginally noted, stands on three buttons and is placed on the surface of the plane-table. A small level is attached to the base-plate, and the instrument is so adjusted that, when made truly level, a line through the sight vane to the zero of the object-vane is horizontal. Above and below this zero, there is, on one side of the object slit, a scale of natural tangents, and on the other, a scale of degrees. In using the clinometer, care should be taken that the sights are upright and parallel, and that they have not been bent. They are usually graduated to a radius of 8 inches, that is, the distance between the eye-hole and the zero of the graduations should be exactly 8 inches, and if the vanes are bent, they should be straightened until the measure is correct; also the distance between the eye-hole and the extreme graduations above and below zero on the tangent scale should be equal to one another. In observing, the eye should not be too close to the eye-hole, but about 2 to 4 inches away from it. To obtain the difference of height between his own position and any other object in view, the observer looks through the hole in the sight-vane, after levelling the clinometer by means of the level on the base-plate, and notes what figure on the tangent scale is cut by the ray to the object. This figure multiplied by the distance in feet, gives the difference of height between the observer and the object in feet.

C. O. No. 32 (Prof.), dated 19th October 1883.

A surveyor can either deduce the height of his own position by observations to two or more points, the heights of which are known, adopting the mean value; or on the other hand, if his own height is known, he can obtain the height of any other point in view within a reasonable distance. It is necessary of course to know the distance in feet of the point observed, and this (which should not exceed three or four miles) is generally measured along the edge of an engine divided cardboard scale placed between the two points on the plane-table, the difference of whose height is required.

Clinometer observations are usually recorded and worked out in the field on form P. 21 in which the whole of the columns should be filled up except the horizontal distances in feet, thus permitting the computations to be subsequently checked if necessary. The serial number, as well as the final clinometric height, should invariably be entered on the plane-table section, thus $\frac{1}{1520}$.

Testing of clinometers.

111. *The level adjustment of all clinometers must be carefully tested by camp officers at the commencement of every field season before they are issued to the surveyors,* and no native surveyor should be allowed to meddle with the level adjustment when plane-tabling. If his observations are discordant, he must report the fact to his camp officer, whose duty it is to readjust his instrument as soon as practicable or send him another.

There are several methods of testing the level adjustment of a clinometer, and the following are as simple as any ; the first requires a theodolite and is suitable for the commencement of a field season before the clinometers are issued, whilst the second, primitive though equally efficacious, method can be adopted whilst a surveyor is at work plane-tabling.

(1) Place the clinometer on the edge of a plane-table, or any other tripod stand, higher than a plane-table stand, if available, and set up a theodolite alongside of it, so that the eye piece of the telescope when clamped at zero, is level with the eye-hole of the clinometer. Level the theodolite carefully ascertain its vertical collimation error if necessary, and clamp the telescope to zero on the vertical arc, *plus* or *minus* the collimation error, so that the axis of the telescope lies in a horizontal plane. Then fix a small piece of paper about 3 inches square on a tree or staff, at a distance of about 100 yards, at such a height from the ground as to intersect the horizontal wire of the theodolite thus clamped; then by means of the milled-headed screw on the clinometer, make the mark read zero on the tangent scale, and bring the bubble of the level into the middle of its run by the capstan-headed screws attached to the level.

In a similar manner, the level adjustment of a clinometer can be tested by observing to 3 or more well defined trigonometrical points whose heights are known, when any such points happen to be visible from a camp.

(2) Place the clinometer on a plane-table set up at a point A, take a measurement of the height of the eye-hole of the clinometer

above the ground, and mark the spot with a small heap of stones. Tie a strip of white cloth or handkerchief round a bamboo at the same height as the eye-hole of the clinometer above the ground, and have the bamboo held by a *khalási* at a point B about 100 yards off, and observe the reading of the cloth on the bamboo, on the tangent scale of the clinometer. Then proceed to B, and set up the clinometer at the same height above the ground as it was at A. Send the flagman to A, and again observe the reading of the cloth on the bamboo. If an elevation at A, the reading at B should show an equal depression if the level is in proper adjustment, otherwise there will be a difference, half of which will give you the correction to be applied. Then by means of the milled-headed screw make the reading of the mark on the tangent scale equal to the corrected reading, and bring the bubble of the level into the middle of its run by means of the capstan-headed screws. Then return to A, send the flagman back to B, and verify this reading.

C. O. No. 55 (Prof.), dated 24th November 1887.

Height Indicator.

112. The difference in height can also be obtained without computation by the "Height Indicator"* designed by Colonel Wahab, R.E., which is so arranged as to give the horizontal equivalents for given vertical intervals and *vice versâ* for any inclination. The height indicators at present issued are designed for the scale of 4 inches = 1 mile, and by doubling the heights they can be used for a scale of 2 inches = 1 mile, but instructions for the preparation of height indicators on any scale are given in the order marginally noted. The use of the indicator also saves the labour of recording the clinometer readings, and computing the heights, but as the results obtained are entered directly on the plane-table, it is not possible to check the accuracy of the surveyor's work, otherwise than by retaking the heights in the field. This, however, should usually be done in any case, to check the accuracy of the plane-tabler's clinometric observations.

The method of using the clinometer and height indicator in hill-sketching is as follows:—the surveyor having fixed his position on his board, finds his height by observations to surrounding known points and enters the data on form P. 21. He then determines the heights of a number of points in his vicinity, such as junctions of streams, prominent knolls, points on spurs where there is a marked change in slope, etc., entering their heights at once on his board but keeping no record on P. 21. If the slope on which he stands is fairly uniform,

* To be obtained from the Trigonometrical Branch Office, Dehra Dun.

he can then find the position of points on the contours above or below him, by observing the slope of the hill with his clinometer, and obtaining the horizontal equivalent for the difference in height between his position and that of the contour from the height indicator. Thus if the slope be ·16, the height of the observer's station 2,890 feet, and the contour required 2,800, he will measure with the dividers the distance on the line opposite the figure ·16, equal to 9 sub-divisions on the left of the scale and plot this on his board in the direction in which he has measured the inclination. The distances of the contours next above and next below the observer's position being thus determined, the contours can be easily traced between the points so found, and the operation is then repeated at subsequent plane-table fixings; or if desired, the surveyor can set up his plane-table on the contour by chaining to one of the points found on it, and then using his clinometer as a level, lay out the contour in the usual way. Intermediate contours are then interpolated by eye with the aid of the heights already fixed, at sufficiently close intervals to shew all important features.

Number of clinometer heights.

113. Clinometer heights need not necessarily be taken at every plane-table fixing, except in very thick jungle where it is often impossible to fix one's position by interpolation, and surveying has to be carried on by plane-table traversing. In fairly open country where interpolation is possible the number of clinometer heights should be regulated by the nature of the country and scale of survey, generally speaking the requisite proportion is from 2 to 4 per square mile on the 2-inch or 1-inch scale. A greater number of heights will generally be required in undulating country than in mountainous tracts.

Clinometer heights are primarily needed for the delineation of contours, consequently they need not all be shown on the fair maps although they should all be entered on the plane-table section. Only a sufficiency of those, being means of two or more observations, should be scattered over the map area at important points such as the crests of hills, junctions of streams, on roads where they cross streams, fords, or bridges, on passes, at large towns, etc., etc.

Should there be an insufficiency of trigonometrical heights on a plane-table section, the heights of points fixed by the plane-tabler can be accurately ascertained with the clinometer, and these will again serve as data for subsequent clinometer observations. Clinometer heights may often with advantage be taken where the height of the top of an object has been given by the triangulator, and the height at ground level is required, or to points whose geographical co-ordinates have been obtained, but whose heights have not been ascertained trigonometrically. Should it be required afterwards to show these heights on the fair maps, the conventional sign for a clinometrical, as opposed to a trigonometrical height, should be employed although they refer to the latter class of fixed point.

For forest surveys in hilly country, however densely wooded, it is generally possible to obtain sufficient clinometric heights by clearing the tops of those steeper hills, wherever a good view can be obtained without very excessive labour; but when the forest lies on flat, or only slight undulating ground, clearing is of no use, and clinometric heights are no longer obtainable directly from known fixed points. In country of this sort, the survey of all detail has to be carried out by plane-table traversing, and the delineation of contours by taking clinometric observations from station to station, for which there is generally ample time whilst the rays to the forward station are being cleared of jungle. Since the rays are often very short (not more than 2 or 3 chains, and sometimes less), experience has shown that the chance of an error of measurement and reading, when taking off with the dividers a very short distance from the plane-table or scale, and applying it to the "Height Indicator" is much greater than when performing the same operation with comparatively a much longer distance, such as 100 chains. To obviate this difficulty Captain Robertson, R.E., writes as follows:—

"Starting from a plane-table fixing for which a clinometric height had been obtained, or from a trigonometrical point of known height, a reading on the clinometer is taken to the forward station giving a value of say —·02 on the tangent scale. A distance of 100 chains is then measured off from the cardboard scale with dividers, and applied to the height indicator scale, which shows that this distance, at the angle of depression already read, gives a difference of altitude of 132 feet, or a decrease of altitude of 1·32 feet for every chain of distance measured. The multiplication of the distance in chains, and decimals of a chain, between the initial and first forward station, by this amount (1·32), gives the correction to be applied for the height of the latter, as soon as the chain measurement is known. In this way a height can be obtained at every traverse station. A check on the accuracy of the results is obtained on reaching the closing station of the traverse, and if necessary, an adjustment of the closing error, can be made throughout the heights of all points on the traverse. This, however, with a moderate amount of practice is seldom found necessary."

Means of securing proper junction with other sheets, overlaps, etc.

114. All villages, temples or permanent objects adjoining, or outside of, the boundary of a topographical survey within a reasonable distance, are to be fixed so as to secure a good junction with the neighbouring maps. When the boundary of a survey is a river, *both* banks must be surveyed.

When the boundary of a district forms the limit of the work or area to be undertaken, the survey should embrace a certain overlap according to the scale of the map. This overlap is necessary to ensure a good junction with the maps of the adjoining districts. C. O. No. 44 (Prof.), dated 13th April 1885.

The overlap should be as follows :—

For $\frac{1}{2}$ inch = 1 mile and smaller scales	$\frac{1}{4}$ inch.
Above $\frac{1}{2}$ inch up to 2 inches = 1 mile	$\frac{1}{2}$ "
For larger scales, above two inches = 1 mile . . .	1 "

Beyond the graticule of every full plane-table section, an overlap must also be surveyed to admit of the ready comparison of the detail of neighbouring field sections.

This overlap must be :—

For 2 inches = 1 mile and smaller scales . . .	$\frac{1}{4}$ inch.
For scales, above 2 inches = 1 mile	$\frac{1}{2}$ "

These latter overlaps should not be included in the area of the surveyor's out-turn.

When marginal discrepancies have to be adjusted, erasures are not to be made on original plane-table sections, and all corrections must be shown in red.

Incomplete field sections.

115. If for any reason a surveyor has to leave his section unfinished, he must be careful to make the edges conform to parallels and meridians, and not to an indefinite or broken line. Such a boundary as this latter makes the subsequent joining up difficult and uncertain. In mountainous country, however, it is sometimes of advantage to apportion the work between plane-tablers by physical features rather than by hard-and-fast meridians and parallels. It is manifestly more economical to allot to one surveyor a valley with its two slopes up to the summit of its bounding ridges, rather than to give him a ridge with its two slopes down to the bottoms of the flanking valleys.

Village field books.

116. A register of village names and other details, including the information required for the compilation of atlas sheets as referred to in paragraph 154, must be kept. Form P. 29 is that which is usually employed, but executive officers may find it necessary to modify the form to meet the requirements of the particular survey on which they are engaged. The register should be filled up *daily* in ink, otherwise wrong names may be inserted, and confusion arise. C. O. No. 38 (Prof.), dated 11th March 1884.

Village field books must be retained in the party until the fair maps and the Atlas records (*vide* paragraph 154,) for which they are required are completed. They may then be destroyed. C. O. No. 71 (Prof.), dated 6th March 1890.

C. O. No. 61 (Prof.), dated 28th August 1889.

Village names on field sections.

117. Every plane-table sheet must have entered on the margin, the names of the villages which fall in the sheet. It has occasionally been the practice of some surveyors, who are unable to write the names of villages on their field sheets with even tolerable neatness, to keep a tracing of the sheet, on which from time to time they enter the clinometer heights and the sites and names of the villages. Such a proceeding is highly objectionable owing to the liability of loss or misplacement of the tracing, which may possibly necessitate a partial re-survey. In such cases the surveyor must number the villages on his field sheet and make a reference table in the margin, writing the names therein as well as he can in English, or in the vernacular. The correctly spelt names in English are entered in their place during the recess. In Burma the names should be written by the *thugyi* or head man of each village, and the village field books are subsequently sent to the Government Translator for transliteration.

It is absolutely necessary that each field sheet should be complete in itself, and not be dependent on any book, tracing, or other sheet for any topographical information.

Statistical and other information.

118. Topographical surveyors have generally many opportunities of collecting statistics about the country under survey, and it is most important that they should avail themselves of such chances, especially in little known districts. The officer in charge of the party should impress upon his assistants the great value of information of this kind when intelligently collected and systematized.

Partalling, and checking field work.

119. The officer in charge of a topographical party is entirely responsible for the accuracy of the maps produced by his party, and it therefore becomes one of his most important duties to arrange for the systematic checking and testing of the work of his subordinates. Nowadays it is impossible for the officer in charge to test all the boards himself: this must be done by the assistant in charge of each camp, while the officer in charge will usually find his time fully occupied in administering the party and visiting the plane-tablers *while at work*, noting their methods of working, pointing out how their work can be improved, and generally advising and instructing them: the systematic checking of each plane-table section, is done by the camp officers or their assistants *during the progress of the survey, and after its completion.* Officers in charge of parties should, however, check as many plane-tables as their other work will permit, and this most essential duty should not be left exclusively, as a matter of course, to camp officers. The methods by which this can be carried out are various;

and the choice must be left to the discretion of the officer himself. In open country, tolerably flat and unenclosed, a check-line measured with a perambulator is as rapid and accurate a method as any. The plane-table should be set up somewhere near the edge of the ground to be tested, and the position carefully fixed by the surrounding trigonometrical points. The perambulator may then be started off in a bee-line through the work, its readings being recorded where the line passes any features on the ground, until it is desirable to change the direction. The plane-table is then set up again, the distances of the features noted along the line are compared with the work thereon, and then a new line being chosen, the process is repeated as often as necessary. Rays should be taken to neighbouring villages, hills, streams, etc., whenever the table is set up. In hilly ground the use of the perambulator is impossible, and chaining is too slow except for small areas. The examiner must then content himself with numerous fixings, testing the topography by rays, and noting whether the sketching adequately represents the ground, and by checking the clinometer heights, and contour lines obtained thereby. The best way of testing a plane-table is to set it up on some prominent point A. Select a conspicuous object B, such as a tree, some distance off, and start your chainmen in the direction of B, the tindal noting the cuttings of roads, streams, etc., along A B. Whilst the men are chaining from A to B, you proceed by a circuitous route to B, setting up your plane-table at suitable intermediate positions a, b, c, d, etc., and check the topography on the way. On arrival at B, the tindal reads out the distances along A B where topographical details were encountered, which you then check on the plane-table.

No plane-table should be considered complete, unless it has been tested by competent authority, and this should usually be done both by in situ *fixings, and by chaining, and no plane-table should be considered as checked by* in situ *fixings alone where it is possible to check by means of a perambulator or chain partal.* A chain *partal* is the best test of the accuracy of detail in a surveyor's work, and it is seldom impossible. Supplementary topographical surveys, where previous surveys are transferred and inked in blue on a plane-table section, and the detail examined and corrected in the field, generally require more rigorous testing and *partalling* than original work, for there is always the temptation for an unreliable surveyor to accept, and ink up the old work without checking it, and thus obtain credit for a large outturn. Remarks on the examination of original plane-tables in the field should be recorded on them in ink, and signed and dated by the examiner, as it is of much importance to place this permanently on record. The edges of each plane-table should be compared with adjacent surveys and any small discrepancies rectified. Discrepancies of any importance should be thoroughly examined on the ground, and it should be ascertained as far as possible whether they are the result of inexperience on the part of the plane-tabler, or deliberate shirking, as in the latter case very heavy penalties are liable to be incurred.

C. O. No. 36 (Prof.), dated 11th March 1884.

Completion of detail on original plane-table sections.

120. Before the original field sections are sent to Calcutta for record the following details must be attended to in finishing them, and making them permanently intelligible and complete records for future reference.

(1) No names will be entered on the face of a field section, only the reference numbers, which may be typed.

(2) The spelling of the village and other names in the marginal reference table, outside the border, must, after comparison with the village field books, and verification by competent authority, be corrected when necessary, and the names printed or typed in English.

(3) Intersected points with single values, *i.e.*, fixed by two rays only, which are found wrong, should be crossed out on the plane-table section, and deleted in red in the marginal table of references, the fact being reported to the officer in charge of the computations, and triangulation charts.

(4) The edges of a field section must be examined with reference to adjacent work, and corrections, where necessary, made in red ink, and initialled by the officer in charge, or camp officers.

(5) Trigonometrical heights to be hand printed or typed, but not too large.

(6) Symbols employed on the survey should, as far as possible, conform, both in drawing and colouring, to those given in the published specimen sheet and orders on the subject, but in every survey, there may be need for the use of other symbols to represent information not therein provided for, and moreover, to suit particular tracts of country, they may be modified with the approval of administrative officers. Symbols should not be exaggerated, as drawn on fair maps for reduction, thus in surveys on the 2-inch scale for reduction to half scale, the symbols for the 1-inch scale for reproduction should appear on the field sheets.

(7) A border must be drawn round the graticule similar to that in use on standard maps; the figures for the latitudes and longitudes to be carefully hand printed, or typed.— The border may be broken to avoid interfering with the marginal reference tables, or offset when the survey has, for any reason, been extended beyond the edge of the normal section area. It should include the whole area, even if only a portion has been surveyed.

(8) The places from, and to, which the roads lead, when they pass out of the section, must be hand printed or typed within the border. The word "from" to be entered when the town or village lies west of the

village to which the road leads, and the word "to" when it lies east of the village from which the road comes.

(9) On the top of the sheet, in the centre of it, and outside the border will be typed the words "Survey of India," and immediately under it the name of the Province or Agency, in bold block letters. In the right hand upper corner, the number of the section must be given thus $\frac{\text{Sheet No. 55}}{\text{E}}$. In the left hand upper corner, the District or Native State name should be typed, and in the intervening spaces, the following items should also appear, *i.e.*, the season and scale of survey, and the magnetic variation. Area statements should also be given in a convenient place in the margin.

The paper is never to be detached from the cloth on which it has been mounted. The size of all the sheets should be nearly equal, allowing for the removal of the dirty edge. As a further protection the edges must be bound with ribbon as soon as possible after the sections are cut off the board.

Military Surveys.

121. Special surveys of limited areas on the scale of 2 inches = 1 mile are sometimes required by the Military Department for tactical purposes in the manœuvring of troops. The only difference between these surveys and an ordinary topographical survey is that the contours have to be inserted with greater care and exactitude, especially in undulating ground, where also a much larger number of clinometric and relative heights must be scattered about in places of military importance. The positions and heights of all conspicuous objects such as isolated trees, mounds, rocks, houses, temples, permanent wells, etc., should be carefully fixed for the purpose of range finding. Bridges, culverts, embankments and cuttings on railways, must be shown, and all roads, and footpaths carefully classified. The depth of the surface of the water as well as the depth of the water in wells should also be recorded.

Surveys of a similar nature are sometimes required of military defensive positions on the scale of 4 and 6 inches to the mile, and larger. In such surveys still greater accuracy is required, and the contour lines should be at a maximum vertical interval of 10 feet apart, whilst every 25-foot contour on undulating ground, must be carefully measured with a water level, or clinometer used as such.

Re-magnetizing compass needles.

122. A good compass that is fairly sensitive and plays freely, is a great aid to rapid plane-tabling, inasmuch as it usually enables the surveyor to set his plane-table so correctly, that the intersections of the rays to the surrounding points give him at once his true position, without the necessity of a second approximation. In order to magnetize needles when a pair of magnetic bars is available for the purpose, draw

the southern pole of one bar along the northern pole of the needle from the centre outwards, taking care to keep the bar moving continuously in one direction—that is, the bar should not be rubbed backwards and fowards along the needle—and simultaneously in a similar manner draw the northern pole of the other bar along the southern pole of the needle. The needle must be held down by a second person whilst this is being done. After giving 12 strokes to one side, the needle should be turned over, and the reverse side similarly treated. No needle will work well unless the pin is sharp, the agate bearing dry and clean, and the balance properly adjusted.

The magnetizing bars, when not in use, should be so placed as to have the north pole of one towards the south pole of the other, and the armatures attached to them. Needles, when not in use, should be thrown off their pivots by the lever provided for this purpose: this should always be done whenever it is taken off the plane-table. All needles should be tested by camp officers before being served out for use in the field.

Chapter V.

Mapping.

123. In a properly constituted topographical party, engaged in standard mapping only, the detail survey of each field season should be fair mapped at recess quarters and submitted for publication before the party again takes the field, and every endeavour must be made towards that object, for the efficiency of a party is best gauged by the absence of all arrears of mapping.

Introductory remarks.

The fair mapping should be undertaken by the Provincial officers, surveyors, and sub-surveyors of a party, who must consider this an important part of their duties, and executive officers must give much time to educating the members of their parties in becoming efficient draftsmen, and typers.

It is only in exceptional cases that the services of special draftsmen are needed in a party, *e.g.*, to bring up a large accumulation of arrears of mapping, or when special surveys on large scales are undertaken in addition to the routine surveys for standard maps. In such cases an executive officer must apply to his administrative officer for sanction to enlist extra hands as draftsmen. These he must recruit, and train himself, on small salaries of R10 or so, until they are capable of doing work on a fair map, when, should they show aptitude, and evince signs of becoming efficient draftsmen, their pay may be substantially increased to R25 or more, but they should be kept on the temporary establishment for some years to prove their diligence and capacity for such work.

The recess establishment for mapping and computing should be divided into sections, supervised by the Provincial officers who were in charge of camps during the field season, or by other senior assistants.

124. The paper on which fair maps are drawn is "Whatman's special drawing paper." It must be carefully selected, as much of the success in photo-zincographing the sheet depends on the paper being perfectly white, smooth, clean, and free from wrinkles, and blemishes of all kinds. It should not be mounted on cloth.

Drawing paper.

C. O. No. 34, dated 10th February 1883.

C. O. No. 38 (Prof.), dated 6th October 1884.

In forest survey parties, where there is a large amount of fair mapping, the original field sections are placed over a tracing glass, and the fair maps drawn direct on bank post paper; also in some parties the original field sections are utilised as fair maps, though the result is seldom satisfactory.

Paper with a highly glazed surface is objectionable on account of its shine, which may interfere with the photographic operations, also because it is wanting in a proper bite for the pens, and lines thicken. It moreover does not stand scratching and erasures well.

Fair maps should be kept flat and not rolled up, which tends to produce creases and wrinkles. Stains, folds, or creases will cause faint patches on the ground of a negative, which may result in the obscuring or blocking up of the lines of a drawing in those parts.

C. O. No. 17 (Prof.), dated 14th June 1881.

Recipe for restoring damaged drawing paper.

125. There is a method of partially restoring damaged drawing paper which it may be useful to adopt on certain occasions; but where good paper can be obtained in the first instance, it is much preferable to any thus doctored. It is as follows:—

Take 1 drachm of isinglass steeped in 2 oz. of water for 12 hours, and simmer it for 15 or 20 minutes over a fire. When nearly ready add, very slowly and with much stirring, 20 grains of common alum (*phitkari*) in powder, then strain through linen and apply it with a flat brush to the paper damped and stretched on a drawing board; when dry, wash the paper over with water, which will indicate by the absence or otherwise of spots, whether a second wash of the above is necessary. When the paper has thoroughly recovered, take the brush and wash it well with plain water to take off any superfluous isinglass, and finally absorb the water with a clean linen rag. This treatment may be applied to a sheet of paper on which a map has been already begun, if the precaution is taken of laying it face downwards on a clean table, and securing the edges by pasting slips of paper round them, and applying the above solution carefully to the back only. Experience shows that when thus treated the graticule is little, if at all, distorted.

C. O. No. 38 (Prof.), dated 6th October 1884.

Cleanliness of maps.

126. The utmost care must be taken of the paper both to prevent dirt and creases; whilst the map is in progress, it should be kept covered with brown paper, only allowing the portion that is being worked on to be exposed; there is no excuse for dirt on a map that is prepared at leisure in office. A brown paper envelope open at one end for the insertion of the map is recommended. An opening should be cut on one side, the actual size of the drawing within the graticule, and the edges of the envelope strengthened by cloth binding to keep it from tearing. A map should never be cleaned up with any form of india-rubber; it weakens the lines, and in many cases breaks them, and ruins the names which have been typed. If a map has not been carelessly dealt with, and too black a pencil has not been used, there should be no necessity for cleaning it up at all; if cleaning is indispensable it should be done with stale bread crumbs.

127. Type of the various descriptions, now used for topographical maps, is obtained on indent from the Drawing Office, Calcutta. On receipt of type, a proof should be taken of each fount as it lies in block: (it is well to remember that type when wetted holds together better than when it is dry). The number of the letters, spaces and quadrats should be counted, and noted alongside the print of the fount. The knowledge that a proper list is kept, will go far to prevent petty theft by menials. Strong trays of equal dimensions, and of sufficient size to hold the largest fount in stock, and space for not less than 70 divisions, should be constructed. The type should be sorted into them carefully, each fount in a separate tray, and each letter into a separate division in that tray, and a print of the letter, or whatever is contained in the division, impressed distinctly on the upper side of the space. The capital alphabet, or upper case, should be kept separate from the lower case. There is an established proportion with respect to the number of each letter in any fount: it follows therefore that the space required for each letter in the tray is in the same proportion.

Type.

C. O. No. 13 (Prof.), dated 23rd September 1880.

128. The cleaning of type that has been used is a very important point and on it a good deal of the success of the typing depends. The impressions will never be clear and black, unless the old and dry ink is removed from the face of the type; nor will they be fine if the face and hair lines of the type are destroyed by rough usage during the process of cleaning.

Cleaning type.

C. O. No. 56 (Prof.), dated 23rd September 1880.

After an impression has been taken, and before the type is removed from the holder, it can be cleaned by lightly passing over it, a soft small camel's hair brush dipped in turpentine, and then dabbing gently with a ball of cotton wool. Type is thus always kept clean in the tray. The dabbing may be dispensed with if the type is not wanted till the turpentine has dried. It should be remembered that if it is necessary to wipe the fresh ink off the type when in the holder, a leather should be used and not a rag or cotton cloth: the hairs from a rag get into the ink, and spoil the impression by rendering it woolly. The typer should have by his side *away from the map* a little pot of turpentine; it is no trouble using it. If by neglect the old ink has got hardened on the letters, they should be boiled in a pot in a solution of soda (*sajji matti*), set up afterwards on a type board, and polished with a very soft boot-brush, wetted in the same solution, and then dried with cotton wool. A hard brush, or old tooth-brush, should on no account be used, nor should the face of type ever be *rubbed*.

The somewhat irksome duties of cleaning and sorting should never be neglected, but should form part of the daily routine.

C. O. No. 13 (Prof.), dated 23rd September 1880.

Type-holders.

129. Type-holders are of two sorts, the ordinary vertical pressure holder, and the Gastrell pattern which has a lever. The one is used for ordinary names, and the other for headings, foot-notes, etc

The former is composed of two parts, the type-holder and the socket. A little practice will enable the typer to place the letters properly in the holder, but the following remarks deserve his careful attention. The type should always be placed as nearly as possible under the centre of pressure, *i.e.*, the handle of the holder. Great care should be taken to get the face of the type level, and the letters in a straight line, to attain which end they should be gently shaken in the holder, the back and side screws being moved alternately a little at a time, until the type is just held firmly: no excess of pressure should be used. When small type is used, a piece of wood of suitable shape should be introduced into the holder to fill up part of the type space, so as to save the flat spring from undue tension.

C. O. No. 13 (Prof.), dated 23rd September 1880.

Pressure and pads used in typing.

130. The pressure and pad for each sort of type differ considerably; as a rule a small size type requires a thinner pad, and less pressure than type of a large size; regard however must be paid to peculiarities of construction in the type itself. Practice alone will make perfect in regulating the pressure and kind of pad required for each fount.

It is most objectionable to use a soft pad of many folds of blotting paper, or a sheet of india-rubber under the map when typing: the result of this is that the type is pressed deeply into the paper and the indentations caused thereby will cast shadows which reproduce in photography. It is no doubt easier to work with a soft pad but it only requires a little extra care and trouble to get clear impressions on a hard pad, such as cardboard. Greater pressure is required, but the indentation made in the paper will be little or nothing, and the result will be sharper and better, more especially in the photo-zincographed copy.

Ink for typing.

131. Typing ink should be rubbed up daily: the old ink is easily cleaned off the slabs with a few drops of turpentine. The ink should be sticky between the roller and slab, and give off a crackling sound when rolled. Thin ink is useless, and appears brown on a map: it will not dry and it smears.

The ink used in the Calcutta Office is "Winstone's Black Type Printing Ink No. 1."

A small quantity of the ink should be rolled on the slab, practice only will determine the exact amount required for each sort of type, but large type necessarily takes more ink than small, and does not require such a stiff ink. A light even roll backwards and forwards with the roller on the face of the type, is all that is required to ink up a name. A typer can be neat and clean if he chooses, but printing ink is apt to leave its mark, and when that mark is heavy, it is a difficult business to erase it from a map. Typing ink, slabs, and rollers should never be permitted to lie upon the same table as a fair map. It is easy to keep all such material upon a stool alongside the typer.

Ink for drawing.

132. The ink to be used for drawing maps is Indian ink. It must be prepared daily and rubbed slowly on a smooth surface: if the ink is ground rapidly and on a rough surface, it will be gritty and give constant trouble with the pens. It should be sufficiently thick to give black, not brown, lines. Draftsmen, who find their pens not working well, occasionally dip the point into water, or on a wet sponge; this habit is most objectionable, for although it answers the purpose of making the ink flow better, it makes it pale and unsuitable for photography. If the paper seems at all greasy, a little ox-gall may be added to the water with which the ink is rubbed up.

Scales and methods of drawing standard maps for reproduction and reduction.

C. O. No. 38 (Prof.), dated 6th October 1884.

C. O. No. 125 (Prof.), dated 24th May 1905.

133. Standard maps are drawn either on the 1-inch scale for reproduction or on the 2-inch scale for reduction to the 1-inch by photography. A map for reduction by photography should be so drawn that the reduced result shall be exactly like a map drawn for reproduction on the reduced scale.

The 2-inch fair maps must be projected on graticule in size 7′ 30″ of latitude by 15′ of longitude, so as to form the two sections of a standard 1-inch map which is 15′ latitude by 15′ longitude. The two sections bear the sheet number of the 1-inch standard, but are distinguished as N.-W. Section, and S.-W. Section. To facilitate the compilation of the two sections into one sheet, an overlap of half an inch in width is mapped along the adjoining edges. The lines along the adjoining edges of the sections are drawn in blue with black dots at the corners where the two sections are joined, and borders are only drawn where they are required for the final 1-inch maps. No names need be repeated in the overlap, which should be obtained by tracing from the adjoining sections. Very great care must be taken in making the details along the edges of the two sections agree with perfect accuracy along the common lines of contact. Before the sections which form a complete standard map are despatched to Calcutta, tracings must be made of the details along the graticule, and kept in the party office, so that the agreement may be accurate on adjoining maps.

Attempts have been made from time to time to draw maps in a slightly exaggerated style, so that they are fairly good when reproduced to full scale, and also when reduced to half scale. The results however have not been successful.

Orders are occasionally issued to a party to produce two sets of maps on the 2-inch scale, one for reproduction, and the other for reduction to the 1-inch scale. In this case the former should be drawn as finely, neatly, and with the same type, as a map on the 1-inch scale; the general appearance of the map should not be coarser because it is on double the scale; the real difference lies in the fact that more minute detail, and a greater number of topographical items can be shown on the 2-inch than on the 1-inch scale, because there is four times the amount of paper to draw upon: but this extra area of paper must not be filled up by representing the same items in a coarser style of drawing.

The other map for reduction will of course be in an exaggerated style, with such detail omitted as would cause confusion when reduced. The simplest method of obtaining the reduction is to carefully paste some bank-post paper over photo-zincographed copies of the 2-inch maps and then to pass them through a press. The paste should be made of cornflour with a little alum dissolved in the water with which it is cooked; a very thin solution of gelatine in hot water, or the alcoholic solution of gelatine given in paragraph 153 answers the purpose well. The bankpost paper is sufficiently transparent to allow of the details being seen through it, without being so distinct as to reproduce in the subsequent photograph. The necessary details for the exaggerated map are drawn at once on the bankpost paper over the dimly seen map beneath, in the proper style for reduction. Some judgment is necessary in selecting the details for omission, but this soon comes by practice. Printed copies of maps prepared in this manner and known as "tracing prints" can be obtained from the Calcutta Office, also prints in light blue or grey ink without the bankpost paper, but these have the defect of being always slightly greasy, and difficult to draw upon, and the blue ink has a tendency to turn green, so that details not required are liable to reproduce. Black print reductions to half scale joined together in one standard sheet, mounted on stout drawing paper, and covered with bankpost paper can also be supplied. Also cyanotype blue-print reductions to half scale, the detail being transferred to the fair map either with a tracing glass, or by transfer paper.

Stages in preparation of maps.

134. A map must be drawn and examined with the original, step by step as it progresses. However accurate and minute the original may be, its value will be lessened exactly in proportion to the errors and omissions allowed to pass on the fair map. The following is the procedure to be generally observed in consecutive order, in the preparation of maps for publication:—

(1) Projection of graticule, and rectangular co-ordinates.
(2) Plotting of trigonometrical, and traverse points.
(3) Inking in trigonometrical points, and village trijunctions.

(4) Tracing, or transferring details in pencil.
(5) Adjustment of edges with adjoining sheets.
(6) Inking in town and village sites.
(7) Typing of district, pargana, forest reserve names, etc.
(8) „ town and village names and heights, bench marks, etc.
(9) Inking in roads, railways, rivers, water-courses, broken ground, edges of cultivation, boundaries, etc.
(10) Typing, and drawing of minor symbols, rivers and stream names.
*(11) Hill-shading or contouring.
(12) Finishing borders, headings, foot-notes, references, scale, area statement, index to adjoining sheets, etc.
(13) Final examination.

Each stage must be examined by another person, and after correction, passed by the Provincial officer in charge of the section, before the next step is commenced, so that the "final examination" is reduced to a very simple matter. The signatures of the draftsman or typer, examiner, and section officer must be recorded on form P. 73, on the completion of each of the above stages.

All notes by an examiner should be entered on form P. 72, and handed over to the section officer for his orders. It is evident that all the details of a map cannot be examined at a glance; it is therefore necessary to adopt some plan by which a portion only may be examined at a time; this is most conveniently managed by dividing the subject into numbered rectilineal figures. The portion of the fair map not under examination should be kept carefully covered, in order to avoid soiling; especial care being taken that the paper is not creased or wrinkled by being pressed over the edges of a table.

Standard maps will now be published in black and three colours, *i.e.*, the contours in brown, the roads and paths in red, rivers, perennial streams, irrigation canals and distributaries, permanent tanks, symbols for wet cultivation, wells and *karezes* containing water, in blue, and all remaining detail in black. It will only be necessary to draw two sheets, *i.e.*, one for the hills, and one for the detail and typing, but to enable the Photo-Litho. office to recognize what portions of the detail are eventually to appear on the published maps in red and blue, it will be necessary to prepare two separate tracings of the detail shewing the items which are required in these two colours.

C. O. No. 126 (Prof.), dated 24th May 1905.

* The hill sheet, which is drawn separately, may be commenced after (8), the rivers, double-lined roads and streams being traced from the outline sheet, and inked in *very* faint blue (cobalt) lines.

C. O. No. 38 (Prof.), dated 6th October 1884.

C. O. No. 125 (Prof.), dated 24th May 1905.

Projection of graticule.

135. Each standard map (on the 1-inch scale) should be projected for 15 minutes of latitude, and 15 minutes of longitude, irrespective of the amount of drawing to be entered on it, so that there will be two maps in each standard sheet, one E, and the other, W. For the 2-inch scale the dimensions will be half of the above quantities, and so on in proportion for other scales.

If the graticule is to be projected by spherical co-ordinates one of the the meridians of longitude is first laid out with the aid of Tables XXXI to XLI, on the paper. From its extremities the upper and lower parallels of latitude are drawn with beam compasses, and intersected by the diagonals. The other meridian is now tested for length against the first, to which it should be exactly equal.

If the survey is based on rectangular co-ordinates, the first step will be to lay out in pencil by means of the rectangular co-ordinate plate alluded to in Chapter IV, paragraph 97, a net-work of equal squares. These are then numbered with reference to the origin of the survey, and the corners of the graticule plotted from their rectangular co-ordinate values, which are taken either from Table XLII, or computed on form P. 48. The lengths of the sides and diagonals of the graticule are now tested by means of Tables XXXI to XLI.

Finally the graticule is sub-divided into 5-minute divisions for the 1-inch scale, or 2½-minute divisions for the 2-inch scale, so as to enable the draftsman, when tracing, to disperse the slight differences that are sure to be found between the graticules of the field sections and the fair map.

Plotting of points.

136. All trigonometrical and traverse points on which the survey has been based must be plotted with the greatest accuracy, and checked. After being checked, the trigonometrical points and village trijunctions should be inked in, in conformity with the specimen symbols supplied by the Calcutta Office. Diagonal scales of latitude and longitude on cardboard can also be obtained; by using these, trigonometrical points may be plotted by their spherical co-ordinates on maps without the labour of constructing special scales.

Tracing.

137. The tracing is done by superposing the fair sheet on the original map over a tracing glass mounted on a folding wooden frame placed on an ordinary drawing table out of which an aperture, about the size of the glass, has been cut. The sides of the table are closed in with tin, whilst another sheeting of tin slopes outwards underneath the table. The tracing glass is then placed against a doorway leading out into the open, or against a low window, the upper portion of the doorway being panneled in to exclude the light except from below, whence it is thrown on to the

glass or tin by a man sitting outside with a heliotrope to reflect the sun's rays. The room should be darkened as much as possible, and if not dark enough, a wooden framework covered with black calico should be constructed so as to enclose the tracer and tracing table. Tracing should always be done with a hard pencil.

This system of tracing direct is however not always applicable when sunlight is deficient, and in the case of closely drawn, hill-shaded originals mounted on cloth, when the opacity is such that many mistakes occur, and lead to frequent errors in the inking in. It is better in such cases to have traces made on tracing paper in ink, and transfer the detail by means of black lead paper to the fair map, piece by piece, as it is required for inking in; if it is all transferred at once, the fair map becomes much smudged and dirty.

Inking in village sites.

138. In inking in village sites, the lines marking their limits should be straight, when they have been surveyed by tangents to their edges; the eastern and southern edges being shown by thicker lines. The main streets of large villages must always be drawn. Isolated huts and very small scattered hamlets must be shown by solid black rectangles. C. O. No. 13 (Prof.), dated 23rd September 1880.

Typing.

139. While it may be difficult to teach draftsmen to get good impressions from the larger kinds of type, any man can acquire proficiency in typing the smaller sized names which form the largest proportion of what is found on our maps. Names should always, if possible, be typed direct on to a fair map. The practice of typing on separate slips of paper, and pasting them on to the body of a map is objectionable, for the slips are liable to come off in after years. The necessity for pasting typed names on the body of a map is nearly always due to carelessness or bad work. D. O. No. 108 (Prof.), dated 16th January 1904.

The system of pasting on slips can, however, be used with advantage in headings and foot-notes, in dealing with corrections on fair maps, in changes of village names, and when the character of typing on an old fair map has to be altered, also where a large area of hill work has to be revised.

It has been found that "Large Bank Post $16\frac{1}{2} \times 21$, weight 11 lbs." is the most suitable paper for this purpose, and officers who may require it should use no other kind, and always quote the above description when indenting for it.

A proof of every name should be taken in a book (which should, if possible, be leaved with paper similar to that on which the map is being drawn), before it is typed on a map, to see that the letters are evenly placed, and that none are defective. No impression should be made on a map till a satisfactory trial has been obtained. A book such as this will also afford an easy means of checking a typer's daily outturn.

All defects in impressions of type must be made good by hand. A good test for ascertaining the degree of blackness of the lines of any map drawing, is to hold the sheet up against the light, when the relative blackness or brown colour (showing thin or weak ink), will be at once apparent.

C. O. No. 38 (Prof.), dated 16th October 1884.

Typing province, district, etc., names.

140. District and all such names should be arranged either in straight or in single very gently curving lines; each letter should conform to the radius of the portion of the curve on which it falls, and no letter should be upside down or nearly so. When space is limited to avoid over-crowding, the names of *tahsils* or *parganas and forest reserves* may be omitted on the map and numbers substituted; a table of reference to the corresponding names must then be given in the footnote.

If it is desired to type letters on a curve in an extended name, such as a province or district, a curve is laid down on the map, and along it, at proper intervals, a mark for each letter is made. At these marks normals to the curve are drawn. In the mill-board on which the type-holder is mounted, a central narrow slit is cut, and when the board is so adjusted that the normal drawn on the map coincides with this slit, it is obvious that the letter will stand in its proper relation to the curve. Double curves should be avoided. The typing of pargana names must be uniform. No adjacent province, pargana, district, or state names are to be typed on blank areas of which material is available at the Calcutta or Dehra Offices, to complete any map up to graticule limit.

Typing village names.

141. The following very simple and effective method of placing a name on any particular spot is recommended in preference to any other. Under the mill-board on which the type-holder is mounted, is placed a piece of tracing paper projecting beyond the edge, so as to receive the name when the type-holder is pressed down; under this again is laid a piece of ordinary stiff paper * not projecting under the holder, but at the sides; so that by laying hold of it, the whole apparatus, tracing paper, holder and all, can be lifted up and placed in any desired spot. An impression is first stamped on the tracing paper, and then the whole arrangement is moved bodily, until the name on the tracing paper lies in its proper place over lines previously ruled on the map where the name is to be typed. The slip of tracing paper is then torn off, the type re-inked, and the name stamped on the map.

The general rule is to type village names "due east and west, immediately to the east of the site;" this rule should be adhered to except when topographical detail, such as the outlines of water-courses

* Ordinary sand-paper with the rough surface upward answers very well, as the grain prevents the tracing paper and the mill-board from slipping, when raised.

and smaller rivers, may thereby be obliterated. It is obviously undesirable that any important details which have been surveyed with care should be omitted from the fair map merely because they happen to fall on a place which, according to this rule, is reserved for a name. In such cases the position of the name may be altered, or it may be broken, or in exceptional cases it may be typed obliquely; but great care must be taken that there shall be no doubt as to the site to which each name refers.

Typing heights.

C. O. No. 23 (Prof.), dated 25th April 1882.

142. In entering heights on the fair maps, it will generally be found that the trigonometrical heights refer to points on hills or other conspicuous spots. To render the map more useful, the officer in charge should select for insertion clinometric heights of points of importance, such as bridges, passes, roads crossing rivers or streams, junctions of rivers and streams, etc. The type for each class of height is entered in the specimen table of type to be used for topographical maps, and issued from the Calcutta Office. Trigonometrical heights of tower stations and buildings should be expressed in the form of a fraction, the numerator of which is the height above sea level of the station or summit of the building, and the denominator that of the ground level as follows:—

△ AKRA T. S. $\frac{141}{93}$

The following foot-note should also appear on the map:—*Where double values of height are given, the lesser indicates the ground level.*

The names of trigonometrical stations should only be typed alongside the stations if they represent well-known hills or sites, but not if the name is derived from the nearest village.

Inking in rivers, streams, etc.

143. The direction of the flow of rivers is shown by an arrow. If the river flows out of the body of the map, the arrow must be shown in the border outside the graticule. The northern and western edges of water in lakes, rivers and streams shown by a double line, must be thickened.

When inking in small streams which, commencing with a single line, gradually increase in thickness until important enough to be shown by a double line, care should be taken that the change is not made too soon; and when it is made, that the relief line is not too thin, or there will be a want of continuity in the stream. The change from single to double lines should generally be effected where some affluent joins the main stream.

Single line streams must be broken when they cross double line roads, or cart tracks.

Inking in cultivation.

C. O. No. 118 (Prof.), dated 20th August 1904.

144. Cultivation will be shown by dotted lines, the interior being left blank; it will include all new fallow and small patches of waste land scattered

within it. The dots are not to be drawn along roads and streams which pass through cultivation.

C. O. No. 44 (Prof.), dated 13th April 1885.

Inking in boundaries.

145. Particular attention is also to be paid to the correct rendering of the symbols for the different kinds of boundaries. As a guide to the draftsman cards have been lithographed, which give the correct lengths and sizes of the lines and dots; these may be obtained on indent from the Calcutta Office. In several of the patterns, the distinction between two different kinds of boundaries, lies merely in the size and thickness of the lines, the symbol used being the same; if care is not taken, and one is made a little too thin, or the other a little too thick, confusion may easily arise.

C. O. No. 94 (Prof.), dated 5th December 1901.

Forest boundaries, when drawn on the 1-inch standard maps, must be shown by the forest boundary symbol only. All pillars or other permanent marks will be omitted.

C. O. No. 125 (Prof.), dated 24th May 1905.

Village boundaries will not be shown on 1-inch standard maps, but a skeleton showing such boundaries must be prepared for each map so that they can be sur-printed if necessary.

Inking in roads.

146. In inking up the roads it is essential to use a drawing pen; no draftsman, however well his hand may be trained, can make a stroke as even and firm as may be obtained by the use of a drawing pen, especially if the road be a sufficiently important one to be shown by a double line. Some judgment is necessary in selecting the most suitable roads for insertion in a map. In well populated areas, the field section is almost always overcrowded with them, and in drawing the fair map many of these must be omitted, and only such as have some continuity in passing on from one village to another, should be retained. In hilly country, or where the ground is covered with irrigation distributaries from canals, it is rarely advisable to reject any, as the means of communication in such tracts form one of the most important items in a map. Roads passing through cultivation are not to be broken. When a cart track follows a stream, it must be indicated by a broken line drawn parallel to the stream.

Symbols.

147. A list of symbols admissible in topographical maps, on various scales, has been engraved for the use of the Department, and should be strictly adhered to; it can be obtained from the Calcutta Office.

Symbols for bungalows, factories, a spear and shield or flags (for police *chaukis*) must never be employed; in their stead will be printed the words Bungalow, Factory, Police Station, etc., or suitable initials such as D.B., I. F. (Indigo Factory) which must be explained in the footnote.

No cross hatching of villages, nor water-lines in tanks, should be drawn, as such lines, even when well drawn, are never reproduced satisfactorily by photo-zincography.

Wells should be shown very sparingly, unless in a very waterless country, when the position of wells may be of the utmost importance. Those in the neighbourhood of main roads, and those from which villagers obtain their drinking water are of most importance on a topographical map.

All bunds or embankments for training river beds must be shown on all maps. Canal irrigation channels and arteries must also be shown if of sufficient depth to form military obstacles.

Small patches of cultivation or waste land, single or outlying huts, trees in the midst of cultivation, very small groves of trees, unimportant surface irrigation channels, tanks, etc., should be omitted on a 1-inch map. These minute items have a fragmentary appearance and detract from the clearness of a map. C. O. No. 8 (Prof.), of 8th May 1879.

Sandbanks in rivers are to be shown by heavy dots near the banks of the river, the dots being drawn gradually finer down to the water's edge. The dotting on a sandbank forming an island should be uniform, and fine.

Hill-shading, and contouring.

148. In inking up the hill-shading or contouring, the chief point to remember is that the lines must be firm, and not too close to each other, as the tendency of photo-zincography is almost always to press out and blur the strokes in the original drawing. To effect relief, the contours must be thickened where the slopes are steep and the contours close together. Precipitous ground, also ravines and broken ground, must be shown by small detached vertical touches, even though the general hill drawing is done on the horizontal system. C. O. No. 1 (Prof.), dated 24th January 1879. C. O. No. 15 (Prof.), dated 16th November 1880.

In the case of maps in which the hills are printed in brown or grey, executive officers should invariably draw both the outline and hill-shading on identically similar paper, two sheets that have been subject to the same climatic conditions being chosen, it having been found by experience that, when drawn on different kinds of paper, the registration becomes extremely difficult, owing to different degrees of expansion. The best paper for the purpose is Whatman's special drawing paper; bankpost is unsuitable. C.O. No. 87 (Prof.), dated 7th February 1900.

In addition to the water-courses, all necessary outline is entered on the hill sheet in *light* blue (cobalt) before hill drawing is commenced. If drawn too dark, the blue lines will reproduce in photography.

It is also most essential that detail, such as boundaries, triangulated points, etc., which run along ridges, or on hill tops, be entered in blue on the hill sheets, to ensure the outline and hills being in agreement when the sheets are reproduced. Even with perfect agreement between the originals, a certain amount of distortion is unavoidable at times during the reproduction process, so it is the more essential that care should be exercised in guarding against preventable faults. C. O. No. 100, (Prof.), dated 17th November 1902.

C. O. No. 107 (Prof.), dated 19th December 1903.

To ensure the legibility of the typing, the hills have to be printed in an unduly light tint of brown, while if a colour sufficiently dark to show them up clearly is employed, the names can only be read with difficulty. To allow of a suitable colour being used for the hills, spaces must be left on the hill sheets wherever the smaller sized names, such as those of villages, streams, etc., will fall. The greatest possible care must be taken in marking off the blank spaces, that they are placed in *exactly* the proper position, and also that the spaces thus left are not larger than is absolutely necessary to allow of the name being clearly read, as large gaps in the hill-shading round the names on the published sheet present a very unsightly appearance. There is no necessity for leaving gaps round the larger sized type, as this shows up sufficiently well through the fairly deep shade of brown, or grey of hill drawing. The above instructions will be necessary only in the case of names for which Pica or smaller sized type is prescribed. In maps for reduction, gaps must be left for the corresponding larger type employed. Spaces must always be left for heights so that they may be easily read, and contours should not cross double-lined roads.

C. O. No. 100 (Prof.), dated 17th November 1902.

C. O. No. 48 (Prof.), dated 25th May 1886.

Typing of river names.

149. The names of rivers should be typed in conspicuous places parallel to their courses following the curves, and not in hard straight lines. When a river crosses the graticule limit, its name should be typed in the border.

Headings, footnotes, borders, etc.

150. Officers in charge of parties, by applying early in each recess, can obtain printed slips on bankpost paper, giving most of the details required for the headings and foot-notes. The items required can then be cut out and pasted on the sheets where needed, care being taken to use only the gelatine solution given in paragraph 153 for pasting them on.

The headings, foot-notes, borders, etc., must conform to the specimens issued from the Calcutta Office, one is for reduction to half, and the other for reproduction to full scale. When a map has been compiled from larger scale surveys, the original scale and date of survey, and method employed in reducing or reproducing the map must be inserted as a footnote, also the date when any portion of a map has been revised. Tables of areas must be inserted in accordance with the requirements of the particular survey under execution: also a linear scale drawn at the bottom of the map within the border. The magnetic variation should be entered at the top of the map *to the nearest quarter of a degree*, thus "Magnetic Variation 3° 15′ East," as given on the specimens above referred to.

C. O. No. 99 (Prof.), dated 18th September 1903.

In the case of all maps based on rectangular co-ordinates, the origin of the survey must invariably be entered as a foot-note.

151. The final examination must be conducted by an experienced officer, of another section if possible. It should not be delegated to junior assistants who of all others have had the least experience in mapping.

Final examination.

One method of examining the details of a copy with its original, is by superposing the one on the other over a tracing glass. C. O. No. 5 (Prof.), dated 13th June 1879.

Another method of examining a map is through a sheet of tracing paper fastened to the sheet to keep it in position. On this tracing paper any errors can be noted without the surface of the map being exposed, and can easily be located for correction when the examination is finished. Much time can be saved if an examiner corrects slight mistakes noted as he finds them.

Every map should also be examined under a magnifying glass to discover all weak, pale, and broken lines, and for touching up the typing of names. Much laborious retouching on the zinc plate may be saved by half-an-hour's work of this nature.

It must be distinctly understood that the responsibility of errors in a published map lies with the officer in charge of the party who submits it, and not with the Calcutta and Dehra Offices which exercise only a general supervision on the style of the drawing and printing, and conformity with the orders on such points as the graticules, foot-notes, conventional signs, etc.

The officer in charge of a party will sign every map submitted for publication in the right-hand lower corner. C. O. No. 64 (Prof.), dated 8th August 1892

Form P. 73, duly filled in, must accompany every map submitted for publication, and on the return of a fair map from the Photo-Litho. Office after reproduction, this form is pasted on the back of the sheet in the Calcutta Office.

152. All maps must be completed in every sense before submission for publication, and officers in charge of parties and drawing offices are held responsible for every detail depicted thereon. Incomplete maps can only be submitted with the sanction of administrative officers, and only in very urgent cases.

Procedure for submission of fair maps.

When a map is complete, it should be sent at once for publication, and not kept in a drawing office until others are ready for submission, in order to send them all off in a batch. Maps should not be marked urgent unless there is a real necessity, in which case the latest date on which the map should be available must be stated in the forwarding letter.

Every map should be submitted with a covering letter and invoice, addressed to the Deputy Surveyor General or administrative officer, who will then pass it on to the Assistant Surveyor General in charge of the C. O. No. 87 (Prof.), dated 7th February 1900 drawing office for careful scrutiny and report as regards technical details, but no examination or comparison between the originals and fair maps will be made in the Calcutta and Dehra Offices. The administrative officer will then issue orders, either for its publication, or for its return to the officer in charge of the party or drawing office concerned, for correction and resubmission.

When a map is finally approved at the office of publication, a certain number of prints are struck off, and stamped "Uncorrected proof." Two proofs are then forwarded without delay to the officer in charge of the party, or drawing office, responsible for the map.

The executive officer will pass one copy on to the officer who superintended the drawing of the map, who, after correcting any errors or omissions, either in the body of the map, or in relation to the adjoining maps, will affix his own signature, and return the proof to the officer in charge, who then scrutinizes the map generally and attaches his signature before returning it to the office of publication. This duty of final examination of a proof copy should be considered "urgent," so that all other work may give way to it, and the publication be in no way delayed. Officers in charge of parties should, however, recollect that this proof is not sent to them to give them an opportunity of completing the map by the addition of items omitted from the manuscript map, but merely that they may scrutinize it, and point out slight omissions and defects. It cannot be too strongly insisted on that the manuscript should be quite complete and accurate throughout. Corrections and additions on the zinc plate are troublesome, and are very apt to spoil the appearance of a map.

The other proof should be coloured up in accordance with the rules given in the specimen tables of conventional signs to be used on topographical maps, and returned to the Calcutta Office where it is recorded, and serves as a guide to the colourists in the issue of maps from that office. The items to be tinted are towns and villages, cultivation, forest, tanks, rivers, sandbanks, roads and boundaries.

C. O. No. 56 (Prof.), dated 10th March 1888.

Corrections to maps.

153. If it is necessary to make considerable corrections on a map, it is far better to paste thin bankpost paper over the faulty portions and re-draw that part, than attempt to erase the errors and re-draw over the scratched paper.

To mount bankpost paper on a map, the paper should be cut to the size required to cover the faulty portion. It should then be coated over the back with a warm gelatine solution, preferably that given below, and quickly laid in place, covered with a sheet of clean paper and well rubbed down. An excellent implement for this purpose is a rubber covered roller, like a large type inking roller, some 6 to 8 inches long.

The gelatine solution is made as follows, and has the advantage that it has little or no tendency to cockle the paper. Take 1 oz. of gelatine and soak in 4 oz. water, when soft, dissolve by heat and add 2 drs. glycerine. Then add little by little $1\frac{1}{4}$ oz. methylated spirits, shaking thoroughly between each addition. If the spirits is added too quickly, the gelatine will be thrown down out of solution. This solution must be warmed before use as it sets into a hard jelly.

When a map, subsequent to being sent for publication, is found to be inaccurrate owing to misspelling of names, etc., it can be procured from the Calcutta Office for correction, and subsequently submitted for publication as a new edition. C. O. No. 87 (Prof.), dated 7th February 1900.

Though corrections on a large scale will not be carried out in the Calcutta Office, minor corrections easily effected on the zinc itself can be done. If the officer in charge finds he is unable to decide whether the corrections are such that a new edition of the map should be published or not, he should refer the matter to Calcutta where the corrections will be carried out, or the fair map returned to his office for correction or re-drawing (in the absence of definite orders from his administrative officer) as the officer in charge may think fit.

154. On the publication of a standard map two copies are sent to the officer by whom it was prepared. One is kept as a record in his office, whilst the other is returned to the Calcutta Office, with all information required for the Atlas sheets noted thereon. C. O. No. 69 (Prof.), dated 12th August 1895.

Atlas sheet material.

Towns and villages which should appear in the Atlas sheets, are numbered in red, in accordance with the style of lettering which should be used for each, as given on the specimen accompanying the order quoted in the margin; roads and paths to be inserted in the Atlas sheets should also be entered. As a guide to the number of villages and roads which should be inserted, the executive officer should ask the office which publishes his maps, to supply him with a blue-print reduction to Atlas sheet scale of the sheet in question.

These 1-inch sheets will then, after signature by the executive officer, be sent to the Assistant Surveyor General, Drawing Office, Calcutta, for the guidance of the drawing office when preparing the Atlas sheets for the engraving office.

155. The external boundary of India between British and Foreign Territories is *no longer* to be shown by a riband of carmine.

Colouring of boundaries.

General maps of India are to be coloured by ribands and washes as under, in accordance with the colouring of the 32-mile Map of India as signed by the Secretary to the Government of India, Foreign Department, on the 20th February 1901 :—

C. O. No. 91 (Prof.), dated 10th April 1901.

F. D. No. 943 E. B., dated 22nd March 1904.

Washes.

British India and country under British administration	Pink tint.
Native States	Yellow tint.
Border tribes under British control .	Burnt Sienna tint.
Afghanistan	Light Blue tint.
Foreign possessions in India . .	Green tint.

All internal boundaries on provincial maps, standard sheets, Atlas sheets, ¼″ maps, etc., to be shown by ribands of colour in accordance with the table below, *except in the case of* thána *boundaries which, when entered, are in all cases to be shown by a riband of carmine.* This riband is to be shown in addition to the distinguishing riband of all *Sub-Provincial* boundaries, but when a *thána* boundary is common to that of a *province*, it should be omitted :—

Ribands.

Punjab	Indigo.
North-West Frontier Province . .	Bluish Purple.
United Provinces	Burnt Sienna.
Bengal	Green (Hooker's No. 2).
Assam	Indigo.
Burma	Burnt Sienna.
Bombay	Purple.
Central Provinces	Indigo.
Madras	Burnt Sienna.
Coorg	Green (Hooker's No. 2).
Ajmer	Do. (Do).
British Baluchistan	Do. (Do).
Baluchistan	Do. (Do).
Afghanistan	Light Blue.
Foreign possessions in India . .	Green (Emerald).
Native States	Yellow.
Russia	Reddish Purple.
Persia	Burnt Sienna.
China	Purple.
Tongking	Green.
Siam	Indigo.

The width of the riband on any particular map should vary with the importance of the boundary; thus that for a Province should be wider than that for a Division, and so on.

C. O. No. 40 (Prof.), dated 17th August 1886.

Distribution of maps after publication.

156. In order that the published maps of the Survey of India may be utilized to the greatest possible extent, the officers in charge of parties are required to attach to each standard map sent

in for publication, a slip giving the names and addresses of those persons to whom presentation copies of that particular map are to be sent. In this category should be included any native chiefs, or large proprietors who may have given aid to the survey party, and the chiefs of native states which may be included in the map. The names may also be given of any officials who may wish to have the map sent to them on service; but in conformity with Resolution No. 17S. of the Government of India, Revenue and Agriculture Department, dated 23rd February 1886, the cost of these issues will be debited to the department to which the officials belong.

Issue of uncorrected proofs to outside departments.

157. Previous to publication, copies stamped "Uncorrected proofs" may, if necessary, be issued to officials who may require them for *immediate use*; * the responsible officer should, as a rule, notify beforehand to the office of publication, the names of officials to whom it is desirable to send them. C. O. No. 31 (Prof.), dated 24th August 1893.

"Secret" maps.

158. The rules regarding "Secret" maps having been cancelled, transfrontier maps, equally with those of India, are now, generally speaking, available for public use; but any map on which an external boundary of India, or trans-frontier boundary appears for the first time, must be submitted in proof stage to the local authorities first, and their verified copies to the Foreign Department for final approval, and must on no account be issued to any one until it has been classed as "Public." Similarly all maps near, or across the frontier of India must be submitted to the Military Department for orders as to whether they are to be considered "Public," and until permission to publish has been received, must not be issued to any one without special precautions against its being made available for general use.

District maps.

159. Officers in charge of parties and drawing offices are required to prepare district maps on the ½-inch scale for reduction to the ¼-inch scale. C. O. No. 98, (Prof.), dated 13th June 1902.

As each 1-inch map in any district is published, three or more blue-print reductions on the ½-inch scale must be obtained from the head-quarters office, and such details, and names as are required for the district map should at once be inked up on them, and transferred to the fair map of the district, the work on which should be kept continually going until the whole area is complete, so that the map may be available for issue a few months after the publication of the last standard sheet of a district. The drawing of these district maps should not be allowed to fall in arrears.

* Maps on which boundaries appear for the first time are not to be included in this rule, as special regulations exist with regard to them.

The maps should be carefully, but not elaborately finished, they should show all important towns and villages, roads, canals, and streams, but it should be borne in mind that they are required principally for district officials, and should not be overcrowded with unnecessary detail especially in broken or hilly country. The usual symbols for post and telegraph offices, dâk bungalows, etc., should be used, but no village boundaries should be shown. (Specimens of district maps can be obtained on application.)

C. O. No. 104 (Prof.), dated 7th April 1903.

Degree sheet maps of Burma.

160. As no Atlas sheets of Burma are in existence, or likely to be engraved for many years, the Bangalore drawing office will prepare "degree sheet" maps, in lieu of, but on the same scale as, the district maps of India. Each map will contain an area of one degree of latitude by one degree of longitude, and the hills must be shown by horizontal contours. Specimens showing the style of map, and type to be used, can be obtained from Calcutta, also index maps giving the numbering of the sheets to be adopted in each series.

C. O. No. 86, dated 12th January 1900.

"Map of India and adjacent countries" $\frac{1}{1,000,000}$.

161. It was originally intended that this map should be published on the scale of 1 inch = 16 miles, but it is now determined that the scale shall be $\frac{1}{1,000,000}$ in order to meet the views expressed by the International Geographical Congress.

The orders already issued on the subject of the preparation of the map are to the effect that the sheets of India proper will be engraved, the outlying portions, of which the surveys are not finally complete, being photo-zincographed. As, however, the engraving of the India sheets will be a very lengthy matter, and as a good many of them contain country not yet finally surveyed, it is now decided to bring out a first edition entirely by photo-zincography.

All sheets will therefore be projected and drawn on the scale of 12 miles = 1 inch from the list of co-ordinates supplied, and the fair map completed for photo-zincography, the printing of names and headings being in accordance with specimens which can be procured. Since this work commenced, a more correct projection and table of exaggerated co-ordinates for projection of the sheets has been worked out and circulated to the various drawing offices concerned in the production of the sheets of the map. Certain of the sheets for which there was immediate need, were published as a provisional issue, but these will be re-drawn as soon as practicable on the new projection. As soon as all projections for the provisional sheets have been made, officers concerned will return the old tables of co-ordinates to the Superintendent, Trigonometrical Surveys, keeping only the tables of the revised projections in their offices. Also, as soon as any sheet is projected with the revised co-ordinates, the words

"Revised Projection" are to be clearly written in blue at the top of the sheet. This is essential that the publishing offices may know which projection they are dealing with.

The hills will be drawn in the vertical style on a separate sheet, and on similar paper to that on which the outline is drawn.

The zinc plates will be prepared by direct printing from reversed negatives and not by photo.-transfers, by which means the scale will be kept exact, and correct registration made easy. After a sheet is published, if it is one of those to be engraved, dry prints on tracing paper will be supplied to the engravers to work from. C. O. No. 90, (Prof.), dated 17th May 1900.

The sheets of Persia and the North-West Transfrontier will be prepared in the N.-W. Frontier Drawing Office, the remainder at the Calcutta and Dehra offices.

Orthography of native names.

162. The proper transliteration of native names into English must be carefully attended to. For most parts of India, lists of names showing the proper spelling have been circulated by order of the Government, but these lists cannot embrace every name that the surveyor will meet with, and consequently he should be conversant with the system in use.

The system of transliteration adopted by the Government of India, a modification of that proposed by Dr. Hunter, is given herewith. It must be in all cases strictly adhered to for the spelling of all names throughout India, with the exception of Burmese and Arabic names for which special rules are issued. G. I. O. No. 86, dated 5th June 1885.

Rules for transliteration.

Every letter in the vernacular must be uniformly represented by a certain letter in the Roman character as follows :—

Vowels.

Persian.		Devanagari.		Roman.	Pronunciation.
Initial.	Non-initial.	Initial.	Non-initial.		
اَ	َ	अ	not expressed	a	As in woman.
آ	ا	आ	ा	á	„ father.
اِ	ِ	इ	ि	i	„ bit.
اِيـ	يـ or ي	ई	ी	í	„ machine.
اُ	ُ	उ	ु	u	„ pull.
اُو	ُو	ऊ	ू	ú	„ rude.

Vowels—contd.

Persian.		Devanagari.		Roman.	Pronunciation.
Initial.	Non-initial.	Initial.	Non-initial.		
ای	ۓ or ي	ए	े	e	As in grey.
اَی	ۓَ or يَ	ऐ	ै	ai	„ aisle.
او	و	ओ	ो	o	„ hole.
اَو	وَ	औ	ौ	au	As ou in house (nearly), being a combination of the a and u above.

Consonants.

Persian.	Devanagari.	Roman.
ب	ब	b
بھ	भ	bh
چ	च	ch
چھ	छ	chh
د or ڈ	द or ड	d
دھ or ڈھ	ध or ढ	dh
ف	wanting	f
گ	ग	g
گھ or غ	घ	gh
ج	ज	j
جھ	झ	jh
ک or ق	क	k
کھ or خ	ख	kh
wanting	क्ष	ksh
ل	ल	l
م	म	m
ن	न, ञ, ण, ङ, or anuswara	n
پ	प	p

Consonants—contd.

Persian.	Devanagari.	Roman.
پھ	फ	ph
ر or ڑ	र or ड़	r
ڑھ	ढ़	rh
ث, س, or ص	स	s
ش	श or ष	sh
ت, ٹ or ط	त or ट	t
تھ or ٹھ	थ or ठ	th
و	व	w or v
ی	य	y
ذ, ز, ض or ظ	wanting	z
ژ	ditto	zh
ع	ditto	omitted, the accompanying vowel only being expressed.
wanting	ज्ञ	gy

Accents must be used in the spelling of all names on maps, and they must be introduced on all old maps when new editions or reprints are under preparation. C.O. No. 83 (Prof.), dated 25th May 1897.

It frequently happens that the fiscal name of a village, as given in the list, differs from the name by which the village is best known and commonly called by the people of the country; the latter appellation is obviously that which is required on a topographical map, the discrepancies, therefore, should be carefully elicited by field surveyors and noted by the entry of both names on the field sheets and the well-known name on the fair map.

Vernacular lists of all village names must be obtained from the district officials *(the English lists in the district offices are not to be trusted)*, and the transliteration should be made in party and drawing offices from these lists. The native surveyors should enter all names in the vernacular in their village books, and the English equivalent should be entered by the camp officer or executive officer opposite to them, after comparison with the vernacular lists obtained from the district officials. Names of rivers, hills, etc., should also be checked by referring them to district officers.

Chapter VI.

Trans-frontier Reconnaissance.

Preliminary remarks.

163. Trans-frontier reconnaissance differs from ordinary topographical surveying in two ways. Firstly, the time at the disposal of the surveyor is usually limited and his movements confined to certain lines of advance; and secondly, there is not the same necessity of possibility in such reconnaissances for the minute accuracy which should characterize a topographical survey. Trans-frontier reconnaissances are essentially made for geographical or military purposes, the two being often, but not always, combined.

Scale of survey.

164. In geographical surveys, the almost universally adopted scale is that of four miles to one inch. On this scale all the detail which there is time to sketch in hurried operations, can be shown, while at the same time the plane-table sheet covers a large area, and includes fairly distant hills, a very important point in work of this nature.

In military surveys, the choice of scale to be adopted will naturally be regulated by the extent of the area which the operations are likely to cover, the rapidity with which it will probably be traversed, the size of the prevailing features of the country, and the duration of the expedition. The scale of four miles to one inch is very generally adopted, and is all that is necessary in a hilly country sparsely inhabited, where the movements of the expeditionary force are rapid, and no long halts occur; but where the expedition covers a small area, or the country is thickly inhabited, or the features are small, it would be advisable to adopt the larger scale of two miles to the inch.

In addition to this, which may be called the general map of the country, important routes will have to be surveyed on the scale of one mile to the inch, while special maps in the neighbourhood of military posts or positions may require an even larger scale.

All these larger scale routes, etc., would be reduced and incorporated in the general map of the country.

Necessity and advantages of triangulation.

165. The necessity of basing all trans-frontier work on triangulation cannot be too strongly insisted on. As triangulating, when time presses, is difficult and laborious, there is a strong tendency to drop it, in advancing rapidly across the frontier, and to adopt some easier and less accurate method of survey. This is a great mistake; for the possibility has been

proved, even when moving with an army in the field, of executing a triangulation which will be of enormous assistance to the survey.

The advantages of having such a triangulation are numerous. By means of it, plane-tabling by interpolation from fixed points—by far the most rapid and accurate method of sketching—can be executed; the latitudes and longitudes of all the fixed points are obtained, and are available to plot, at any moment, on any sheet, and on any scale; the work is sure not to accumulate any appreciable error; the compilation of sketches made by different persons is enormously facilitated, as they can be adjusted with correctness relatively to one another, even when disconnected; very distant points can be fixed with sufficient accuracy from comparatively short bases; and heights can be accurately determined.

166. A complete equipment of the most approved type is kept up for issue to survey parties operating with an army in the field, but as it may often fall to the lot of a survey officer to select his own instruments, a few hints derived from practical experience may be found useful.

Equipment.

The regulations regarding the Survey of India on field service are found in the "Field Service Regulations, Intelligence and Survey."

Instruments are kept ready for issue at Dehra Dun, but as nearly every expedition varies as to the amount of transport available, nature of survey, etc., there cannot be any hard-and-fast rule as to what instruments should be taken.

Tents are obtained from the Ordnance Department, warm clothing for *khalásis* from the Supply and Transport Department.

167. A 6-inch transit theodolite reading to 10 seconds is the most useful; if fitted with micrometers in the eye-piece for subtense work, so much the better. One should be selected which has the level on the vertical limb and not on the telescope, and in which the vertical verniers are not obstructed by tangent-screws in front of them, otherwise there will be difficulty in illuminating them at night. Some of the newer theodolites have glass diaphragms with cross-lines cut on them; these are not so good as those of the old pattern, as dirt collects on the glass and obscures the view of faint distant objects. The theodolite should always be packed in two boxes, the horizontal circle in one and the vertical circle in the other, as the instrument has often to be slung across a mule or carried up a high hill on men's backs.

Theodolites.

The stand should be a braced folding tripod. In selecting one for use, the chief points which should be attended to are, that the heads of the legs can be screwed up so tight that the whole stand becomes absolutely rigid, and that the feet are so shod that there is no possibility of the shoes working a little loose, and so introducing an element of unsteadiness. The long conical iron shoe, such as is used on plane-table stands, gives great trouble in this respect.

Spare screws and nuts for the head of the stand should, if possible, be taken as they are apt to break or fall off, and get lost. The nuts of the new pattern stand are kept on by a split pin; in other cases it is advisable when marching to tie the stand up in a bag to avoid the possibility of the loss of the nuts. A spanner, to fit any nuts on the head of the stand, should be taken.

Plane-tables.

168. The usual survey pattern 24 × 30-inch plane-table with folding stand is generally most useful. If, however, the expedition is over a strictly limited area, a smaller and lighter plane-table, about 24 × 20-inch, may be found large enough, and is much more portable. All plane-table screws should be interchangeable, and a few spare ones taken, as well as spare bolts and nuts for plane-table stands.

Whatever pattern of sight-rule is taken, it should have the ruler portion fitted into a wooden case to protect the edge from injury, and if the sights are folding and kept up by springs, spare springs should be taken.

Heliotropes.

169. A few light heliotropes are required to mark points that could not otherwise be observed, and for this purpose the light cavalry heliograph answers very well.

Rules for trans-frontier surveying.

170. The rules for trans-frontier surveying may be laid down in a few words, as follows:—

(1) Base your work on triangulation whenever feasible, no matter how rough such triangulation may be;

(2) Always keep up a survey of the route of march, usually on double the scale of the general map, or larger, the distance measurements being obtained by the most accurate means which the nature of the country, length of marches, and other considerations will allow of. By the time you arrive at the forward camp, the surveyor entrusted with this route survey, should have the day's march ready plotted, with a reduced tracing on the scale of the general map, which you then transfer to your own plane-table in its true position. If for any reason, such as an unexpected change of route, the triangulation temporarily fails, you always have this route survey to fall back on.

(3) When triangulation fails, route surveys should be checked by astronomical observations for latitude and azimuth at camps along the line of march.

171. As it may be necessary, at any time, to measure a base, two steel 100 feet tapes should be taken, as they are more accurate and much lighter than chains.

Steel tapes.

172. A good reconnoitring telescope is most useful, though to get the maximum value out of it, it should be fitted on to a stand, such as a light prismatic compass stand.

Telescope.

173. Some method must be arranged of measuring the distánces along the line of march, as a traverse of the route passed over will usually be required. The instrument selected for this purpose will depend on the nature of country passed through, the rate of marching, whether the march has to be made along a road among baggage animals, and also a good deal on the predilections of the surveyor.

Distance measuring instruments.

The distances may either be measured directly by means of a perambulator, or indirect measurements may be made with a subtense theodolite, or ordinary theodolite in conjunction with a subtense bar.

The bicycle perambulator is that now used; it should be tested over a known distance, and the error noted. The *khalasi* pushing the wheel should also have a bag containing a spanner, screw driver, oil, spare nuts, shot for ball bearings, and two spare cyclometers, and should the wheel be likely to be used over very long distances, a spare rubber tyre should also be taken.

174. As it is important to fix the heights of passes, plains, camps, etc., and as they can rarely be fixed trigonometrically and not always with a clinometer, it is necessary to carry some height measuring apparatus on all occasions, and should the survey be entirely disconnected, even temporarily with the Indian traingulation, the necessity is still more marked.

Clinometers, barometers, etc.

Both aneroids and hypsometers give very useful results if the observations are taken carefully as noted hereafter, one or more of George's mercurial barometers are also sometimes useful.

175. A good supply of angle books should be taken both for triangulation and astronomical observations. For the former, P. 40, which has the horizontal and vertical observations on the same page is best; a plentiful supply of forms, paper, etc., should be taken, strongly bound blank ruled foolscap books are most useful for recording all irregular work and computations, instead of working on loose scraps of paper which sooner or later get lost.

Angle books.

176. It is important that men should be selected who are physically suited and accustomed to the country in which operations are being carried on.

Khalásis.

For work on the North-West Frontier, Punjabis, in Burma, Hazaribagh men, in Tibet, Nepalese or other hill men, are the best.

The fewer men taken compatible with the successful carrying on of the survey the better, specially where the *khalásis* do not speak the language of the country, also an interpreter and guide have to accompany each surveyor.

177. The list given below, may be subject to alterations according to the locality under survey, but it will give a good guide as to the instruments to be taken.

List of instruments.

Each planetabler should have—

1 Plane table with water-proof cover and stand.
2 Rectangular compasses.
1 Sight rule.
1 Clinometer.
1 Binoculars.
1 Holdall.
1 Small colour box containing besides colours, 12 drawing pins.
1 Haversack.
1 Prismatic compass without stand.
1 Aneroid.
Stationery, forms, and spare cloth.

Each triangulator should have in addition to the above—

1 6-inch subtense theodolite with vertical circle and tripod stand.
1 Telescope.
2 Chronometer watches (rated to keep sidereal time).
1 Shortrede's log-tables.
1 Chambers' log-tables.
1 Auxiliary tables.
1 Nautical Almanac.
1 Hints to Travellers.
Star charts.
1 Circular protractor.
3 Heliotropes (small).
2 Hand lamps for observing.
2 100 feet steel measuring tapes.
1 Beam compass.
1 Gunter's scale.
Stationery and forms.

The officer in charge of the survey party should also have—

1 Portfolio (small) for letters and plans.
2 Spare aneroids.
Spare compass and drawing pens.
2 Chronometer watches.
2 Perambulators.

1 Magnet.
1 Pantagraph.
1 Parallel ruler.
3 Ordinary thermometers.
2 Maximum and minimum thermometers.
2 Hypsometers.
1 Office table including appliance for copying.
1 Office tent.
Stationery and forms.
1 Copy of "Field Service Regulations, Intelligence and Survey."

Above all is it imperative that all instruments should be carefully examined by an officer before issue, and proved to be in good working order.

Base measurements.

178. In starting a trans-frontier survey, a base from which to extend the triangulation must be obtained. In the neighbourhood of our frontiers, thanks to the Great Trigonometrical triangulation, and the various extensions of it executed by topographical survey parties, bases are as a rule ready to hand, but should a base be not available, the first operation necessary will be to measure one.

This can be done in two ways :—

(*a*) By direct measurement with a 100 feet steel tape. This is often a somewhat troublesome undertaking. Two intervisible points half a mile or more apart, the ground between which is suitable for accurate chaining, must first be selected and the ground cleared as much as time allows. If there is any choice allowed in the position of the base, it is better to adopt that which affords the greater facilities for extending the triangulation by fairly symmetrical triangles. An error in the measurement of the base may possibly be corrected afterwards, when there is time and opportunity for measuring a fresh base in a more favourable spot; whereas, even if the base be measured with the utmost accuracy, the results will be unsatisfactory if the extension is not judiciously planned and executed over good ground; two measurements (each with a different steel tape if possible) of a base a mile in length should agree to within one foot.

(*b*) When it is impossible to get ground capable of being chained over with fair accuracy, a subtense measurement from one end of the base, of a bar at the other end must be made.

This was done at Lhasa where 50 sets of ten measures were taken, as owing to the swampy nature of the ground direct measurement was impossible.

The first method is preferable if the ground is suitable.

179. The base being measured, or under preparation for measurement, it is necessary to observe its true bearing or azimuth and the latitude of one of its ends. To obtain the latitude it is necessary to know the local time with fair accuracy, so that three classes of observations must be taken, *viz.*, those for time, latitude and azimuth.

Astronomical observations.

With regard to astronomical observations in general with a small theodolite, it is advisable, except when on rock, to drive into the ground three strong wooden pegs, on the heads of which the feet of the theodolite may rest. It is wise, if possible, to do this by daylight, as it takes a little time to get the pegs so driven in that the theodolite can be levelled without doing violence to the foot-screws.

The adjustments of the eye-piece for distinct vision of the wires, and of the object-glass for solar focus so as to eliminate parallax, should also be performed during daylight, as they are very difficult to do at night.

The wires may be illuminated either by the small axis lamp placed opposite the end of the perforated axis or by throwing a light on the narrow white reflector which is now generally attached to the object end of the telescope; but in its absence a piece of paper or cardboard $\frac{1}{10}$ or $\frac{2}{10}$ inch wide can be used, secured by a piece of thread or an india-rubber band and bent across in front of the object glass at an angle of about 45°. An axis lamp is preferable, if it works well; this, unfortunately, is not always the case.

For reading the verniers, a bull's-eye lantern or electric torch is required.

The process of getting the star into the field of the telescope is much facilitated by fixing on the telescope rough fore and back sights with their tops aligned parallel to its axis.

The barometer and thermometer must be read and recorded to enable the correction for refraction to be calculated, but no great exactness of reading is required.

When reading the horizontal verniers at night it will be found advantageous to read them from the side, so as to be able to throw the light straight on to the verniers in a line with the graduations.

A sidereal chronometer is convenient if a number of observations have to be taken; but unless there is the chance of having to take some delicate observations, such as longitude by telegraph, it is hardly worth the trouble of carrying one. For all practical purposes, a fairly good watch with a seconds hand does well enough, but it must be such that the seconds hand completes its revolution, as the minute hand covers each minute mark, and that it does this *at all parts of the hour,* otherwise there will be trouble in settling which is the correct minute.

In observing stars with a watch it is simplest to treat it as a sidereal watch with a large rate, as by so doing, the trouble of reducing the results into mean time is avoided.

It is only necessary to touch lightly on the methods of observing for time, latitude and azimuth, as it is assumed that surveyors are all well acquainted with the manipulation of theodolites. It is, however, strongly recommended that they should make themselves thoroughly familiar with the various astronomical observations and computations *before* they are ordered on trans-frontier expeditions.

Time observations.

180. For the computation of latitude observations it is necessary to know the local time with tolerable accuracy; for azimuth it may be required more accurately.

The usual and the most convenient way of obtaining the local time from the stars is to observe one star to the east and one to the west, and take the mean of the values obtained. The object of observing two stars on opposite sides of the meridian is not only that one may check the other, but also to eliminate errors in refraction.

Two stars should be selected which are moving rapidly in altitude, and are at a convenient elevation above the horizon, say 20° to 50°. The stars on, or near, the prime vertical (that is, due east or west of the place), will be those which are moving most rapidly in altitude.

The process of observing is as follows:—The instrument being properly levelled, the star is brought into the field of the telescope and the vertical circle clamped with the horizontal wire a little in advance of the star; the exact moment by the watch, of the star crossing the wire is noted, and the readings of the ends of the level bubble, and of the verniers on the vertical arc, are taken and recorded. The face is then changed, and the process repeated.

This forms one complete observation and it is advisable to take two such to each star, the usual order being one face left, two face right, one face eft. The mean of the lot, corrected for any dislevelment of the instrument, is used for purposes of computation; but should the results from two stars disagree, the observations to each star can be split up into two, and by this means the error probably discovered. Unless there is some mistake in the observations, the values of the watch error, deduced from the two stars by observations with a 6-inch theodolite, should agree to within two seconds, and probably much less; though, if they agree to within five seconds, the mean is probably close enough to the truth for latitude computations.

Should great accuracy be required, it will be found that better results can be obtained by observing fainter stars of the 2nd magnitude rather than very bright 1st magnitude stars. Of course the sun can be observed for time in the same way as a star, except that there are one or two more corrections to be applied in the computations.

181. The most accurate method of getting the latitude consists in observing north and south stars, on or near the meridian, in pairs of about equal altitude. Except in the case of the pole star, what are called circum-meridian observations are necessary, and for the computation of these, there is a special formula. The length of time before and after transit for which this formula holds good, varies with the position of the star. As a rough rule stars should be observed between altitudes of 25° and 65°, and should be within 20 minutes in time of their meridian passage. The object of the observations is to obtain a series of altitudes of the star, at known times, about the time of its transit across the meridian. The observations must of course be taken in pairs, face left and right. It is sufficient to take three or four pairs and it is as well that they should be fairly divided, some before and some after transit, but this is not absolutely necessary. When the error of the watch is known beforehand, it is easy to determine the watch time of transit and commence the observations accordingly. If, however, it is not known, it is best to set up the instrument as nearly as may be in the meridian by its compass, and then see when a star is sufficiently near the meridian to commence observing.

Latitude observations.

It is a convenient method of determining the latitude to use the pole star as the north star, and to balance and check it by observing a circum-meridian star to the south, as nearly the same altitude as the pole star as can conveniently be obtained. It is not necessary to observe the pole star near the time of transit. The latitude can be computed on form P. 43 with the aid of the tables in the Nautical almanac.

With a 6-inch theodolite the value of latitude obtained from the north and south stars of a pair should not differ by more than 15 seconds; and when several such pairs have been observed, their means should all agree within 8 or 10 seconds, and are often much closer.

For ordinary purposes one pair of north and south stars gives a fairly good latitude. It is better however to take two pairs, as then a fair result is likely to be obtained, even if one of the observations should be vitiated by some error. There is no object in indefinitely increasing the number of pairs, six good pairs will be ample for all purposes.

Another, and a very simple method of obtaining the latitude is to observe the altitude of one or more pairs (north and south) of stars as they cross the meridian. For this observation, no time observations or computations are required, it is only necessary to know roughly the time, so as to be in position a few minutes before the first star crosses the meridian. Then co-lat. = N. P. D. $\pm$ Z. D., the sign being $\pm$ for $\frac{N}{S}$

stars. If the pairs are of nearly equal altitude say within 10°, the corrections to refraction for barometer and thermometer may be neglected, as they will cancel. The error due to taking the observation on only one face will also cancel.

This method is preferable where time is of great importance, but the first method should be adopted when possible.

Latitude can also be obtained by circum-meridian observations to the sun, but should only be used if there is a possibility of the sky being overclouded at night, or on a triangulating station which cannot be visited at night, when even a rough latitude is often invaluable.

182. The true bearing or azimuth is obtained by observing the horizontal angle between a referring mark and a star, either at a known moment of time or when the star is at a known elevation. From either of these elements the local time of observation or the altitude of the star at the moment of observation, the latitude being known, the star's azimuth can be computed, and that of the referring mark deduced.

Azimuth observations.

Properly the referring mark should be at a considerable distance, say half a mile from the observer, in order that the same focus may suit it and the star. Unfortunately it is seldom possible to have it so far away at night in an enemy's country, and generally speaking a distance of 300 or 400 yards or even less has to be adopted.

As the distance is so short it is very necessary that both instrument and lamp be centred very exactly over their marks.

It is best after having in the afternoon observed the horizontal angle from the end of the base, between the referring mark and some well defined point, to leave the theodolite stand in position till night. This saves the very troublesome operation of levelling and centering the stand at night. It is also as well to make a man sit by the referring mark till evening, as not only is such a mark difficult to find in the dark, but it is also very likely to be removed by some one. In observing, one focus should be adhered to both for star and lamp, so the focus should be adjusted for the star, and when observing the lamp the eye should be kept far back and as steady as possible so as to minimize the effect of the parallax caused by the bad focus.

The azimuth is usually obtained as follows: knowing the time within a second or two, the horizontal angle between the lamp and the pole star is observed, and the time noted at which the star is intersected.

The actual observation is taken in the order:—lamp, star, star, lamp; then the face is changed and the observation repeated on the other face. This method has the additional convenience, that if the latitude is known roughly, the approximate altitude of the pole star is also known, and it can be found in the telescope and intersected after sunset and before it is too dark to see a distant station; thus avoiding the necessity of havin a referring mark.

Should the pole star be invisible, owing to clouds, etc., the angle between the lamp and any star, which is at a convenient altitude and is moving slowly in azimuth, is observed, and the time noted at which the star is intersected, sufficiently good results can be obtained by taking any two stars towards their elongation, which are on opposite sides of the meridian, and fairly near, say within 45° of the pole. Whichever method is used, by taking the means of all the observations, a mean horizontal angle between the star and the lamp, and a mean time of observation of the star, is obtained. From the mean time of observation, knowing the declination of the star and the latitude, the star's azimuth at the time of observation is computed, and by applying the observed angle, the azimuth of the referring mark is obtained.

The third method avoids the necessity of knowing the true local time. It involves getting both the horizontal and vertical readings of the star at the same instant. To do this it is necessary to make the star pass through the intersection of the cross-wires. From the altitude of the star, its azimuth for the same instant can be computed; so by observing in the same manner as by the first method, except that the star is made to pass through the intersection of the cross-wires, and the elevation, instead of the time of intersection, recorded, the same result is obtained. If, in addition, the time of the star crossing the wires is noted, all the elements necessary for computing the time are available, and the computation will be an easy one, as the figures will be nearly the same as in the azimuth computation, only arranged differently.

This method saves time and work when it is necessary to observe for time, latitude and azimuth on the same night. It is not quite so easy as the first observation and requires a little practice to make the star pass through the intersection of the wires. The best way to work it is to set one wire—the horizontal one is perhaps the best—in advance of the star, and then by moving *the tangent-screw of the other wire only*, to place the intersection of the wires so that the star will pass through it.

The stars selected for this observation should be of a convenient, but not high, altitude and rather north of the prime vertical. Observations should be taken as usual to both east and west stars, and the mean result used.

Azimuths can also be obtained by observations to the sun, but in this case it is usually better not to attempt the simultaneous observation, but to observe for time first, and then take the horizontal angles to the right and left limb. In very hasty triangulation, where a considerable azimuthal error is likely to accumulate, and where it is often impossible to connect the triangulation with a station near camp, it is necessary to observe an azimuth at a hill station. In these cases it is often impossible to reach the station early in the day or to remain there long. Time observation to the sun should be taken about 2 to 3 hours before or after noon, and it is often better to take simultaneous observations to the sun for azimuth, thus also saving the time spent on the double observation. These azimuths shouldbe taken as often as possible.

As the azimuth will be affected by the angles of the triangulation, there is no advantage in observing a lot of stars so as to get an azimuth, within 2 or 3 seconds of the truth, when, whatever precautions may be taken, the triangulation is sure to contain angles that are incorrect to the extent of 15 or 20 seconds, or even 30 seconds, on account of the ill-defined nature of the points observed. It is better to take any good opportunity of observing fresh azimuths which can be connected with the triangulation, so as to prevent the accumulation of azimuthal error. The azimuth of the referring mark deduced from two stars should agree within 20 or 30 seconds, and if the stars have been well chosen, and the observations carefully taken, the agreement will be much closer.

Longitude observations.

183. The determination of the longitude of a station by telegraphic exchange of signals has on several occasions been employed in trans-frontier work. The local time of each telegraphic signal has to be noted from a chronometer at each station, and the errors of the chronometers are determined by star observations.

If possible the two observers should, before or after the work, exchange signals in adjoining rooms to determine the personal error.

The two observers by exchanging stations and re-observing will eliminate personal error; and if more than two stations are to be observed at in succession, the observer at No. 1 station should proceed to No. 3, and then the observer at No. 2 to No. 4, and so on. This of course is not often possible in trans-frontier work.

To obtain the local time, eight well selected stars in pairs east and west should be observed before signalling, and eight after.

Observations on one night will give a fair result, it is preferable, however, in order to obtain a really good value to observe on three nights.

When signalling always press the button in the same way, and if, as is generally the case, you are working by break circuit, note the time when you press, and not when you hear the click. Similarly when receiving signals always receive them in the same way, do not take some by ear, some by eye.

The signalling should be carried out as follows—

Observer at A calls up —.—.—. (dash and dot three times).

„ „ B answers —.—.—. (do. do.).

Observer at A waits about 30 seconds, then sends five short sharp signals at irregular intervals from 20 to 30 seconds apart. A notes and records the instant of sending each signal; B notes and records the instant of receiving each.

After an interval of about 1 minute, B sends five similar signals.

These ten signals complete one "set" with an interval of a minute, the second set can be commenced omitting the calling up, etc.

Six "sets" are sufficient for one night.

The final result is the difference of longitude between the stations at which the observers at A and B observed their time stars, and not between the telegraph offices.

Method of carrying on triangulation.

184. The method of carrying on a triangulation in trans-frontier work is shown in the diagram at the end of this chapter.

A, B, C, D represents a small triangulation in the neighbourhood of the first camp. Whilst engaged on this, you ascertain from your interpreter, or guide, the direction of the next march, and observe to a hill or two, such as E, which is at no great distance from the line of march, and which can probably be reached either during the march, or after arrival at Camp 2, or at the beginning of following day's march. At E you again select, in a similar manner, a point F in the direction of the second day's march, and observe it, and as many as possible of the points as were fixed from your triangulation in the vicinity of Camp 1, and thus obtain values for Ec, Ed, Ee, and Ef. By means of these bases, and your observations at F, you obtain a mean value for EF.

In choosing a base there is little use trying to select naturally marked points for its ends. It is sure to be on low ground, and when obervations are made back to the ends from one of the hill stations, it will be impossible to recognize them unless they are marked by some very conspicuous artificial object such as a heliograph. The minimum length for a base may be taken as half-a-mile, the maximum will depend on the distance of the points to be fixed from it. While the ground for the base is being selected and prepared, a perambulator base of two or three miles should, if possible, be run and by means of it the positions of the surrounding prominent objects cut in on a plane-table. This having been done, the first steps of the triangulation can be laid out, the next stations selected and, if necessary and feasible, men sent out to put up marks on them to observe to.

If the precaution to ascertain the position of the surrounding hills before laying out the triangulation is not taken, it will possibly be found that it is not nearly so symmetrical as was expected, and as it might have been with the same expenditure of labour.

In observing it is a good plan to set up the theodolite always by the compass, so that the telescope points to the magnetic north when the theodolite reads 0° 0′. By this means all readings are also magnetic bearings, and it frequently assists the finding of a point which has been observed to, to know its magnetic bearing from the previous station. Another advantage is that the comparison of the computed azimuth of any ray with its magnetic reading will give the compass variation at that spot.

Unless there are very well defined points to observe to, it is useless repeating the observations; and it will be quite sufficient to take one observation face left and one face right to each object, but it must be noticed before closing work that the two readings are accordant within reasonable limits, depending on the nature of the object observed.

Another good method for intersected points is to take a round of angles on one face and then work round again on the same face, setting the theodolite to each of the recorded readings in succession, and then looking through the telescope to see if it is fairly on the object.

With regard to what to observe, a good rule is to observe every prominent object that is observable. Time after time observations taken more or less by chance, or simply to carry out the above mentioned rule, have turned out most useful. Of course if the time is limited a choice of objects must be made. In this case each of the previous stations should be observed once on each face and also all points on ahead on which it is possible stations may be made; and after that observations on one face only may be made to as many points as possible, choosing those, by preference, which from their position or well marked character afford most chance of being well fixed and of being useful when fixed. When observing to high distant mountain peaks the work should be got through as early as possible; often, after 10 A.M. snowy peaks are covered with clouds, and in desert countries high winds get up and dust-haze obscures all distant objects. The best rule to follow is to observe first all points on which the sequence of the triangulation depends, next the distant intersected points, and lastly the nearer ones. Points selected for stations must be well marked naturally, so that when they are visited it may be possible to identify, within a few feet, the point that has been previously observed.

As a rule it is best to observe the highest points of a hill, because they are nearly always the easiest to recognize. Observations are apt to be made to what appears to be a well marked bush or rock not quite on the top. Such points are always most difficult to recognize on arrival on the hill. If there is any doubt, readings should be taken to every point on the hill which is likely to be suitable for a station.

Should the observations have been taken to a prominent tree or rock, when the hill is visited the theodolite should be set up on the highest point and the reading of the tree or rock which had been observed to, taken and its distance measured. If no tape be available, or the ground is not suitable for measuring, a man should be sent to the point with a stick of known length and instructed to hold it horizontally and at right angles to the direction of the observer. The horizontal angle subtended by the two ends of the stick must then be measured, from which the distance can be computed with sufficient accuracy; knowing its distance and its reading from the theodolite, it is easy to correct all the previous observations to what they would have been if the position occupied by the theodolite had been observed. This is just as accurate as, and simpler and far more convenient than, reducing all the angles taken at the station to the position of the mark. The position occupied by the theodolite will in general be easy to recognize and observe to afterwards, when the usual pillar is built.

Triangulation in forest country.

185. When triangulating in a forest-covered country, there is nothing for it, but to be content with fewer stations and to try and clear the hills as much as possible, which is a work frequently of great magnitude.

In clearing a hill, one large tree should always be left standing conspicuously near the station, and during the observations a reading to it taken and the distance measured.

It often happens that owing to the shape of the hill top or to the limited time available, complete clearing is out of the question. In this case something can be done by raising the theodolite sufficiently from the ground to allow of a clear view, by a comparatively small amount of lopping of the branches of the surrounding trees. The method which was employed in the forest-clad hills of Assam, was as follows:—A suitable tree was selected, its trunk cut off at a convenient height, say 30 to 50 feet from the ground, and a scaffold erected round it; on this, and at about 4½ feet below the top of the trunk, a platform of bamboos was made for the observer to walk on, the platform and scaffold being quite isolated from the tree trunk. It is seldom that a tree with a straight trunk much over 30 feet can be got, but it is mainfest that the ability of placing the theodolite at that height will save an enormous amount of hill clearing. The highest to which Mr. Ogle succeeded in raising his theodolite (a 6-inch) by this means, with a perfectly isolated platform, was 45 feet. Colonel Woodthorpe, however, had on one occasion a platform built in a banyan tree for a 6-inch theodolite at a height of 107 feet from the ground. In this case it was not possible to completely isolate the observing platform but the great size of the tree made up to a considerable extent for the unsteadiness thus caused, and the accuracy of the observations was not affected to any very appreciable amount.

186. In choosing intersected points the main object should be to select such as will be of use to the plane-tablers. They do not require to be fixed with the same accuracy as stations, and it is therefore not necessary that they should be so sharply defined; but they should be conspicuous points about which, when seen by the naked eye, there can be no mistake.

Choice of points.

When triangulation has been carried some distance, there is frequently a chance of its breaking down, owing either to non-identification of points previously observed to, or from the line of advance preventing flanking stations from being visited. When this is the case, if a station happens to be visited before 9-30 A.M. or after 2-30 P.M., it is an excellent plan to observe an azimuth of the sun, if it is visible, and refer it to one of the back stations. This azimuth, with the observed angle between any two well fixed points not too much in a line, will give a very fair fixing of the positions of the visited stations.

One of the great difficulties of this sort of work is that there is seldom reliable information in which direction the next march will be, or which of the hills that have been seen from a commanding point, is likely to be passed close enough for ascent. All that can be done is to make out as well as possible from the guide, the direction of all the principal routes, and select points for stations along each of them. This uncertainty about movements is one of the chief reasons for the rule previously given, *i.e.*, to observe everything.

The length of sides permissible in the triangles, depends on the height of the stations and the consequent extent of view from them, the nature of the objects to be observed, the clearness of the atmosphere, and the maintenance of sufficient symmetry. The greater part of Afghanistan and Baluchistan is very favourable for triangulation and, as far as view is concerned, it is possible, if desired, often to have triangles of 30 and 40 mile sides, and intersected points sometimes as far distant as 100 miles.

There are other considerations, however, which generally make it advisable to keep the sides between 10 and 20 miles in length. If a point is observed from a hill A, and not again till a hill B, 30 miles off, is reached, it is highly possible that it connot be seen from B, or that, even though it is visible, the spot previously observed to, cannot be recognized; at any rate it is unlikely that a shot from a third station will be obtained so as to fix it satisfactorily. Again if it is eventually fixed it will have been of no assistance in mapping, as it will have been passed before its position was determined. Whichever way marching is being done, great efforts must be made to fix points on ahead in that direction to assist the plane-tabling, as the whole object of the triangulation is to assist the mapping. The points fixed on ahead for this purpose do not require to be fixed with extreme accuracy, and as a rule they will eventually be much better fixed, but it is important to get values for them as soon as possible, on which to base the topography. To effect this involves observation from a good many more stations than would be required if the triangulation was done first and plane-tabling afterwards. To aid in the future recognition of the points observed to, as each point is observed, its outline as it appears in the telescope, should be carefully sketched in the angle book. After observing, the station should be marked, if possible, with the usual mark-stone; and if stones are available a large pillar should be built to furnish a point to observe to. A pillar as high as a man, and three feet in diameter at the base, can be seen a long way against the sky-line.

If observations from a point on which such a pillar has been previously built are being made, it is as well before pulling it down to make way for the theodolite, to lay a couple of lines of stones, whose prolongations intersect at the centre of the pillar. If this precaution is not taken, it will very possibly be found that, when the pillar has been pulled down and the place littered with stones, it is impossible to tell within three or four feet where the theodolite ought to be put, unless there should happen to be a mark-stone, which is by no means always the case. Stations should always be carefully described, and if the hill is a difficult one to ascend, the best way up should be noted.

Even if the triangulator has not to do topography *pari passu* with his triangulation, he must still carry a plane-table for the purpose of keeping a triangulation chart, to assist him in identifying his points and as a graphic record of what he has done. To each point to which observations are taken, a ray is drawn, the name entered in the angle-book written along it, and on the ray a sketch of the point as it appears to the naked eye is made.

If several peaks have been observed for the first time from the top of a hill, very great difficulty will be found in recognizing them as they disappear from the observer's view on his descending the hill and remain hidden till some other hill is reached. If however even a rough clue to their distance can be found, their identification will be greatly facilitated. To effect this, when the observing is finished, it is a good plan to get on to some neighbouring hill fairly close, say three or four miles off, from which second plane-table rays to the intersected points can be obtained. There should be no difficulty in recognizing them, as the second point of view will be so very similar to what it was from the observing station; and though the intersections will be very acute if the points are distant, still the approximation they give, will be of great assistance in identifying the points.

Computations should always be kept up to date, and it will be found most advantageous, in spite of the work entailed, to calculate the latitudes and longitudes of all points required for use, instead of trusting to plotting them by distances. The plotting is far more accurate; detached sketches, based on graticule plotted points, can always be put together; the co-ordinates of points can always be transmitted to a distance; and the distance beween points not directly connected can readily be computed, which is particularly useful for interpolations.

The question of how much time to devote to topography, and how much to triangulation, is difficult to decide when both must be done by the same person. Of course triangulation is useless by itself, and if there is no particular object why the positions of points should be known with accuracy, or preparing ground to assist other topographers coming afterwards or working simultaneously, then triangulation must be entirely subordinated to the topography, and carried out only in so far as it assists the execution of the work actually in hand.

The angular errors of triangulation vary so greatly with the nature of the country and the objects observed to, that little can be said as to their probable amounts. In favourable country, such as Afghanistan, triangular errors occasionally come out as large as 30 or 40 seconds; but in such cases there is usually something shaky about one of the angles. To assist in determining to which angle to apportion most of the error, careful notes should be made in the angle book if any observation is exceptionally good, or is at all doubtful.

Heights should be freely fixed; for though the knowledge of the heights of a large number of hill peaks is not very important, they frequently enable heights in the valleys and open ground to be interpolated.

In the high and dry climate of Afghanistan and Baluchistan, the refraction is very much less than in India. Instead of ·065 or ·07 of the contained arc as in India, the mean of a large number of observations gave a coefficient of refraction of about ·05.

Work on the march.

187. When, owing to the rapidity of the march or other cause, anything approaching regular triangulation becomes impossible, it may be practicable to keep an accurate check on position by using detached bases at intervals. From each base, points are intersected to the rear, which have been previously fixed from the last base, and others are fixed on ahead to be in turn intersected from the next base. With this method, it is very advisable to observe a latitude at each base, not only to prevent the accumulation of error, but in case of the connection breaking down. An azimuth is also indispensable for each base. In this way, in suitable country, a sufficiently accurate connection can be maintained in whichever

direction, and however rapidly, the force marches. The essential conditions are, firstly, that there should be two surveyors, one to do the topography and the other the triangulation, and secondly, that there should be sharp, well-marked natural points visible from two consecutive camps. This method is particularly applicable when carrying a survey across a mountain range.

Another method is very useful when the line of march approaches north and south. Latitudes should be observed at all camps, and azimuths observed to all peaks in the line of march or nearly so. When camping abreast of any of these peaks their position must be fixed, with reference to the camp, by means of a short base with the usual latitude and azimuth. The difference of longitude can then be easily computed.

As an example of this method combined with that of short bases, a diagram is given showing the triangulation executed on the line of march of the Afghan Boundary Commission from Ibrahimabad to Kuhsan. The distance by road is 310 miles : this was covered in 16 marches, giving an average of 19·4 miles per diem. In addition there were three halts on the road ; so that 19 days in all were taken in completing the 310 miles. The surveyors were not allowed to leave the line of march until after their arrival at Kuhsan, when the triangulation north of Herat was executed.

As many of the points observed from the short detached bases were afterwards included in the Kuhsan triangulation, there was an excellent opportunity of judging the merits of work executed from these short bases, often not more than half-a-mile in length. The conclusion come to was, that as long as there were well-defined points to observe to, the system was capable of great accuracy.

Trigonometrical interpolations are often very useful, but to ensure their accuracy, it is necessary to have three very well fixed and properly situated points. Where there is any doubt as to minute accuracy of the points, and it is desired to interpolate the position from them, it is best to observe an azimuth to one of the points from the place ; then not only the angles between the various points, but also their true bearings, are known, and it is impossible that there should be much error in the position of the interpolated point. For this purpose azimuths observed from the sun are often very convenient : it must be remembered, however, in azimuths of the sun, that if the horizontal angle is only observed to one limb, the correction to the sun's centre is the sun's semidiameter × secant altitude.

Another very useful method of interpolation is by observations from two stations to two known points. In this case also an azimuth should be observed.

The third method being by an observed azimuth to a point whose latitude and longitude are known, from a station whose latitude is known.

The methods of working out these three cases are given in the auxiliary tables and one or another are constantly being used in transfrontier work.

188. When the triangulation is first started there will probably be no reliable height for the base. If so, an approximate height from barometric observations must be obtained and used throughout the triangulation, all heights observed by any of the party being invariably brought into the same terms. It should be noted particularly that, unless the readings of a standard barometer within a reasonable distance at the sea-level or at some known height, at the same time that the surveyor reads his own instrument, are available, no reliance can be placed on the result. Moreover the readings of the attached and detached thermometers must be recorded at the same time. With these data and a knowledge of the approximate latitude, the height may be determined by means of Tables XVII, XVIII and XIX of the Auxiliary Tables, third Edition, explained at page 33 *et seq.* of the same work. When eventually a trustworthy value for the datum is arrived at, either by joining on to some trigonometrical series, or to the sea, or from a continued series of barometric observations, it is only necessary to apply a constant correction to all the heights.

Datum for heights.

If possible, a George's barometer should be taken. It is the only one which can be counted on to withstand the shocks of travelling; it is most useful to compare with aneroids, or for a series of observations to fix the datum. The instrument is carried empty, and is only filled when wanted: the operation of filling, reading and emptying, taking about a quarter of an hour. As to the aneroids, the small ones of 2-inch to 2½-inch diameter seem to be just as accurate as the larger 4½ or 5-inch ones, and being so much lighter they are much less likely to be injured by a fall or a jar. They should only be employed where they can be constantly compared with a mercurial barometer, or with careful observations of a boiling point thermometer, on account of their great liability to changes of index error. In any case they should only be used for comparative or differential heights, and not for absolute ones.

Barometric heights are mostly unsatisfactory, and many observations taken in Afganistan, and worked out with simultaneously taken observations elsewhere, show that the temperature correction as given in text-books is excessive, the fact apparently being that in that country the temperature observed at ground level is that due to a highly heated stratum of air, and gives no clue to the temperature of the column of air immediately above the point of observation.

In taking aneroid heights along the line of march, the best plan is to read the instrument immediately on arrival in camp and then again next morning before starting, recording the times. This helps to eliminate the changes due to climatic variations of pressure. During halts, series of careful hourly readings should occasionally be made to get data for correcting observations for the diurnal wave of pressure. Every opportunity should be taken of checking barometric heights by comparing them with the heights brought along by triangulation. This can frequently be done by interpolating the position on the plane-table from trigonometrical points and observing their altitudes. The bases can be measured off the plane-table with quite sufficient accuracy for the purpose required.

189. The routine of plane-tabling will be familiar to all survey officers, but there are a few points in trans-frontier work which are worth mentioning.

Plane-tabling.

The great difficulty in all small scale surveying, where the fixings are usually far apart, consists in recognizing the ground and the points to which rays have been taken, as the features look so different when viewed from different directions. As previously mentioned, in dealing with triangulation, it is always advisable to get approximate positions for newly seen objects, by making a second fixing fairly close to the first, so as to get second rays to them before they have changed their appearance. Such approximate intersections will be found of immense value later on, in enabling the surveyor to identify the objects from a different point of view.

When the surveyor is moving from one point to another, he must have his eye continually on the points he wishes to recognize, and note every change in their appearance, otherwise he is liable to find himself in the position of having a number of rays drawn on his paper, and being quite unable to make out to what they were drawn.

As the triangulated points are few, the surveyor will often find that he wishes to interpolate his position or fix himself in places from which none are visible. He has therefore to find his position by employing his previous fixings and the points intersected from them. Here in reconnaissance work, there is scope for great judgment and experience in deciding which rays to adopt and which to reject when these differ irreconcilably, and in proportioning the accuracy of the fixings to the work required of them.

Each plane-table fixing should be clearly marked with a red dot for future reference. The knowledge of the exact spot a man has visited and fixed his position at, is invaluable afterwards in bringing various pieces of work together, and as a clue to the trustworthiness of the sketching.

It is very important that the men should be accustomed to the scale on which they are to work. Native surveyors are greatly creatures of habit, and when they attempt to sketch broken ground on an unfamiliar scale, they are for a time quite at a loss. In military expeditions time is far too valuable to waste in teaching a man his work.

Nothing should be looked on as too distant to sketch. When it is impossible to say for certain that any portion of country will be actually visited and surveyed in detail, it should be remembered that in a country of which no maps exist, any sort of guess at the lie of the country is valuable. Of course the style of drawing should be suited to the way the topography has been obtained.

When country has been sketched from single rays and estimated distances, it often supplies valuable information afterwards if rays to striking features such as peaks, gaps in ranges, etc., are inked in. Even where the detail will not come on to the plane-table, such rays should be inked in, and the description of the point written or drawn on them. The pencil rays drawn to outlying topography on the plane-table are best left in and not rubbed out for the same reason.

Plane-tabling in forest country.

190. In plane-tabling a hilly forest-clad country, to save time and expense in clearing the hills, a good method is to raise the plane-table well above the ground by means of *macháns* or platforms built in the highest trees on the tops of the most prominent hills. A *machán* is a very simple contrivance: thin pieces of wood or bamboos are laid down horizontally and lashed to the branches of the trees; this forms a frame work, over which are tied split bamboos to form the platform for the plane-table and its stand. The upper branches of the tree are lopped off to enable the surveyor to obtain a view. The *machán* is ascended by a ladder, either laid slantingly from the ground to the branches of the trees, or the rungs are tied to the trunk. There is considerable vibration when moving about, but on remaining still this ceases, and the compass is easily set, nor is the table thrown out of position in walking round it, if this is done steadily and not in jerks.

The advantages of the *machán* over clearing are, that time and expense are economized and from the raised position, a better view of the features of the country is obtained.

Should a high wind prevent the use of the plane-table on the *machán* after it is built, a prismatic compass should be used for taking careful bearings, and a note-book sketch made, all of which should be transferred to the plane-table on coming down from the *machán*.

In Assam and Manipur, *macháns* were frequently built, varying in height from 75 to 180 feet: the latter height was seldom attained, but 100 feet and over was of pretty frequent occurrence.

The positions of villages in forest-clad country can frequently be obtained by having fires lit near them and then cutting in the position of the smoke on the plane-table.

It is usual in India to insert numbers alongside villages in place of names, and a list is made at the side showing to what names the numbers refer. This is dangerous in reconnaissance work, as numbers are frequently obliterated with the rough handling of the maps, and as a rule no opportunity occurs of verifying them again. Moreover with a map that is constantly referred to at all stages of its execution, it is far more convenient to have the names entered in their proper places on the map at once.

Plane-table traversing.

191. In suitable ground, where the country consists of wide, open valleys or plains and narrow mountain ranges, and where the plane-table is not allowed to move much off the line of march, the best method of working is by plane-table traverse, the distances being measured by perambulator.

The modern perambulator consists of a suitably mounted bicycle wheel with a cyclometer attached. It is extremely light and very portable and can be used over a great variety of ground, and in suitable ground has several advantages over other distance measuring instruments. In open ground it is frequently possible to run 4 or 5 miles without setting up the plane-table; in which case no more attention is required than to generally supervise the direction. The rest thus given will be appreciated by those who have to march some 16 or 18 miles day after day, getting in all the topography *en route*.

Another great advantage which perambulating has over subtense methods on the line of march of an army is, that the surveyor is generally confined to the exact line of march, and is frequently more or less mixed up with the baggage animals. This renders it almost impossible to get a sufficiently clear view, either forwards or back, to observe carefully to a subtense bar. The perambulator can however be wheeled along comfortably.

With a perambulator in easy country, a good sketcher can average 16 miles a day for a length of time, and can occasionally do 20 miles a day, taking the day at 11 hours ; that is to say, the surveyor can keep up with laden camels and therefore do his day's work without ever getting behind the rear guard, a very important consideration.

When ground is unfavourable for the use of a perambulator, one of the subtense methods of measuring distance must be employed. Of these there are two which have both been used with much success, one measures the angle subtended by a bar of known length by means of a telescope with a micrometer eye-piece, the other measures the angle on the limb of the theodolite itself. The former instrument in its most convenient arrangement takes the form of a theodolite telescope with micrometer eye-piece mounted over a good prismatic compass on a firm stand. Thus the bearings and distance can be observed with the same instrument. This method was used with great success by Colonel Woodthorpe in Chitral, where he did as much as 18 or 19 miles a day with very satisfactory results as regards accuracy.

In the second method referred to, the bar is held horizontally and its subtended angle is measured on the horizontal circle as follows :—

The vertical wire of the theodolite is brought on to the left end of the bar and the reading recorded; the wire is then moved by the slow-motion screw of the upper plate on to the right end of the bar, but no reading is taken. Leaving the upper plate clamped, the telescope with both plates is brought back by means of the lower plate slow-motion screw till the wire again falls on the left end of the bar. The right end of the bar is again intersected by means of the slow motion screw of the upper plate. This process can be repeated a number of times with great rapidity, and then the final reading of the right hand end of the bar is recorded. There are then, after say *n* observations, the initial reading of the left hand and the final reading of the right hand end of the bar. The difference between the two readings divided by *n* will give a good measure of the angle subtended, and from it, of the distance required.

The two readings mentioned are the only ones really required ; but as a precautionary measure, to give a check, it is a good plan to record also the reading of the right end of the bar the first time it is taken. The difference between the readings of the two ends of the bar will give a rough value for the subtended angle, sufficiently near to expose any error in counting the number of times the process has been repeated. Tables are provided showing the distances corresponding to the various subtended angles for bars of 10 feet and 20 feet in length. The advantages in point of accuracy of this method are, that not only a considerable number of intersections of the ends of the bar are obtained, but the uncertainties of reading the limb, which with a 6-inch theodolite may easily amount to 10 seconds, each time the instrument is read, are minimized, the errors of two readings only being divided among *n* measures of the angle. This method also gives the horizontal and not the direct distance.

In flat jungle country, route surveying can be frequently carried on along the beds of shallow streams, the measurements being most conveniently made by means of canes. Lengths of 100 feet are easily procurable in cane-growing countries such as Assam. The canes being light are capable of floating on the surface of the water and are easily pulled taut by the chainmen. The best description of cane is the thin one from 1½ to 2 inches in circumference. A rope chain has also been found of great service in Burma and other forest-clad countries, when the route frequently follows narrow winding foot paths, through dense forests. Cane and rope chains also possess the advantage over chains that they are easily drawn through forest and jungle undergrowth without being caught by thorns in the bushes.

Rough methods of topography.

192. When none of the accurate methods of measuring distance are available, the surveyor must fall back on pacing, timing his march, or some other means of determining the distance passed over. The method of counting one's paces is a very tedious one and should only be resorted to when absolutely necessary, as when marching through narrow forest paths where the interruptions to the march are frequent.

Where the march is conducted without frequent halts, the system of timing the march—especially if riding—is better and more accurate. Timing demands a good deal of attention, but not nearly so much as pacing does; it is consequently less likely that any gross error will creep in.

In reconnoitring in a country where a regular plane-table and stand cannot be used, every effort should be made to sketch the ground at the time of passing through it and the surveyor should not trust to recording it in a note-book and plotting it afterwards.

The cavalry sketching case, which consists of a small board some 6 or 7 inches square with an arrangement for holding paper and with a small magnetic compass fastened on its edge, is an excellent instrument for route sketching. It should be used in conjunction, when possible, with a prismatic compass, the bearings to the more distant or important points being taken by the latter and plotted on the board, while the topography is sketched directly on the board. The advantage of the arrangement is that the board can always be held properly in azimuth by means of the compass on it, so that the sketching on it occupies its true relative position.

In surveying rapid shallow streams flowing through dense forest where, owing to the rapid flow of the water, it would be difficult, if not impossible—without cutting lines along the banks—to use canes for measuring, a good plan is to use "dug outs" (country boats hollowed out of a single tree) and take bearings by means of a prismatic compass suspended in gimbals; then to measure certain distances along the bank and note the time the boat takes to pass over them, carried down by the current only. This will give a scale of distance by time and the route survey can then be roughly carried on, the compass giving direction, and the watch the distance.

In marching along narrow forest paths where the view was so restricted that it was impossible to take continuous bearings of the route, Colonel Woodthorpe found it a good plan to estimate the direction of the route by observing the direction of his shadow or of that of the man in front of him—an occasional bearing being taken to check the bearing of the shadow.

Whatever method of sketching the route is adopted, the smallest opportunity should never be neglected of obtaining any check on the work, either by astronomical observations, the intersection and reintersection of distant peaks, or bearings to known points.

Finishing of work.

193. In inking up work great care should be taken to show what is reliable and what is not. If any site is placed at a guessed distance along a single ray, a portion of the ray should be inked in and a note of interrogation placed against the site. Everything that can be seen should be sketched in, as well as everything that can be gleaned from native information, and notes should invariably be made on the sheet itself to say how each portion was obtained. Such notes are invaluable to the compiler afterwards. When ground has been seen but not sketched, a general description of its character is better than nothing.

When reconnaissance work is being also done by other departments, such as the Intelligence Branch, effort should always be made to get the various parties to work as much as possible on the same points, and record frequent magnetic bearings on their sketches to such points, so that they may be combined.

When working with an army in the field, every endeavour should be made to keep a rough but complete compilation at Head-Quarters for the use of the General Commanding. New work should be added as it comes in, and if doubtful points of compilation are then and there settled while enquiries can be made, this may be invaluable afterwards when the fair mapping has to be done.

Every man plane-tabling, or carrying on a connected sketch of any considerable area, ought to keep a trace of all his inked-in work up to date. This trace should be left behind when he goes out to work, so that if he is attacked, and his sketch lost or destroyed, his previous work may not be lost too. The trace left behind will also be available for the compiler to use, or for any officer to consult, while the original is away. Traces of all work obtained up to date should frequently be sent to the base for use and safe custody.

Village names.

194. As a general rule natives of India spell names of villages, etc., very badly, unless in their own country. Every care should be taken that the names brought in are, if possible, revised on the spot by some local authority,

should an educated interpreter be obtainable In countries like China an Tibet, the names should be brought in, written by him in the characters of the country, and afterwards transliterated.

Reproduction of maps in the field.

195. As there is a constant demand by Generals Commanding for copies of field sketches and of current plane-table sheets, it will be found that no inconsiderable portion of a surveyor's time is taken up in supplying such copies. To obviate this as much as possible, various methods of reproducing maps in the field have been tried.

The simplest way is undoubtedly to keep a carefully made trace on tracing cloth, as recommended above, adding to it from time to time, such new work, as may become available, and then to print from this, ferrotype prints as required. The result is a print of the map in white lines on a blue ground, but there is little practical objection to this. The necessary printing apparatus is usually supplied with trans-frontier outfits.

The method of ferrotype printing is as follows :—Prepare the following solutions in two separate bottles, shaking well till properly dissolved :—

(1)	Citrate of iron and ammonia	1 part.
	Distilled or rain water	4 parts.
(2)	Ferric Cyanide of Potassium	1 part.
	(Red prussiate of potash).	
	Distilled or rain water	6 parts.

Mix up the two solutions in a dark room in equal parts in a China-ware or glass bowl or cup ; then coat the right or smooth side of the paper with a piece of sponge or cloth, taking care that no streaks are visible. The coating should be done twice (cross-ways) after which the paper should be hung up in the dark to dry.

To print, open the back of the printing frame in a darkened room, place the trace face downwards on the glass, and on the back of the trace place a piece of the prepared ferrotype paper, coated side downward. Replace the felt and the back of the printing frame, taking care that the back is pressed well home so as to secure close contact between the tracing and the paper.

Expose the frame to the light—direct sunlight where possible—giving about 5 minutes in a clear sun, and more—up to 30 minutes—in cloudy weather, according to the weakness of the light.

Then take out the print in a subdued light and wash it for about 5 minutes in at least two changes of cold water, until the whites in it are clear, then hang up to dry.

If the blue color is faint and appears to wash out, it is a sign of too little printing. If the whites are not clear, the prints are over printed, or the sensitized paper has been kept too long and has gone bad.

The solution should not be prepared in a larger quantity than required, as it will not keep for more than a few days in rainy weather, and a fortnight in clear dry weather.

The formula for chocolate prints is as follows:—

Ammonia-Citrate of Iron	2½ ounces.
Silver Nitrate	6 drams.
Tartaric Acid	1¼ ounces.
Distilled water	16 „

The Silver should be added to the solution in a dark room or in a darkened tent. The bottle in which the solution is made up, should be kept in the dark or wrapped in brown paper, and *not* exposed to the light; the above solution should be filtered before use, or decanted carefully from the sediment. The solution keeps well.

The paper is coated with a sponge in both directions, in order to ensure an even coating, then hung up to dry in the dark room.

The time of exposure, to make a paper negative from a tracing, with good sunlight is from two to three minutes; for a print from a paper negative, about five minutes; and for one from an ordinary glass negative, about two minutes.

After exposing, the print is washed with its face downwards in a dull light, for about five minutes, then fixed in a bath made up as follows:—

Soda Hypo-sulphite	1 ounce.
Water	10 ounces.

The print is allowed to fix in this bath for ten minutes, then it is washed for ten minutes, in running water, and hung up to dry. These prints can be photographed, and have therefore an advantage over ferro-cyanide prints.

Paper negative method.

196. A second method which has been used with success, but which requires considerably more skill, is to prepare a paper negative of the map to be reproduced by a special process, and then print from this negative ferro-type prints as before. This gives a map in blue lines on a white ground.

The method of preparing the negative is as follows:—Take a small quantity of the common native writing ink which is to be obtained in any bazar and rub it up in a saucer with a little water until it is quite smooth and will just work freely in a pen. Then make a trace of the drawing to be reproduced on bank post paper, the lines being drawn fairly firm and black. Having finished the trace, take a small quantity of a stock greasy ink, made by mixing intimately lamp-black and linseed oil, the amount depending on the size of the trace (for a half plane-table as much as will go on an eight-anna piece should suffice), on the end of a palette knife, and put it on a piece of glass or tin. Work it down smooth with the point of a knife, and add to it about 15 drops of gold size.

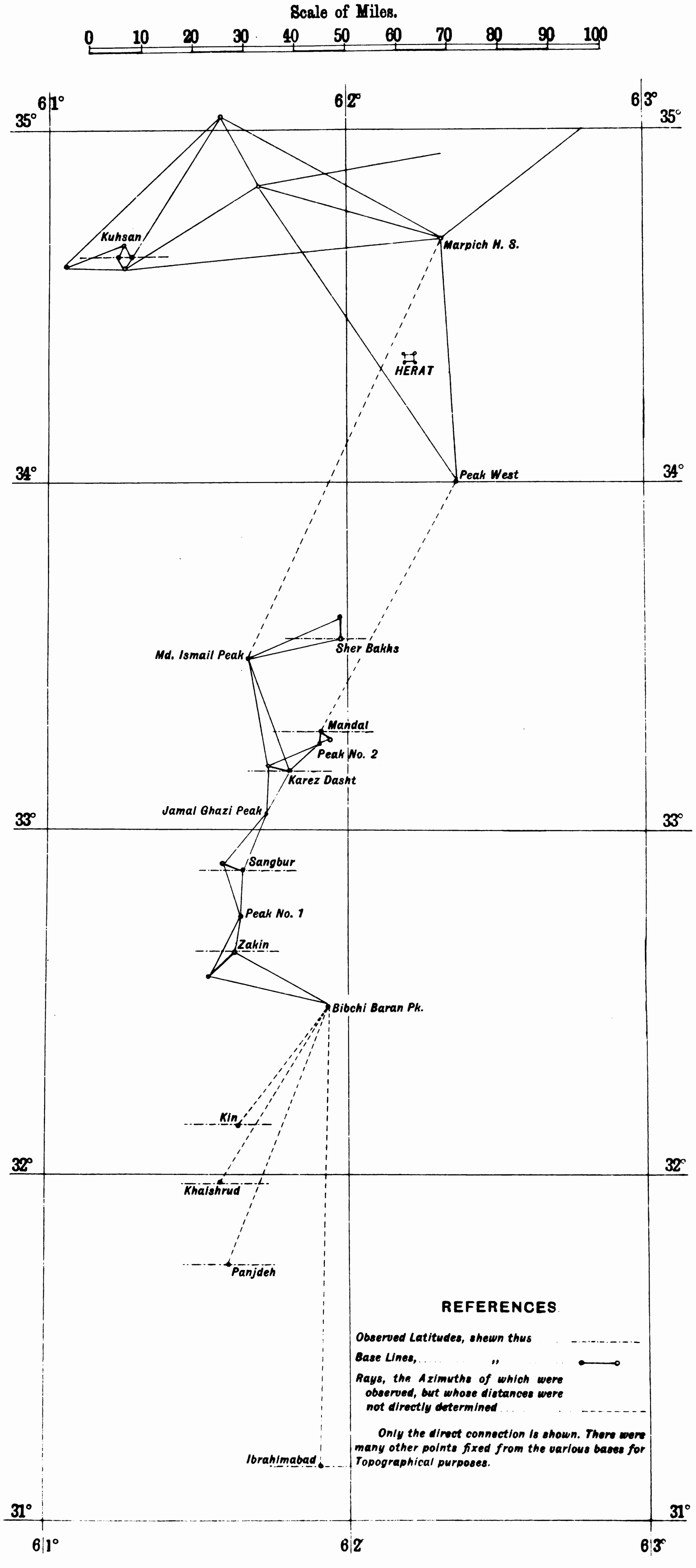
Work these well together and then work the ink up with the edge of a velvet-covered scraper. Now place the tracing face upwards on a smooth surface, and with the edge of the scraper, coat the face of the trace all over with the greasy ink. This is best done by parallel strokes, commencing at the edge of the paper where it is held down by the hand. The papers hould be coated as evenly as possible, no clots of ink being allowed on it, and it should appear almost perfecly opaque when viewed by transmitted light. Great care must be taken to keep the back clean. Now without delay, the whole trace should be immersed in a large basin of cold water, and be allowed to soak for a few minutes. It should then be drawn out and placed on a sheet of glass or a clean board, face upwards, and the face gently washed with water, using a wet camel hair brush lightly on it and plenty of water. If properly done, the whole of the traced lines will clear out, leaving the design in white lines on an opaque ground. If the brush is used too heavily, it will lighten the ground too much. The trace should then be spread out to dry. As soon as the paper is dry, it is ready to print from although the greasy ink will still be sticky, and it should be carefully handled. The ink should dry hard in 24 hours. Should there be much difficulty in clearing the lines, it is generally a sign that the greasy ink is too thick or that too much gold size has been added, it should therefore be thinned with a few drops of linseed oil before attempting another negative. It is recommended that a few experiments be tried on small pieces of paper before trying on a finished map. Fresh greasy ink must be mixed with gold size for each time of using.

The object of the addition of gold size is to cause the ink to harden after the negative is finished. The addition of the linseed oil retards the hardening and thus renders it rather more easy to clear the lines.

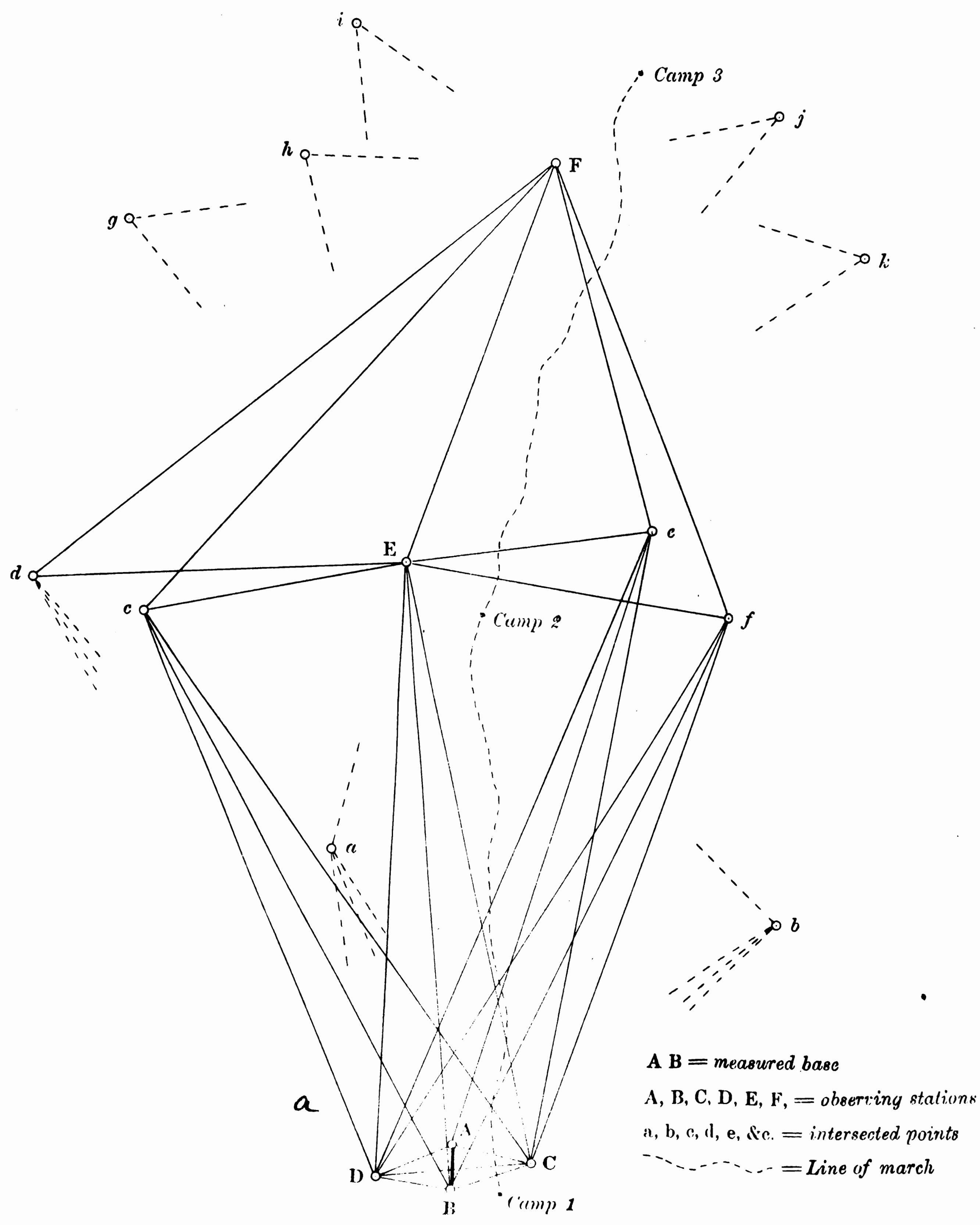
The ferrotype prints should then be printed from the negative as previously described, the negative being placed face downwards in the printing frame and the sensitized ferrotype paper on the back of the negative.

The necessary materials for the above paper negative process are usually supplied with trans-frontier outfits. A simple way of making a paper negative is with ordinary silver printing paper. Ilford's P. O. paper answers very well. Prints can be taken direct from a plane-table section with a sufficiently long exposure; half-an-hour or more is required with drawing paper backed with cloth. The negative should be a dark brown, it becomes somewhat paler after being fixed in the usual hypo-solution. When dry, the back of the negative should be rubbed with vaseline till the white lines shew through; this makes a transparent negative. Whatever method is adopted, paper ready prepared should be taken in a water and light-tight tin tube, as the preparation of paper is not always easy on field service.

of the AFGHAN BOUNDARY COMMISSION between
Ibrahimabad and Kuhsan for the purpose of
fixing the LONGITUDE of Kuhsan



METHOD OF CARRYING ON TRANS-FRONTIER TRIANGULATION



Computation of Latitude by Circum-eridional Zenith Distances

Station	Lhasa Base N. end.					
Date (Astronomical). .	9th Aug. 1904.					
	°	′	″	°	′	″
Longitude	91	5	30			
Object, N. or S. . .	γ. Draconis N.			ε. Sagittarii S.		
	h	m	s	h	m	s
R. A. of object . .	17	54	25	18	17	51
Chr. error	−9	4	56	−9	4	59
Chr. mean time of transit	8	49	29	9	12	52
	°	′	″	°	′	″
Mean obsd. Z. D. . .	21	54	20	64	5	9
Refn.—parallax . .	+		15	+	1	15
Approx. Z. D. = ζ_0 . .	21	54	35	64	6	24
N.P.D. = Δ	38	29	37	124	25	41
$\Delta * \pm \zeta_0 \dagger = \gamma_0$ . .	60	24	12	60	19	17
Log cosec ζ_0	0·428 1231			0·045 9464		
" sin Δ	$\bar{1}$·794 0887			$\bar{1}$·916 3680		
" sin γ_0	$\bar{1}$·939 2814			$\bar{1}$·938 9280		
" *m*	2·194 5143			1·928 1397		
Sum = log *A.m* . .	2·356 0065			1·829 3821		
	°	′	″	°	′	″
A.m . . .		3	47		1	8
ζ_0	21	54	35	64	6	24
$\zeta_0 \pm$ *A.m.* ‡ = ζ . .	21	50	48	64	5	16
Δ	38	29	37	124	25	41
Colat. = Δ ± ζ† . .	60	20	25	60	20	25
Latitude	39	39	35	29	39	35

γ Draconis.			
R. A. of star .	17	54	24·85
G. S. T. of M. N.	9	10	11·84
Corrn. for Long.			59·86
S. T. from M. N. of transit.	8	45	12·87
Retardation .		1	26·05
M. T. of trans	8	43	46·82
Chron. error .	+	5	42·
Chron. M. T. of transit.	8	49	28·82

* Δ is − if the object is below the Pole. † ζ_0 or ζ is $\frac{+}{-}$ according as the object is $\frac{N}{S}$ of the Zenith.

‡ *A.m* is $\frac{-}{+}$ according as the object is $\frac{\text{above}}{\text{below}}$ the Pole ; $m = 2\frac{\sin^2 \frac{1}{2} t}{\sin 1''}$, where *t* is the difference between the chronometer time of transit and that of observation.

Computed and compared by ______________________ ***190*** .

Computation of Latitude from Observations of Polaris out of the Meridian.

Station	Lhasa Base, N. end.		
Date (Astronomical)	8th Aug. 1904.		
	°	′	″
Longitude in arc	91		30
	h	m	s
Mean of Chr. Times	9	26	10
Error of Chronometer	–	5	36
Local Mean Time	9	20	34
Longitude in Time	–6	4	22
Greenwich Mean Time (a)	3	16	12
S. T. at Gr. Mean Noon	9	6	15
Local Mean Time	9	20	34
Acceleration for (a)	+		32
S. T. of Observation	18	27	21
	°	′	″
Mean Observed Altitude	29	22	4
Refraction	–	1	5
	–	*1*	*0*
Reduced Altitude	29	19	59
First Correction	+	17	56
Second Correction	+		24
Third "	+	1	14
Latitude	29	39	33

Computed and compared by ______________________ *190* .

P. 43 A.

Computation of Azimuth from Star Observations when the Latitude and Time are known. Applicable to Stars of North Aspect only.

Station	Dehra.		
Object observed	Polaris.		
Date (Astronomical)	22nd February 1903.		
	°	′	″
Longitude in Arc	74	28	50
	h	m	s
Mean of Chr. Times	8	2	14
Chronometer Correction	−0	22	0
Local Mean Time	7	40	14
Longitude in Time	−4	57	55
Greenwich Mean Time (a)	2	42	19
S. T. at Gr. Mean Noon	22	4	52
Local Mean time	7	40	14
Acceleration for (a)	+0	0	27
Sum = Local S. T. of Obsn. = θ	5	45	33
R. A. of Star = a	1	23	43
$\theta - a$ = Hour Angle = t	4	21	50
	°	′	″
t in Arc	65	27	30
Latitude = λ	28	26	10
Declination = δ	88	47	40
Log cos λ	$\bar{1}$·944 1611		
„ tan δ	1·676 8713		
Sum = Log (b)	1·621 0324		
(b)*	41·786		
Log sin λ	$\bar{1}$·677 7698		
„ cos t	$\bar{1}$·618 4193		
Sum = Log (c)	$\bar{1}$·296 1891		
(c)*	0·198		
(b)−(c) †	41·588		
Log „ (d)	1·618 9680		
„ sin t = (e)	$\bar{1}$·958 8788		
(d)−(e) = Log cot z	1·660 0892		
	°	′	″
z = Azimuth of Star	1	15	11
Angle R. M. and Star ‡	12	9	12
Azimuth of R. M. from N. = A	10	54	1

* To 3 places of decimals. † Sum is to be taken when t lies between 90° and 270°.

‡ In deducing this angle always substract the reading of Star from that of R. M. To obtain A, the *Azimuth of Star* is to be $\frac{\textit{added to}}{\textit{subtracted from}}$ this angle according as it is $\frac{\textit{East}}{\textit{West}}$ of the Meridian, *i.e.*, according as t is $\frac{\textit{greater}}{\textit{less}}$ than 180°.

Computation of Time by observations to a star.

Station	Lhasa Base.			N. End.			
Date (Astronomical)	8	8	04				
	°	′	″	°	′	″	
Longitude . . .	91	5	30				
Object, E. or W. . .	α Bootis W.			α Pegasi E.			
	°	′	″	°	′	″	
Mean Obsd. Z.D. . .	64	20	29	54	37	33	
Refraction—Parallax .	+	1	16	+		52	
Corrected Z. D.=ζ . .	64	21	45	54	38	25	
N. P. D. =Δ .	70	18	59	75	18	25	
Colatitude =γ . .	60	21	0	60	21	0	(N. A. (90∓δ) if δ is $\frac{N}{S}$.)
Sum=2s . .	195	1	44	190	17	50	
s . .	97	30	52	95	8	55	
$s-\zeta$ . .	33	9	7	40	30	30	
$s-\Delta$ . .	27	11	53	19	50	30	
$s-\gamma$ . .	37	9	52	34	47	55	
Log cosec s	0·003 7459			0·001 7558			
„ „ ($s-\zeta$) . .	0·262 1229			0·187 3816			
„ sin ($s-\Delta$) . .	$\bar{1}$·659 9806			$\bar{1}$·530 7401			
„ „ ($s-\gamma$) . .	$\bar{1}$·781 1122			$\bar{1}$·756 4030			
Sum = Log tan² ½ t . .	$\bar{1}$·706 9616			$\bar{1}$·476 2805			
„ tan ½ t . .	$\bar{1}$·853 4808			$\bar{1}$·738 1403			
	h	m	s	h	m	s	
½ t . .	2	22	3	1	54	45	
t . .							
	h	m	s	h	m	s	
t in time† . .	4	44	6	3	49	30	
✱'s R.A. or ⊙'s Eq. of T. .	14	11	18	22	59	62	
FOR STARS ONLY. Local S. T. of Obsn. .	18	55	24	19	10	32	
FOR STARS ONLY. S. T. at Local M. N. .	−9	5	15	−9	5	15	(P. II., N. A. Corrn. for Long. at 9·856 seconds per hour. for E (page 611 N. A.)
FOR STARS ONLY. S. Interval from M. N.	9	50	9	10	5	17	
FOR STARS ONLY. Retardation . .	—	1	37	—	1	39	N. A. page 590
True M. T. of Obsn. . .	9	48	32	10	3	38	
Chr. Time „ . .	9	54	8	10	9	13	
Chr. Error	+	5	36	+	5	35	

† In case of Sun when observed *east* of meridian 12ʰ − t should be entered : and in case of Star when observed $\frac{\text{east}}{\text{west}}$ of meridian, t is to be $\frac{\text{subtracted from}}{\text{added to}}$ its R. A.

Computed and compared by ______________________________ 190 .

Computation of Time by observations to the Sun.

	°	′	″
Station	Dehra Dun.		
Date (Astronomical)	26	7	01
Longitude	78	5	59·3
Object, E. or W.	Sun W.		
Mean Obsd. Z.D.	50	46	35·7
Refraction—Parallax	+		53·5
Corrected Z. D. = ζ	50	47	29·2
N. P. D. = Δ	70	26	9·8
Colatitude = γ	59	39	46·2
Sum = 2s	180	53	25·2
s	90	26	42·6
s − ζ	39	39	13·4
s − Δ	20	0	32·8
s − γ	30	46	56·4
Log cosec s	0·0000131		
" " (s − ζ)	0·1950799		
" sin (s − Δ)	$\bar{1}$·5342414		
" " (s − γ)	$\bar{1}$·7090816		
Sum = Log tan² ½ t	$\bar{1}$·4384160		
" tan ½ t	$\bar{1}$·7192080		
½ t	1	50	35·45
t			
t in time†	h 3	m 41	s 10·9
*'s R. A. or ⊙'s Eq. of T.	—	6	17·4
For stars only: Local S. T. of Obsn.			
For stars only: S. T. at Local M. N.	—		
For stars only: S. Intvl. from M. N.			
For stars only: Retardation	—		
True M. T. of Obsn.	3	47	28·3
Chr. Time "	3	52	20·4
Chr. Error	—	4	52·1

Add or subtract Semi-diameter if only one limb taken.

L. M. T. of obsn.	3	52	20·4	
Long. E.	5	12	23·9	
G. M. T. of obsn.	22	39	56·5	
Decl. at G.M.N.	19	45	54·3	N. A. P. II.
Var. in 22·67 hours.		12	4·1	
Decl. at time of Obsn.	19	33	50·2	

Eqn. of time.	6	16	56	N. A. P. I.
Var. in 22·67 hours.			86	
Eqn. of time at time of Obsn.	6	17	42	

† In case of Sun when observed *east* of meridian 12h—t should be entered: and in case of Star when observed $\frac{\text{east}}{\text{west}}$ of meridian, t is to be $\frac{\text{subtracted from}}{\text{added to}}$ its R. A.

Computed and compared by ____________________ 190

Computation of Azimuth (Horizontal and Vertical Angles observed simultaneously).

Station	Dehra Dún.					
Star, E. or W.	Algenib E.			α Ophiuchi *W.*		
Date (Astronomical)	24th October 1901.					
	°	′	″	°	′	″
Mean Zenith Distance	40	49	15	63	1	33
Refraction	+		45	+	1	41
Corrected Z. D.=ζ	40	50	0	63	3	14
Colatitude =γ	75	21	31	77	21	52
N. P. Distance=Δ	59	39	46	59	39	46
Sum=2*s*	175	51	17	200	4	52
s	87	55	39	100	2	26
s—Δ	12	34	8	22	40	34
s—γ	28	15	53	40	22	40
s—ζ	47	5	39	36	59	12
Log cosec *s*	0·0002842			0·0067029		
„ „ (*s*—Δ)	0·6623146			0·4139515		
„ sin (*s*—γ)	$\bar{1}$·6753622			$\bar{1}$·8114574		
„ „ (*s*—ζ)	$\bar{1}$·8647920			$\bar{1}$·7793289		
Sum=Log tan² ½*A*.	0·2027530			0·0114407		
„ tan ½ *A*.	0·1013765			0·0057204		
	°	′	″	°	′	″
½ *A*.	51	37	38·3	45	22	38·4
A.	+103	15	17	—90	45	17
Angle R. M. and Star	170	36	8	4	37	8
Azimuth of R. M. from N.	273	51	25	273	51	51

Computed and compared by ______________________ *190* .

APPENDIX.

MEMORANDUM

ON 6-INCH VERNIER AND 8-INCH MICROSCOPE THEODOLITES

BY

CAPTAIN H. H. TURNER, R.E.

Theodolites are constructed of various dimensions and according to different designs, but the chief distinction, with the small theodolites of the present day, lies in the manner of reading the horizontal and vertical circles. The two methods employed are:—

(1) The Vernier.

(2) The Micrometer Microscope.

Theodolites, how characterized.

2. It is customary to characterise a theodolite according to the diameter of its horizontal circle, thus a 12-inch theodolite means, that that particular theodolite has a horizontal circle 12 inches in diameter.

Theodolites used by topographical parties.

3. In topographical parties the 6-inch vernier and the 8-inch microscope theodolites are the two now principally used, it is therefore proposed in this memorandum to treat specially of these two theodolites. The descriptions will, however, apply generally to small theodolites of the same types.

Comparison of microscope, and vernier theodolites.

4. The microscope class of theodolite is capable of more accurate work than the vernier class, but it has the disadvantage that the microscopes rely on their wires for their utility, if a wire breaks it may mean that a day's work is lost in fitting in a new one, and for this reason, where rapid daily work is required, the vernier theodolite is often preferable. The two methods of reading the limbs of a theodolite have been in use for many years, but it is only recently that the smaller theodolites have been fitted with microscopes. This, however, is never likely to affect the continued use of the vernier, firstly, on account of the extra expense of the microscope theodolite, and secondly because, in the hands of an unskilled observer, the microscope theodolite might become useless owing to the wires breaking, or the focus of the microscopes becoming deranged.

Nature and stability of stand.

5. The nature of stand, in general use for the two theodolites under discussion, is that provided with moveable legs. The screws and nuts by which the legs are fastened to their top plate are very apt to get loose; to ensure the stability of the stand, an observer should always see that they are tightly screwed up before commencing his observations. If the ground on which the instrument is to be set up is soft and treacherous, three wooden pegs may be driven into the ground for the legs to rest upon, but ordinarily it is sufficient to clear the ground of turf or any loose stones. In some cases where very accurate work is required isolated brick or stone pillars are built on which the stand is set up.

Marking the position of instrument in its box.

6. Before taking a theodolite out, care should be taken to note the exact position of the instrument in the box, and when necessary marks should be written on the woodwork to denote the position of the different parts of the instrument relatively to the box. With the latest pattern of the 6-inch vernier theodolites both parts of the instrument are contained in one box, but the 8-inch microscope and the older patterns of the 6-inch vernier have a separate box for the telescope.

Removing the instrument from its box, and placing it on its stand.

7. Before taking the horizontal limb or lower portion of the instrument from its box the stand should be put up in position, approximately level and roughly plumbed over the station mark; the screw, which clamps the sliding plate to the bedplate should be released, and the sliding plate shifted, so as to allow the flanged feet of the footscrews of the instrument to be placed in the grooves constructed in the bedplate for their reception. Now take out from its box the lower portion of the instrument, consisting of the horizontal circle supported on a tribrach with three foot screws; to do this, grasp the two *Y* uprights firmly in both hands near their base, and lift it gently on to its stand, placing each footscrew in one of the grooves of the bedplate. In many instruments one of the footscrews and one corner of the stand head bear corresponding marks. The horizontal limb of the 8-inch microscope is placed upright in its box, sliding in and out of the box on a separate board; this board must first be pulled out and placed on the top of the box, the instrument can then be lifted by its *Y* uprights on to its stand. The horizontal limb having thus been placed in position on its stand, the sliding plate must be at once moved so as to lock the feet of the footscrews in their grooves, and the screw clamped. Next unscrew the cleats which close the *Y* bearings of the telescope, and wipe the *Ys* themselves with a camel's hair brush to ensure there being no grit on the bearings.

Placing the telescope in its bearings.

8. Everything is now ready for the telescope, but before attempting to lift this from its box, unclamp the vertical level and vernier arm. This being done place the hands, palms uppermost, underneath the object and eye ends of the telescope respectively, and gently lift the telescope from its box; by touching the vernier arm with the thumb at the object end, it can be made to swing down into its proper position, and the telescope can be placed gently in its bearings; the clips of the vernier arm must be made to fall one on each side of the shoulder projecting from the *Y* standard. In some modern theodolites a spring catch is provided for holding the arm attached to the verniers in position: this must be pulled back and given a half turn to secure it before putting the telescope into its *Ys*, an operation requiring both hands. The telescope should always be placed in its *Ys* with the vertical circle over the same horizontal vernier; the reason of this is to ensure that the vertical verniers shall always be read in the same order. With the 8-inch microscope theodolite some little care must be exercised to guide the clamp screw of the vertical limb, so as to pass between the two legs of the *Y* standard. Finally close the *Y* cleats over the telescope pivots, and screw them down lightly. In replacing the instrument in its box, the same routine in reverse order should be followed, it is only necessary to note, that in replacing the horizontal plate of the 8-inch microscope theodolite, the arm of the tribrach, which carries the lower tangent screw, must be placed in its proper position on the sliding board.

Description of the several parts of the theodolites.

9. The following description of the several parts of the 6-inch vernier applies also to the 8-inch microscope theodolite which is similarly constructed, except for the substitution of reading microscopes for verniers, and other small differences in details, which are described in paragraph 34 of this memorandum. The three footscrews need no description, they are provided for supporting and levelling the instrument, and work in the three arms of the tribrach. The boss of this tribrach is pierced with a female axis, in which the lower male vertical axis works; this latter is itself hollow and forms a female axis in which the upper male axis works. Each of these axes is turned and ground slightly conical and the centre portion of either the male or female axis is relieved, so that contact between the two is maintained only at their ends. The base of the axis is provided with a flange, which shares the superincumbent weight with the cone, and it is one of the essentials of stability that the axis of rotation should in every case work smoothly. Between the top of the boss of the tribrach, and the flange of the lower male axis, intervene the lower clamp and tangent screw arm. This brings us to the lower horizontal plate of the instrument which is screwed to the flange of the lower male vertical axis, and so rotates with it; it bears the graduations marked on silver. The silver circle is termed the limb, and is divided into 360 degrees, each degree, being sub-divided into ten-minute intervals. Underneath this lower horizon-

tal plate ar efixed two or three small vulcanite knobs by means of which the instrument may be easily moved in azimuth. The graduations on the limb are read by means of two verniers (or in the case of the 8-inch microscope, two microscopes) 180° apart, with moveable lenses above them. These verniers are screwed to an upper plate attached to the upper male axis, this plate is so constructed that it overlaps and protects the horizontal circle except at the parts exposed just below the verniers. Fixed to this upper horizontal plate are the two horizontal levels and the upper tangent screw. Next we come to the two standards, at the top of which are the *Ys*, which form the bearings of the pivots of the telescope. These standards are firmly screwed to the upper plate, and are made sufficiently high to allow of the telescope being rotated on its transit axis. Projecting inwards from each standard is a shoulder, on either of which the vertical level and vernier arm are clipped by means of antagonistic screws, or by a single screw working against a small spring piston. In this latter case, the piston can be kept out of the way till required, by pulling it back and giving it a half turn, for which purpose it is provided with a milled head. This concludes the description of the lower portion of the instrument, the other portion, consisting of the telescope and vertical circle with vertical level and vernier arm, being completely detachable from this lower portion.

The several parts of the telescope.

10. The telescope rests with its pivots in the *Ys*, it carries with it the vertical circle denominated the "face" of the instrument. The verniers appertaining to the vertical circle carry their clamp, tangent screw, and vertical level with them, the whole being fixed by means of two antagonistic screws, termed "clip," to the projecting shoulder of one of the *Y* standards. As in the case of the azimuthal verniers, the vertical verniers are read by means of two moveable lenses. The telescope consists of an outer and an inner tube, the outer tube is attached to the pivots by a thick metal band, the inner tube, works in the outer by means of a rack and pinion turned by a large milled head, by this means the telescope can be adjusted to any focus. The object glass is fixed into the inner tube. There are in all, four eyepieces for the telescope, two "inverting" of different magnifying power, and two "diagonal," also one dark glass for sun observations. Each inverting eyepiece consists of two lenses, which are screwed into either end of a short brass tube called the "mount." The "mount" slides in a split outer tube, the base of which is enlarged and screwed into the eye end of the telescope. Each of the diagonal eyepieces have their own "mount" and split tube attached to them, so that to insert them in the telescope, the split tube of the inverting eyepiece must first be removed. When the eyepiece is removed, the diaphragm carrying the wires is exposed to view, there are usually one horizontal, and either one or three vertical wires in the 6-inch vernier instrument. The diaphragm itself is held by means of four screws, whose capstan heads appear around the sliding tube of the telescope. These four screws are termed the "collimating" screws. Both pivots of the telescope are hollow and one of them is fitted with glass at the end, so that a lamp placed opposite it, will light up the inner tube of the telescope. In order that this lamp may illuminate the field of the telescope, a small reflector is passed through the telescope tube and by means of the small screw projecting from the telescope, this reflector can be turned in any required direction, and thus the field of the telescope can be lighted up. The illumination can either be done by a hand lamp of the bull's eye or bicycle pattern, or by the small lamp provided for the purpose, which can be fixed to the *Y* standard, by slipping it into the groove just underneath the *Y* bearing.

The foot screws.

11. The footscrews are for the purpose of levelling the theodolite. They should on the one hand have no sensible shake, and on the other should admit of being turned easily. The screws work in female screws at the end of the tribrach arms. In order to prevent shake, the latter is slit vertically and provided with a capstan headed screw for adjusting its grasp.

Lower clamp and tangent screw.

12. The lower clamp rests on the boss of the tribrach; in the newest pattern 6-inch vernier, as also in the 8-inch microscope theodolites, this clamp arm is quite free, but in the older pattern 6-inch vernier theodolite, it was attached to the lower axis by means of a brass ring screwed to the flange of the axis. The collar of the clamp fits loosely on the axis, but on one side a piece is cut away from the collar, and an extra piece exactly fitting is let in by means of a pin running into the clamp arm, thus so long as the screw is not clamped, the arm rotates easily about

the axis. The screw has a flag-shaped head and works in a female screw in the clamp arm; on being screwed up it comes in contact with the pin of the loose piece inserted into the collar, forcing this against the axis, which is thus held tight in the collar, and the clamp can no longer rotate about it; consequently when the clamp arm is moved slightly by means of the tangent screw, the lower axis is also moved. On the other side of the clamp is the tangent screw, two shoulders project from this arm of the clamp, the one having a fine milled-head screw working in it, the other having a small brass tube containing a strong spring piston fitted into it. This fine screw and spring piston clip on to a stud on one of the tribrach arms, so that by turning the screw, the clamp arm is moved slightly relatively to the tribrach, and if the lower plate is clamped this movement will be communicated to both plates.

The upper clamp and tangent screw.

13. The upper clamp is of quite a different pattern, it consists of a small lower clamp plate resting on the lower horizontal plate with its edge fitting underneath the brass rim of the limb, attached to this is a screw, which passes vertically through the upper clamp plate and the upper plate of the instrument, this upper clamp plate overlaps the brass rim of the limb, so that the limb can be held tight between the two plates, when they are clamped together. The screw on the lower clamp plate passing through the upper plate of the instrument is provided with a thumb nut, which when screwed home presses on the collar of the upper clamp plate and thus forces the two clamp plates together clipping the limb of the instrument tight between them, so that any movement of the telescope must be communicated to the lower axis of the instrument. The lower clamp plate has two small pins, which fit into the upper clamp plate, so that when the upper plate is not clamped, the whole clamp moves round with the upper plate.

The tangent screw is on the same principle as the lower tangent screw, the collar of the upper clamp plate being clipped between the piston spring, and a fine milled-head screw.

Horizontal levels.

14. There are two levels for the horizontal limb, the smaller or "cross level," as it is termed, is only used to assist in the rough levelling of the instrument and needs no description. The other level consists of the ordinary spirit bubble in a graduated glass tube held in an outer metal covering and fitted to the upper plate of the instrument at one end by means of an ordinary screw passing through a small bracket on the upper plate, and a collar on the level tube. At the other end it is fixed to a running screw with two antagonistic capstan-headed nuts on either side of the collar through which the running screw passes.

The clips.

15. We now come to the vertical circle and telescope. In instruments in which the clip consists of antagonistic screws, it is important to see that neither screw is bent, as screwing up would then cause a tendency to raise the pivots out of the *Ys*.

Vertical level.

The vertical level is attached to the arm in the same manner as the horizontal level to the horizontal plate.

The pivots resting in their bearings.

16. The pivots of the telescope should rest evenly in their *Y* bearings and the cleats when closed should neither press on the pivots, nor should there be any intermediate space between the former and the latter. The cleats (in small instruments) are fitted with corks underneath for the purpose of pressing on the transit axis, and these corks often require renewing.

The vertical clamp, and tangent screw.

17. The vertical clamp and tangent screw are similar in all essentials to those of the upper horizontal plate.

The vertical circle and verniers.

18. The vertical circle is divided into four quadrants each reading from 0° to 90° counterclockwise, the lines joining opposite zeros being respectively parallel and at right angles to the axis of the telescope; the readings on the vertical circle therefore give zenith distances and depressions on Face Right, and altitudes and nadir distances on Face Left. Each degree is divided, as in the case of the horizontal circle, into 10-minute intervals and these again are divided by means of the vernier so as to read to 10 seconds.

The vernier in every case is read in the same direction as the limb. To obtain altitudes on Face Right, the zenith distance reading must be subtracted from 90°, and similarly to obtain depressions on Face Left, the nadir distance reading must likewise be subtracted from 90°. The observer has the option of recording either altitudes or zenith distances, but having made his choice must always read the same vernier first on both faces. The horizontal verniers are generally marked A and B, whilst those of the vertical circle bear the letters C and D.

The Telescope. Object glass.

19. The power of a telescope is measured by the quotient obtained from dividing the focal length of the object glass by the focal length of the eyepiece. The object glass is protected by a sliding cap with a cover, attached to the outer tube of the telescope by a single screw on which it rotates, thus opening or closing the aperture. The object glass consists of two lenses held together in their cell by a thin brass ring. The cell itself is screwed into the object end of the telescope and provided with a milled rim to facilitate its removal for cleaning purposes. If, however, it is necessary to separate the lenses in order to remove fungus, care must be taken to replace them in the same position relatively to one another and to the cell itself. It will be found that the correct position is marked by a groove ground in the edge of each lens.

Eyepieces.

20. Of the four eyepieces, two are astronomical and have two lenses each, and the object as seen through the telescope is inverted, hence they are called "inverting eyepieces", and they are of different magnifying power. The other two are "diagonal eyepieces," one with four lenses, the other with two, they both contain mirrors, in consequence of which the former inverts vertically but not laterally, the latter laterally but not vertically. The diagonal eyepieces are only needed when observing celestial objects at a considerable altitude. The eyepieces continually require cleaning; to discover whether the dirt apparent is on the eye or object glass, look through the telescope at a clean sheet of paper, and at the same time turn the eyepiece in its cell; if the little specks whic happear in the field revolve with this motion, the eyepiece is at fault. The object and eye glasses should be cleaned with spirits of wine and a silk or other soft cloth free from grit or dust.

The diaphragm.

21. The diaphragm is nicked for one horizontal wire and three vertical wires. Ordinarily one vertical wire will suffice for work done with the 6-inch vernier.

As the wires are liable to be broken or become slack at any time, they have often to be replaced by the observer. The wires employed are either raw silk fibres or spider's web, the former can very well be used with eyepieces of low power, but with high power eyepieces, spider's web should be used.

Removing, and rewiring the diaphragm.

22. To wire the diaphragm it must be removed from the telescope; to do this, take out the four small screws, which hold the eye end of the telescope to the sliding tube; draw out the eye end and remove three of the four collimating screws, then turn the fourth, so that the diaphragm will protrude from the tube and can be conveniently laid hold of and removed. Before renewing the wires, clean the surface of the diaphragm plate and the nicks on it with spirits of wine. Place the diaphragm on a raised surface, a small cotton reel would be suitable, select a clean uniform piece of fibre; take two little balls of wax, which attach to the extremities of the selected fibre, and cut off the remainder. If one of the balls of wax be held in the hand and the other be allowed to hang freely, the fibre will become straight; with a camel's hair brush dipped in water gently brush the fibre to clean and damp it. Now place the fibre on the diaphragm plate, so that the wire will fall into its proper nicks, to accomplish this a magnifying glass will be necessary. The wire will then be suspended across the diaphragm and will be kept in place by the two little balls of wax hanging on either side. When the required number of wires are thus fixed, let a drop of spirit varnish, chloroform or chlorodyne fall on each nick, and put a tumbler over the diaphragm to protect it from dust. After three or four hours the varnish will have set, and the end of the fibres may be cut off, and the diaphragm carefully replaced in the telescope. In doing this the capstan-headed screws must not be strained, as, if pressure is exerted on the diaphragm, it may break a web, or cause it to sag.

The wire diaphragm may be replaced by the spare plain glass diaphragm with horizontal and vertical lines cut on it, which serve in the place of the wires. This diaphragm is fixed in the telescope in exactly the some manner as the wired diaphragm.

Sight vanes.

23. The telescope is fitted with back and forward sight vanes to enable it to be easily aligned : though not necessary when aligning on terrestrial objects, these sight vanes will be found very useful in bringing a star into the field of the telescope. To enable them to be used at night, a light should be thrown on them by means of a hand lamp or bull's eye lantern.

Milled-head for adjusting focus.

24. The adjustment for focus is made by means of the large milled head at the side of the telescope. The milled head carries a pinion which acting on a rack attached to the sliding tube draws the object glass in or out. The milled head may be removed by taking out the four small screws which fasten it to the telescope, the small screw in the centre of the milled head then being unscrewed, the head itself together with the pinion can be removed.

Illuminating arrangements.

25. There remain only the lighting up arrangements for night work; these consist of a small reflector in the telescope tube and a small lamp throwing its light through the hollow pivot on to the reflector. The reflector consists of a small silvered disc attached to a pin passing through the telescope tube with a milled head screw at the top. The reflector, by means of the milled head, can be turned so as to reflect the light passed through the pivot on to the telescope field.

The lamp used for passing the light through the hollow pivot is fixed on to the Y standard by slipping the lamp bracket into the groove just underneath the Y bearing. The bracket can be turned through an angle of about 140° by means of a pin working in a socket against a spring, the purpose of the spring being to keep the bracket steady in whatever position it may be. The lamp itself has two small tongues which slide in a groove in the bracket, so that the lamp can be revolved in the bracket. By this means the lamp being once fixed in the bracket, so as to throw a good light through the pivot, it is only necessary, when the light is not required, to move the bracket slightly. The lamp itself is provided with two small wooden handles on either side, so that the observer may easily manipulate the lamp without burning his fingers. Cocoanut oil mixed with a little kerosine should be used with this lamp. In the new theodolites these small lamps are made of aluminium, so that they may be as light as possible. Another method of illuminating the field of the telescope is by throwing the light of a hand lamp of the bull's eye or bicycle pattern, on to a small reflector placed just in front of the object glass. This reflector consists of a narrow piece of metal, about ⅛ inch wide, painted white and tinged to a split ring. To fix the reflector the cap of the telescope must first be removed, and then the split ring is slipped over the rim of the object glass. The reflector by means of its hinge can be put at any required angle to the object glass.

The magnetic needle.

26. The magnetic compass slides in a groove underneath the lower plate and can be removed at will. The north end of the needle should be placed towards the object end of the telescope, the north end will generally be found marked by a plain steel band near the pivot of the needle. When not in actual use, the needle should always be thrown off its centre by means of the small lever provided for that purpose.

Cleaning the instrument.

27. To clean the axes of the instrument, put the horizontal limb or lower portion of the instrument with its footscrews resting on a table. Unscrew the capstan-headed screw at the bottom of the axis underneath the centre of the tribrach, then unscrew the clamping nut of the upper plate and lift the upper plate off the lower by means of the *Y* uprights. The under surface of the upper plate, the upper male and female axes, the verniers, upper clamp and tangent screw and the top surface of the lower plate can then all be cleaned; next release the clamp and run out the slow motion screw, then lift the lower plate, when the lower male and female axes, the limb, and also the lower clamp can be cleaned. The limb and vernier hould be very carefully brushed free of dust and grit and washed with a little soap and water or kerosine oil, and finally rubbed over with a prepared mixture of lamp black and oil; in this process the tip of the finger should be used. The verniers should never be unscrewed from the top plate, and their edges should be treated with the greatest care. The lamp black can be made by holding an oiled plate over the flame of a wick dipped in oil. The axis of the instrument should be oiled with sewing machine oil, three or four drops of oil on each axis will suffice, it should be distributed evenly with the forefinger before replacing the axis in position. Before replacing the lower plate the tangent screw clip

should be opened out to enable it to catch the shoulder on the tribrach. After cleaning, each part of the instrument should move glibly on its axis.

28. The vertical plate is screwed to the telescope by four screws, which become visible after removing the verniers, etc.; these screws, however, should never be removed, since in construction the vertical plate has been fixed, so that it is as nearly perpendicular to the transit axis, and so that the line joining the zeros of the arc are as nearly parallel and at right angles to the optical axis of the telescope as possible, the undoing of the screws might lead to a permanent derangement of these adjustments. The vertical circle may be cleaned in the same way as the horizontal circle. The vernier lenses, the vertical level, and finally the verniers and arm with clamp and tangent screw, can each in turn be removed from the transit axis by unscrewing their respective screws, they should then all be cleansed and replaced.

Removing and cleaning the vertical plate, verniers, etc.

29. An observer should always be competent to thoroughly clean the instrument with which he is working. A theodolite although a delicate instrument is so made that any ordinarily careful person can take it to pieces, and after cleaning its several parts, put them together again without in any way impairing the efficiency of the instrument. The detailed description of the various parts of the theodolite given above will, it is hoped, assist observers when they find it necessary to give their instruments a thorough overhauling. For cleaning grease and dirt off the various parts, kerosine oil or benzine will be found useful. The silver arc should never be touched with cloth or brush, the finger should always be used. The best lubricant for oiling the various parts is sewing machine oil, but as little as possible should be used, common oil should never on any account be used. For cleaning lenses, spirits of wine and a soft cambric or silk cloth should be used.

Materials for cleaning.

30. Whilst observing the observer should always have a soft camel's hair brush close at hand, and should continuously keep brushing his instrument free of dust.

The observer to brush his instrument continuously.

31. The side of the instrument, on which the vertical circle may be, is termed the "Face" of the instrument.

Definition of "Face."

32. To change face signifies to turn the telescope 180° vertically, that is on its transit axis. Suppose the instrument to stand at face left (which implies that standing at the eye end of the instrument, its face falls to the observer's left hand), you observe a given object through the telescope; now turn the telescope vertically through 180° so that again standing at the eye end, the face is on the observer's right, then to observe the same object as before the instrument must also be turned 180° in azimuth.

Changing Face.

33. The vernier is a contrivance invented by Peter Vernier for the purpose of measuring aliquot parts of the smallest spaces into which the limb of an instrument is divided. It attains this object by measuring the differences between the divisions of two approximating scales, one of which is fixed and called the primary scale, the other moveable and called the vernier.

The vernier.

With the 6-inch vernier instrument both the horizontal and vertical limbs can be read to 10″. Each degree on both limbs is divided into 10′ intervals, to obtain the reading to 10″ the united distances of fifty-nine of these 10′ divisions is taken as the total length of the vernier, and this length is then divided up into sixty divisions, so that fifty-nine divisions of the limb = sixty divisions of the vernier.

Whence $\frac{59}{60}$ divisions on limb = 1 division on vernier
and since 1 division on limb = 10′ of arc
$\therefore$ 1 division of vernier = $\frac{59}{60} \times 10' = 9'\ 50''$
and 1 division on limb — 1 division on vernier = 10″.

Generally if a be the arc measure of one division on the limb and the united distances of n such divisions be taken off on the vernier, then

$$\text{One division on limb} - 1 \text{ division on vernier} = \frac{a}{n+1} \text{ in arc.}$$

Now if the index of the vernier is coincident with the zero of the limb, the first division of the vernier is 10″ short of coincidence with the first 10′ division of the limb, if then this first division is made coincident with the first division of the limb, it is evident that the reading will be 0° 0′ 10″. In like manner if the 24th division of the vernier is made to coincide with the 24th division of the limb, the index of the vernier must have been moved a distance of 24 × 10″ and the reading would be 0° 4′ 0″. To denote the minutes in the vernier, every sixth division is made longer, and every twelfth is marked with its minute number, thus the twelfth division is marked 2, the twenty-fourth 4, and so on, and the minutes and seconds can be read straight from the vernier, and added to the reading indicated on the limb by the vernier index.

Suppose the vernier index to be between 27° 30′ and 27° 40′ and that the 53rd division of the vernier is coincident with a division of the limb ; at the 48th division of the vernier we read the figure 8, and we are five divisions beyond this, so that the reading of the vernier to be added to the 27° 30′ indicated by the vernier index is 8′ 50″, that is, the reading of the instrument is 27° 38′ 50″.

The 8-inch microscope theodolite. Differences from the 6-inch vernier.

34. The 8-inch miscroscope theodolite is very similar in the details of its construction to the 6-inch vernier, and it will only be necessary to notice here the differences between them. In taking the instrument to pieces it will be noticed, that the upper male axis ends in a screw, which projects below the female axis of the tribrach, a capstan-headed nut being screwed on. Over this nut a cap and washer are screwed to the axis of the tribrach, the cap acting as a protection to the capstan head and also forming a support for a hook from which the plummet can be suspended. Another slight difference is that the lower clamp is not fixed on to the lower axis, but is entirely free from it, this however is also the case in the new pattern 6-inch vernier. In addition there are some small differences in the telescope and vertical circle, the latter is graduated from 0° to 360° instead of being divided up into four quadrants. The telescope has its milled head for focussing at the top or bottom of the telescope according as the instrument is F. L. or F. R. instead of at the side. On the reverse side of the transit axis to the face, a counterpoise is fixed, so that the transit axis should not be liable to an upward tilt on that side and to prevent dislevelment when changing face owing to lack of balance. The bracket holding the vertical level, as also parts of the telescope tube and sight vanes have been constructed of aluminium in order to lighten the instrument.

The main difference between the 8-inch microscope and the 6-inch vernier theodolites lies in the method adopted for sub-dividing the limbs ; the method of sub-dividing by means of the vernier has been described above, the method by microscopes consists of reading the limb by means of micrometer microscopes.

Microscope brackets.

35. In the 8-inch microscope theodolite the microscopes for reading the horizontal limb are held in aluminium brackets screwed to the upper plate between the two legs of the *Y* standards. The bracket is so fixed that the axis of the microscope is normal to the divided limb, the collar is slit down its centre, and the slit is closed by means of a capstan head screw, so that when this is loosened the microscope can be made to slide up and down in the collar.

*Description of microscope.

36. The microscope is a compound microscope consisting of three lenses, one of which O. is the object lens, the other two EE forming a positive eye-piece. Below the eye-piece is a small brass box, called the micrometer box, this contains the wire diaphragm D. and the index plate or comb C. The index consists of a *V* nick cut in a metal plate which slides in a groove in the upper plate of the box, this index plate C can be moved slightly without unscrewing the box by means of a small screw T. passing through the side of the box and a tongue on the index plate, the tongue works against a small spring V. which is placed between it and the side of the box. The head of the screw is on the side of the box remote from the micrometer head. The micrometer screw M passes through the side of the box and works in a female screw in the diaphragm ; as the screw is turned, the diaphragm is moved in the box. On either side of the micrometer screw are two small spiral springs SS, which press against the diaphragm and thus prevent lost motion between the male and female screw of the micrometer. The final movement of the screw, when intersecting a division of the limb, should always be made against these springs, *i.e.*, screwing up, or clockwise motion. The

* Note.—The letters in this paragraph refer to the drawing of the micrometer box at the end of the memorandum.

micrometer screw has a milled head H at its other extremity fastened on by a small screw ; between this milled head and the side of the micrometer box is the graduated micrometer head G, this fits loosely on the micrometer screwspindle, retaining its place when the screw is turned by friction only. The arc to be measured by the microscope is a space of 10 minutes by one revolution of the micrometer screw ; its circular head is graduated in 10″ divisions each minute being numbered 1, 2 up to 10, the half minutes being marked by having a longer division with a lozenge at the end. There is an index K on the micrometer box giving the reading of the micrometer head.

Removing the diaphragm of the microscope.

37. In the event of the observer finding it necessary to open the micrometer box for wiring the diaphragm or for any other reason, he should first remove the small comb screw, which is found on the side remote from the micrometer screw ; then the side of the box through which it passes, taking care in doing so, that he does not drop the index plate spring, which after the removal of the comb screw is loose in the box ; next the upper plate of the box with the eye-piece should be removed. Finally unscrew the micrometer screw and the diaphragm can be taken out. The reticule consists of two parallel wires separated by a space slightly greater than the thickness of a division of the limb. The diaphragm is nicked for these wires. For method of rewiring see paragraph 22 of this memo.

The vertical microscopes.

38. The vertical microscopes are similar to the horizontal microscopes and need no separate description.

Adjustments of the instrument.

39. The adjustments of the theodolites, should be performed in the order given below—

(1) Centering over a given mark.
(2) Adjustment of levels and levelling.
(3) Adjustment of transit axis.
(4) Adjustment of Telescope.
(5) Setting the level of the vertical circle to its zero of altitude and collimation in altitude.
(6) Setting the vernier lenses in a vernier instrument, or the adjustment of the microscopes and their runs in a microscope instrument.
(7) Setting the instrument to zero.

Centering.

40. The centering of small theodolites over a given mark is effected by means of a plummet suspended from the centre of the instrument. This adjustment is very easily performed, the plummet should always be centered exactly over the station mark.

Leave adjustment.

41. An instrument is level, that is, has its vertical axis truly perpendicular to the horizontal, when each end of the level bubble remains steady during a complete rotation of the instrument in azimuth. From the above definition it will be seen that the bubble need not be in the centre of its run when the instrument is level ; if, however on levelling the instrument the bubble, is found to be far from the centre of its run, it should be adjusted in the following manner.

If the level is completely out of adjustment, place the level of the horizontal circle of the instrument parallel to a line joining two footscrews, and by means of these, bring the bubble to the centre of its run, now turn the instrument round exactly 180° in azimuth, then half the error of displacement of the bubble lies in the footscrews, the other half is the error of the level itself and should be corrected by means of the level adjusting screw. In the 6-inch vernier and 8-inch microscope theodolites this consists of antagonistic capstan-headed nuts, above and below the level tube, working on a screw thread, or merely of a capstan-headed screw. Correct, therefore, half the error by the footscrews, and the other half by the level-adjusting screw. The instrument should then again be turned 180° in azimuth into its original position, and if the level is still much out of adjustment the process should be repeated. If the bubble is only displaced a few divisions from the centre of its run, it is better not to adjust it, as frequent tampering with the adjustment screws may render them useless. The proper time for effecting any small adjustment is when the instrument is level

Levelling the instrument.

42. The process of levelling the instrument is as follows: Place the level parallel to any two footscrews and bring the bubble to the centre of its run, then turn the instrument 180° in azimuth. Suppose the bubble to occupy now a different position in its run, move it by means of the two footscrews into the approximate mean of the two positions, then turn the instrument 90° in azimuth, and by means of the third footscrew move the bubble into the approximate mean position already indicated. This process must then be repeated, but this time instead of bringing the bubble to the approximate mean position, it should be brought as nearly as possible to the true mean position. And the process must be continued until the bubble gives the same reading for every position of the instrument in azimuth. The process should always conclude with the third footscrew. The mean position of the bubble is called the zero of the level. When the level is parallel to two footscrews these latter must always be moved together and in such a manner that both thumbs either turn inwards, or both outwards, the movements being equal but opposite in direction.

The adjustment of the transit axis level.

3. The body of the instrument being duly levelled, the next care of an accurate observer is to render the transit axis truly horizontal. Both the 6-inch vernier and 8-inch microscope theodolite have under one of the bearings a screw with capstan-headed ntagonistic nuts, by means of which the *Y* bearing may be raised or lowered. The amount of adjustment is regulated by the indications of a striding level which must be placed upon the pivots during the process of levelling them. The striding level is furnished with two feet of V shape, to rest on the pivots of the theodolite; at one end of the level there are two antagonistic screws, wherewith to adjust the bubble to parallelism with the line of bearing of the feet. Each time the level is placed on the pivots, particular care must be taken to note that the level bears at either end on two points of each pivot, otherwise the bubble, owing to the obliquity of the level, will run towards one end. If the feet do not bear properly, the screws which attach them to the level tube must be released, and the feet gently turned till it is found by successive trials, that the bubble remains stationary, even though the level is inclined a little on one side or the other of true verticality.

Method of adjusting transit axis.

44. This adjustment is carried out in the following manner: open the cleats, and place the striding level on the pivots, distinguish the two ends of the level by the letters S and O, and the two pivots by F and P, S standing for the end of the level at which the capstan-headed screw is, and F for the pivot to the side on which the face of the instrument is. Now suppose in the first instance that the S end of the level is at F, and that the readings of the bubble in that position are S and O, gently take off the striding level and reverse it end for end and replace it on the pivots, so that S will now be at P, and suppose the readings of the level in this position are S′ and O′, then half the difference between the readings of the same ends in the two positions will be the inclination of the transit axis, to be adjusted by the antagonistic nuts under one of the *Ys*. The other half difference of the readings is the error in the level itself, which if it amounts to any considerable quantity may be practically corrected by the appropriate screws attached to the level. It is essential that the body of the instrument be truly level throughout the process, and after making any change in the *Ys*', it is generally necessary to relevel the body of the instrument before proceeding.

Adjustment not to be carried out if error is small.

45. If the apparent error of inclination of the transit axis does not amount to more than seven or eight divisions of the level, it is inadvisable to alter it, as frequent tampering with the screws will in time loosen them, the apparent error, it must be remembered, is double the real error. For terrestrial observations, it will be sufficient to test the instrument for this adjustment at the commencement of the season's work, and again before the close.

Testing value of level scale.

46. The value of the divisions of the scale of all levels used on an instrument should be occasionally determined. For methods of testing see Chapter II, page 33, paragraph 48.

47. Adjustments of the telescope are four in number :—

Adjustment of telescope.

(a) Obtaining distinct vision of wires.
(b) Eliminating parallax.
(c) Collimating in azimuth.
(d) Making the vertical and horizontal wires respectively vertical and horizontal.

Adjustment for distinct vision of wires.

48. The adjustment for distinct vision of wires is of a personal nature, as it varies with the focus of the observer's eye. The eye-piece must be drawn in or out of its cell until distinct vision of the wires is obtained. To perform the adjustment direct the telescope to the sky, or hold a piece of white paper obliquely, a short distance in front of the telescope, so that the wires being projected on a blank field may be viewed by the eye undistracted by other objects. The wires will be truly in the focus of the eye, when they appear sharply defined and all the little specks of dust on them are seen clear and distinct. In doing this adjustment the eye is often strained, so that after it is completed, the observer should rest his eye a few minutes and then again look at the wires ; if they do not appear sharply defined, the adjustment must be repeated. The adjustment being finally completed to the observer's satisfaction, the eye-piece must on no account be altered, while the adjustment for the elimination of parallax is being carried out. It is useful to scratch a line on the eye-piece mount to mark its position in the cell, so that it is known for all time.

Adjustment for elimination of parallax.

49. The wires having been properly focussed ; direct the telescope on a distant well defined object, intersecting it with the vertical wire, then move the object glass in or out, till that object appears in sharp focus. To test the accuracy of the adjustment, intersect the object with the vertical wire, and move the eye slowly to one side, if the object still appears intersected, there is no parallax : if, however, any relative displacement is noticed, parallax is present, and the observer must proceed to eliminate it. If on moving the eye laterally, the image of the object appears to move in the same direction as the eye, then the image of the object and observer's eye are on opposite sides of the wires, and the object glass and wires must be approximated to each other ; this is called " far parallax." If, on the other hand, the image appears to move in the contrary direction to the eye, the imperfection is called " near parallax," and may be rectified by augmenting the distance between the object glass and the wires. The observer having determined, whether there is " near " or " far " parallax, should move the object glass accordingly until the image and wires are in the same plane, that is until there is no parallax visible. If after completing this process he finds, that his wires are not as distinct as they might be, he can slightly move his eye-piece to give him a better definition of the wires. The object glass is moved by turning the milled head attached to a pinion working in a rack, which causes the inner tube of the telescope in which the object glass is fixed, to move in or out. The adjustment varies rapidly for near objects owing to the variability of the angles of incidence which rays from such objects undergo. But so soon as the rays become parallel or nearly so, the point of no parallax will be found constant for all objects more distantly situated. For instance the point of no parallax for the sun, or any star, and for any terrestrial object over 15 miles distant, will be found to be identical. The " solar focus " is the point at which parallel rays of light, similar to those received from the sun, meet each other after passing through the object glass.

The following points might, with advantage, be noted in eliminating parallax :—

(a) The distant object selected should, if possible, be sharply defined against the sky line.

(b) The adjustment should be made early in the morning or late in the evening, when the air is steady.

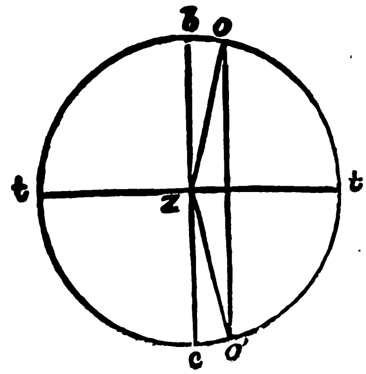
(c) If the adjustment is done for solar focus, the observer should scratch a line on the inner tube to mark the extent to which the object glass should be protruded, so that in the event of the observer having at any time to change his focus, his object glass can be readjusted to solar focus without trial.

(d) The adjustment of the object glass when once properly made is the same for all observers ; the adjustment of each eye-piece is a personal adjustment, and varies according to individual eyesight.

50. The line of "collimation" in a telescope may be defined to be the line joining the centre of the wires, and the optical centre of the object glass In a theodolite, the telescope rotates on the transit axis, and the line of collimation in a telescope thus mounted, should be at right angles to the transit axis, otherwise it will not describe a great circle when the transit axis rotates.

Collimation.

For let t t and OZ be the directions of the transit axis, and line of collimation respectively, and suppose the line OZ to rotate round the axis t t, previously made truly level; it is clear that it will not pass through the zenith at all, but after a semi-revolution the point O will arrive at the point O′. The line of collimation will in fact describe a cone, the base of which will be a small circle, which intersects the transit axis at right angles. The adjustment therefore consists in making the line OZ. perpendicular to t t.



51. There are three methods of collimating in azimuth:

1st.—By changing pivots, a process applicable only to small instruments.

Methods of Collimation.

2nd.—By changing face, an unsuitable method where the vertical circle is not a complete one.

3rd.—By Gauss's method.

52. *First method.*—First open the *Y* cleats, and see that the clips of the vertical arm are not biting the shoulder of the *Y* standard. Select some distant fixed object at about the same level as the instrument, intersect it and see that both upper and lower clamps of the horizontal plates are firmly clamped: lift the telescope out of its *Ys* and turn the verniers through 180°, then replace the telescope with pivots reversed. This must all be done very gently, care being taken not to shake the instrument, as the success of the operation depends on the Ys remaining unmoved. If the telescope in its second position still intersects the fixed object, the line of collimation is true, if not, the object will appear to one side of the wire, and half the apparent error should be corrected by the diaphragm screws at the eye end of the telescope. After making this correction, the object should be again intersected by the tangent screw, and the pivots again reversed; if the object is not intersected, the process must be repeated. Two or three repetitions will suffice to perfect the adjustment, and when it has once been effected, it should not again be tampered with, unless the error of collimation amounts to 30″ or more with small theodolites.

Collimation by changing pivots.

A variation of the above method is to obtain the apparent collimation error by measuring it on the limb of the theodolite. After intersecting the object in the first instance, read and record both verniers or microscopes of the horizontal limb, then reversing the pivots as before, again intersect the object with the tangent screw, and again read the verniers or microscopes. One half the difference of the readings will be the true error of collimation; set the instrument therefore to the mean reading, and then intersect the object by means of the diaphragm screws. Repeat the process until the intersection remains constant or very nearly so on changing pivots.

53. *Second method.*—This method is sufficiently accurate for all instruments though, of course, subject to graduation error.

Collimation by changing face.

The difference of the readings on opposite faces, as obtained by observing an object alternately face left and face right, gives double the error of collimation, so that as in the second case of the first method, the instrument may be set to the mean reading, and the object intersected by means of the diaphragm screws. The process should be repeated till the intersection remains perfect or very nearly so on changing face.

If the distant fixed object, by means of which the collimation has been determined, is situated above or below the horizon, the collimation error thus obtained must be reduced by multiplying it by the cosine of the elevation or depression of the object observed On the other hand the amount of the collimation error at the horizon being known the azimuthal error at any altitude may be obtained by multiplying by the secant of the altitude. This clearly shows that an error of collimation produces its least effect on azimuthal readings when the altitude of the observed object is nothing. It is, moreover evident, that the system of observing with the face of the instrument alternately left and right must necessarily eliminate the effect of the error, because it lies in contrary direction on the two faces.

Collimation by Gauss's method.

54. *Third method.*—This method requires two auxiliary telescopes, so that it can rarely be performed in the field. It is, however, superior to both the foregoing methods, dispensing as it does with both the practical difficulty of reversing pivots, and the angular measurement, whereby errors of graduation become involved.

The process is as follows: Take two small theodolites, adjust them to solar focus eliminating parallax, and set them up one on each side of the instrument to be collimated distant about 5 feet from it, so that all three instruments shall be nearly in the same straight line. To effect this set the telescope of the centre instrument horizontal, and place one of the auxiliary theodolites, so that its wires may be seen on looking through the centre instrument. Now turn the centre telescope 180° in a vertical plane, and place the other theodolite so that its wires may be seen also. Then move the centre telescope by removing it from its *Ys*, so that the two external telescopes may be adjusted upon each other, and their wires made to mutually intersect, after this they are not to be disturbed. Replace the centre telescope in its *Ys*, and directing it upon one of the small theodolites, intersect the image of its wires, and then turn the telescope 180° in a vertical plane, so that it may now point to the other theodolite; if the wires of this latter are found to be also intersected, the line of collimation is truly at right angles to the axis of rotation, otherwise one-half of the apparent deviation is the true error, and should be adjusted by the diaphragm screws. The process should be repeated until the error is eliminated. To render the wires of the auxiliary theodolites distinct, light should be reflected into their eye-pieces by holding pieces of paper obliquely behind them.

It is evident that although for one theodolite the above process may seem rather tedious, where several theodolities are to be collimated, they can be rapidly and easily done by this method. When once the two auxiliary theodolites are in position successive theodolites can be set up between them and adjusted one after the other, and when the theodolites are of the same type and size, it would only be necessary to change the telescopes without removing the stand.

Making the vertical and horizontal wires respectively vertical and horizontal.

55. To verify the horizontal wire, level the instrument, then set the telescope on some distant well defined object near the horizon, and move the instrument in azimuth, when the object should appear to move along the wire from one extremity of the field to the other. Similarly with the vertical wire, move the telescope in altitude so that a distant object may appear to traverse the vertical wire. If the object does not remain intersected at all parts of the field, the error ought to be rectified by moving the wire plate in the appropriate direction. The relative position of the wires with respect to each other having been fixed by the maker, it is only possible to adjust one wire by means of the diaphragm. This adjustment must inevitably re-introduce collimation error, so that if it is required, it must be carried out simultaneously with the adjustment for collimation. For the method of rewiring the diaphragm, see paragraph 22 of this memo.

Setting the level of the vertical arc to the zero of altitude, and collimation in altitude.

56. In dealing with the vertical limb, if everything were in perfect adjustment, we should have the following conditions satisfied:—

(i) The vertical bubble would stand in the centre of its run when the verniers or microscopes read zero on the vertical limb, in every position of the instrument in azimuth.

(ii) The above condition being fulfilled, if the instrument be rotated in azimuth the line of collimation should move in a plane at right angles to the axis of motion, that is the line of collimation should be parallel to the zero line of the vertical circle.

In practice it is not necessary for either of these conditions to be exactly fulfilled, since the method of taking vertical angles on both faces liminates any errors due to both of them. If, however, the combined error is large, and it will be found convenient in working, to keep it small, it can be practically adjusted in the following manner in both the vernier and microscope theodolites. Bring the level bubble to the centre of its run by means of the clips; the instrument being say F. R. intersect any fixed terrestrial object with the horizontal wire, and read the vertical limb; now change face to F. L, bring the bubble to the centre of its run by means of the clips, and again intersect the object with the horizontal wire. The mean of the two readings thus obtained, gives the true vertical angle. Now set the verniers or microscopes to read this true angle on say F. R. and intersect the same fixed object with the horizontal wire by means of the clips, the level will then be out of its centre of run, and must be brought to its centre by means of its adjusting screw.

Alternative method.

57. For microscope theodolites there is an alternative method. Obtain the true vertical angle to any terrestrial object in the same manner as described above, then intersect the object with the horizontal wire and clamp the telescope vertically and horizontally. Now move the vertical microscopes until they give the reading of the true vertical angle as deduced from both faces. The final adjustment to the proper reading must be made by using the index screw. This method is however not recommended for small microscope theodolites.

Adjustment of vernier lenses in the 6-inch vernier theodolite.

58. This consists in properly focussing the vernier and limb with the lens, this can be done by raising or lowering the lens. The most suitable point to focus is, where a division of the vernier coincides with a division of the limb, and the line of intersection of the vernier and limb should bisect the field of view.

Adjustment of microscope in the 8-inch microscope theodolite.

59. The arc measured by the microscope of the 8-inch theodolite is 10′ by one revolution of the micrometer screw, the micrometer head is therefore graduated into ten divisions of one minute each and these again are sub-divided into divisions of ten seconds, and the observer can estimate to 1″. Now in order that the screw may be competent to measure a 10′ space without excess or defect, it is clear that the image of the latter must be magnified so as to occupy precisely the length of one revolution of the screw. Suppose that an object (the divided limb of the circle for instance) is placed at the solar focus of the object lens, the rays passing through the lens become parallel and the image will be formed at an infinite distance, but if it be placed beyond solar focus, an image is formed within the tube of the microscope, and the two points where the divided limb and its image are situated, are called "conjugate foci," the latter of which recedes upwards as the other approaches the object lens. If we call the distance of the limb or object from the lens f, and the distance of its image from the same lens F, the length of the image will exceed that of the object, in the ratio F to f or F/f will represent the magnified state of the image. Hence it is evident, that the expression F/f will have an increased value, if we either augment F or diminish f. This is the fundamental principle to be attended to in adjusting the runs, *viz*, if the object glass be protruded, it will approach nearer to the limb, whereby the size of the image will be increased, and it will require more traverse of the micrometer screw of the microscope to measure it, and this will also be the case, if the whole microscope be made to descend towards the limb.

Conditions of adjustment.

60. For the microscopes to be in correct adjustment, the following conditions must be fulfilled :—

The image of the divided limb and the micrometer wires should be so distinctly visible together, that no parallax can be detected, and in this state of good vision, one revolution of the screw should exactly measure one of the 10′ spaces of the limb, or two revolutions should measure two 10′ spaces.

Distinct vision of wires. Elimination of parallax.

61. To obtain distinct vision of the wires place a piece of paper on the limb, and illuminate it by means of the reflector; now slide the eye-piece in its cell until the wires appear sharply defined. This is a personal adjustment, and varies with the focal length of the observer's eye. If on removing the paper the limb is not visible, the microscope must be moved bodily up or down till the limb is seen distinctly. It can easily be discovered, whether the microscope should be moved up or down, by moving the eye-piece; if, on thrusting this latter in, the limb becomes visible, then the microscope should be moved down, and *vice versâ*. To move

the microscope, loosen the capstan-headed screw which clamps the microscope in its bracket. Having rendered the lines on the limb visible simultaneously with the wires bring one of the divisions to the centre of the field, and intersect it with the micrometer wire. Now move the eye to the left or right, and if the intersection remains steady, there is no parallax, but if the object appears to shift with respect to the wires, then notice in which direction it moves. If there is "far parallax," the object glass should be moved up " nearer the wires, if there is near parallax," the object glass should be moved nearer the limb. In making this adjustment, it is convenient to leave the object glass in about the centre of its limits of movement, so that in adjusting for run, no difficulty may be experienced if the object glass has to be again moved.

Adjustment of "run."

62. The next consideration is to adjust the run of the microscopes. For this purpose place a division of the limb, say 0°, exactly under the centre of the microscope, and then measure with the micrometer the exact number of revolutions and divisions between 359° 50′ and 0° 10′. As the required range of the micrometer is less than 10′ on each side of the index, the arc measured should not be greater than 20′. It will be noticed that one of the specified divisions on the limb will be arrived at, by revolving the micrometer in the order of the graduations, and the other by revolving it in the direction contrary to the graduations; by subtracting the reading of the latter from the former, we shall have the exact number of minutes and seconds measured by the micrometer. If this is short of 20′, the magnifying power is too small, and the object glass must be protruded in order to augment the image, but if the measured space exceeds 20′, the object glass must be screwed upwards to diminish the image. Now in the former case, protruding the object glass will throw the image higher up the microscope, and produce "near parallax," to correct which, the whole microscope must be bodily moved further from the limb, and this again will diminish the run, so that the first correction should be a little over done, to counteract the subsequent adjustment for parallax, the whole process must be repeated until the two conditions, "correctness of run" and "freedom from parallax," are very closely satisfied.

One microscope only need be adjusted for "run."

63. In order to obviate the necessity of adjusting both microscopes to a perfect run of 10′, it is best after adjusting one for distinct vision of wires and parallax to take its "run," and then when adjusting the other microscope to compensate for the error of this run, that is, if the run of the first microscope gives 19′ 38″ the run of the other should be adjusted to 20′ 22″ or nearly so. The "run" should be repeated in at least three different parts of the arc, and at least two readings of each microscope taken in each position. It must be remembered that the final intersection with the micrometer should always be made by screwing against the spring, *i.e.*, a clockwise revolution of the milled head; to enable this to be done when screwing the reverse way, the wires of the micrometer should be taken beyond the division of the limb to be intersected, and then brought back, and the division finally intersected by the screwing up motion.

Recapitulation of method of adjusting runs of microscopes.

64. To recapitulate the process shortly. Set the instrument to 0° by the index and a whole degree stroke will then fall nearly under the zero of each microscope. Measure the 20′ spaces under the two microscopes A and B, taking no notice of the whole degree stroke in the centre; since the sum of the 10′ spaces will be given at once by reading extremes, repeat each measure at least once. Now turn the instrument round 60° in Azimuth, and measure the 20′ spaces as before, and then move it again another 60°, and again measure the 20′ spaces. The mean value of each microscope will thus be obtained from the mean of 20′ spaces, in three positions on the limb, and the mean run will be obtained from six 20′ spaces. If the error of the mean run of the microscopes amounts to more than 5″ in 20′, it will be advisable to correct that microscope which is most erroneous. It is possible to adjust the microscopes to a mean error less than this, but with the above mean error, the maximum error of any one reading of the two microscopes would be only 1·25 seconds, and since the seconds on the micrometer head are estimated, this may be taken as within the limits of the observation error of the microscopes. In performing the adjustment, the final correction for run, if small, should be made by raising or lowering the whole microscope, until the required value of the run is correctly obtained. The reason for this being, that the microscope is more sensitive, as regards the value of the run, than

it is with respect to parallax. An example is given below, where the runs of the two microscopes are recorded before the final adjustment, and after the final adjustment. The reading on the micrometer head is called a high reading when the micrometer, as the screw traverses the limb, turns in the order of the graduations, and *vice versâ* the low reading signifies, that the micrometer head has been turned in the reverse order of its graduations.

Reading of Index.	Horizontal Angles.						Remarks.
	A			B			
	High Reading.	Low Reading.	Difference.	High Reading.	Low Reading.	Difference.	
0°	9′ 50″	9′ 48″	20′ 2″	0′ 22″	0′ 14″	20′ 8″	
0°	9′ 49″	9′ 49″	20′ 0″	0′ 20″	0′ 11″	20′ 9″	
60°	9′ 42″	9′ 44″	19′ 55″	0′ 11″	0′ 6″	20′ 5″	
60°	9′ 45″	9′ 44″	20′ 1″	0′ 10″	0′ 6″	4″	
120°	9′ 16″	9′ 15″	20′ 1″	9′ 38″	9′ 26″	20′ 12″	
120°	9′ 14″	9′ 15″	19′ 59″	9′ 35″	9′ 27″	20′ 8″	

Mean = 20′ 00″·7 . . . . . . Mean = 20′ 07″·7
Mean of two microscopes . . . . . . = 20′ 05″·9
Error of 20′ run . . . . = 0′ 3″·9
Adjust B microscope to read less.

Reading of Index.	Horizontal Angles.						Remarks.
	A			B			
	High Reading.	Low Reading.	Difference.	High Reading.	Low Reading.	Difference.	
0°	9′ 19″	9′ 15″	20′ 4″	7′ 25″	7′ 25″	20′ 0″	
0°	9′ 18″	9′ 16″	20′ 2″	7′ 30″	7′ 29″	20′ 1″	
60°	9′ 44″	9′ 42″	20′ 2″	7′ 43″	7′ 45″	19′ 58″	
60°	9′ 41″	9′ 40″	20′ 1″	7′ 43″	7′ 45″	19′ 58″	
120°	9′ 45″	9′ 43″	20′ 2″	7′ 53″	7′ 53″	20′ 0″	
120°	9′ 43″	9′ 40″	20′ 3″	7′ 50″	7′ 51″	19′ 59″	

Mean = 2′ 001″·7 . . . . Mean=19′ 59″·3
Mean of two microscopes . . . . =20′ 00″·50
Error of 20′ run . . . . . . = 0′ 00″·50

65. The above operations are liable to disturb the lateral adjustment of the microscope, this can be regulated by taking off the top of the micrometer box, and sliding the index plate towards the side required to bring the necessary division of the limb under the index of the microscope. The final minute portion of the adjustment is done by the index screw, after replacing the top of the micrometer box. If the comb be moved or adjusted in the slightest degree, care must be taken to set the zero of the micrometer head to correspond with the zero of the comb. For this purpose take the milled nut of the micrometer head in one hand, and the graduated head in the other, then turn the latter round, taking care not to turn the micrometer screw also, and when the zero on the graduated head corresponds with the index of the microscope, the adjustment is complete.

Lateral adjustment of the microscope.

Microscope to act tangentially to the circle.

66. Finally the microscope should act in a tangential direction to the circle. The intersecting medium consists of two parallel wires, separated by a space slightly greater than the thickness of a division of the limb. To get the tangential direction correctly, the two wires should be made parallel with a degree division of the limb. This may be done by turning the microscope round in its collar till the micrometer is brought to act in the right direction. Care must also be taken that each microscope is set over the same part of the limb divisions, that is, the microscopes should be equidistant from the centre of the circle.

Distance apart of microscopes.

67. The microscopes should be fixed 180° apart, and coincide with a whole degree stroke when the index is at 0°, but on account of the centering error, it is convenient, in order that the reading of B microscope may always be larger than that of A, to make the former read about one minute in excess. By this means the degrees read on the A microscope will always appertain to B microscope; whereas if the microscopes were placed exactly 180° apart, by reading of the limb at one part of the circle, it is conceivable, that owing to centering error, at some other point of the circle, the reading between them would be less than 180°, and we should have, say, from A microscope the reading 60° 0′ 10″, and from B microscope the reading 59° 59′ 50″, which would complicate the recording.

Adjustment of vertical microscopes.

68. The vertical microscopes are similarly adjusted. They must, besides being set diametrically opposite one another, be freed from index error.

Selection of division of the limb for intersection.

69. In selecting which division of the limb should be intersected by the micrometer the rule is to select that division which appears to fall nearest to zero in the first microscope, and to intersect the corresponding division in the other microscope; thus the limit of range of the micrometer is kept within 10′, and for one reading is not more than 5′.

Runs of the microscopes to be taken at commencement of season.

70. The runs of the microscopes should be carefully taken and recorded at the commencement of the season, and should be checked at each new station of observation.

Illuminating the limb.

71. In illuminating the limb for night observations, the light should be thrown perpendicularly on the reflector, taking care that the field is equally illumined, and that both sides of the division lines are distinctly seen and sharply defined. The best method is to turn the reflector of the microscope so as to face outwards from the instrument, and the observer, as he looks into the microscope, by holding the lamp in his left hand, can throw the light perpendicularly on to the reflector.

Setting to zero.

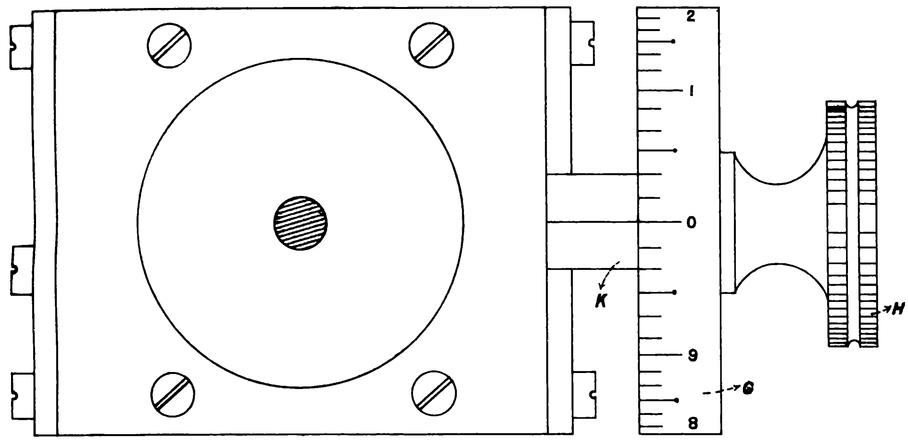
72. This is a temporary adjustment which has to be carried out during the work of observing angles. Setting to zero requires that a particular object or station shall have a given reading on the limb. For this purpose, set vernier or microscope A to the given reading, and clamp the upper plate; unclamp the lower plate, and turn the telescope until the given object is nearly on the wire, then clamp the lower plate, and finally intersect the object with the lower tangent screw. Before performing this adjustment the instrument should be roughly levelled. The object aimed at in setting to zero is to observe the required angles at several different portions of the arc of the circle, and by this means cancel as far as possible any graduation error.

Method of observing.

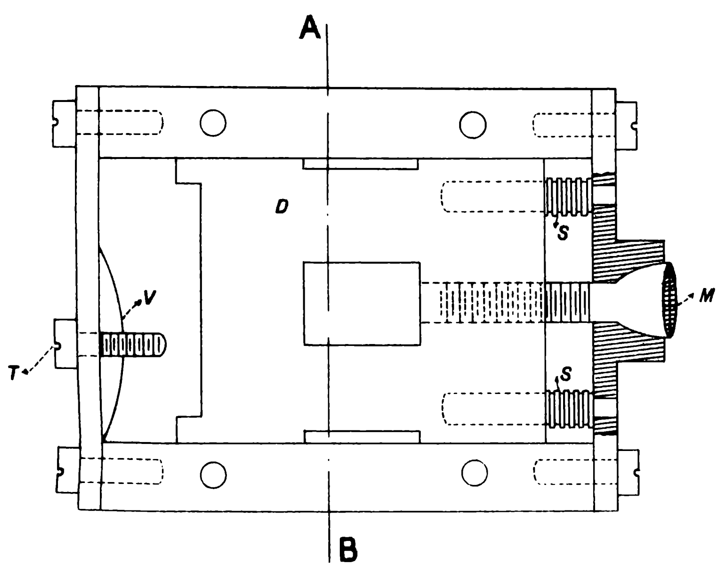
73. The method of observing angles is fully described in Chapter II, page 25, paragraph 42 *et sequitur*, and need not be entered into here. It may, however, be remarked that in observing horizontal angles, the vertical clamp should always be free, and similarly in observing vertical angles, the horizontal clamp should be free.

H. H. TURNER, *Captain, R.E.*

MUSSOORIE;
The 4th August 1904.



PLAN.



PLAN WITH TOP REMOVED
AND END IN SECTION.

D = Diaphragm.
M = Micrometer Screw.
T = Comb or Index Plate Screw.
S S = Spiral Springs.
V = Comb or Index Plate Spring
K = Micrometer Head Index.

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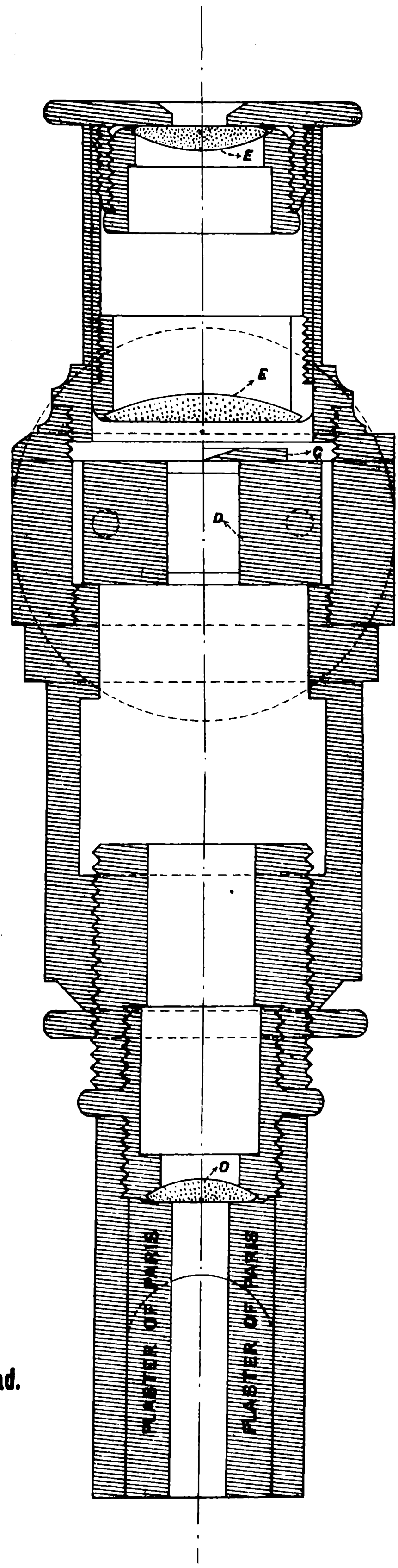
LE FULL SIZE.



E E = Eyepiece Lenses.
O = Object Lens.
C = Comb or Index Plate.
H = Micrometer Milled Head.
G = Graduated Micrometer Head.

SECTION ON A B

Litho., S. I. O., Calcutta.

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