Stereo-Photo Surveying
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That day, July 16, as we were making a halt, Kaznakoff and I, accompanied by Badmajapoff and Dadai as interpreters, and guided by the chief's elder son, set out to call at the house of their absent father. Entering the large, roomy, and comfortable tent, which was divided into two parts, one reserved for the guests, and one occupied by the women and household accessories, we took our places. Opposite us smoked a huge fireplace, with projecting sides, on which were some eight copper or iron pots of different calibre. The cook and mistress were busily occupied at the fireplace. They were assisted by the latter's young daughter, whilst a servant was making butter in some large tubs. After the well-known ordinary welcome, we were offered tea and "juma," and, afterwards, liberal portions of mutton from a sheep which had been especially killed in our honour. The eldest son of the "bey-khu" waited upon myself and my assistant, while his secretary attended to the wants of our interpreters. Neither the mistress of the establishment nor her daughter stopped looking at us from the moment of our entry till our departure. Having tendered our thanks for their hospitality, we took our leave, but not before the eldest son presented us with a fox and other gifts usually offered to an honoured guest.

(*To be continued.*)

STEREO-PHOTO SURVEYING.*

By F. VIVIAN THOMPSON, Lieut. R.E.

I. The Object and Uses of Photographic Surveying.

The object of photographic surveying is to map the detail of a triangulated area at a minimum expenditure of time and labour in the field, and at a total cost so far below that involved in plane-tabling as to warrant the sacrifice of that high degree of accuracy attainable in good plane-tabling. From this it might appear that photographic surveying is necessarily less accurate than plane-tabling. This is not the case; but, to attain the same degree of accuracy in detail, so many plates would, in certain classes of country, be required, and the plotting would be so tedious, that the photographic method might be less economical than plane-tabling.

One of the chief reasons why photographic surveying has not proved more popular in the past is that the method has been wrongly applied, and attempts made to compete with the plane-table or the chain in large-scale work. The economical advantages of the photographic method over plane-tabling increase as the scale of the map decreases, and as the ruggedness and general steepness of the country increases. These two conditions, viz. scale and nature of the country, must be carefully considered before a photographic survey is embarked upon. Atmospheric conditions require less consideration, the balance being slightly in favour of photographic surveying in most countries, if a stereoscopic method is employed. Generally speaking, a small-scale contoured map in mountainous country of 2 inches to 1 mile or under, and of sufficient accuracy for all ordinary purposes (military operations included), would be most economically turned out by a photographic method. The time occupied would vary from one-fifth to one-tenth of the time occupied in plane-tabling the same area, and the cost would vary in approximately the same proportion.

Plane-tabling is necessarily slow, but thorough. To compete with the camera the plane-tabler must hurry, and hurried plane-tabling could not compare with the work plotted from photographs. In very hilly and precipitous country everything

* Research Department, February 21, 1908. Map, p. 588.

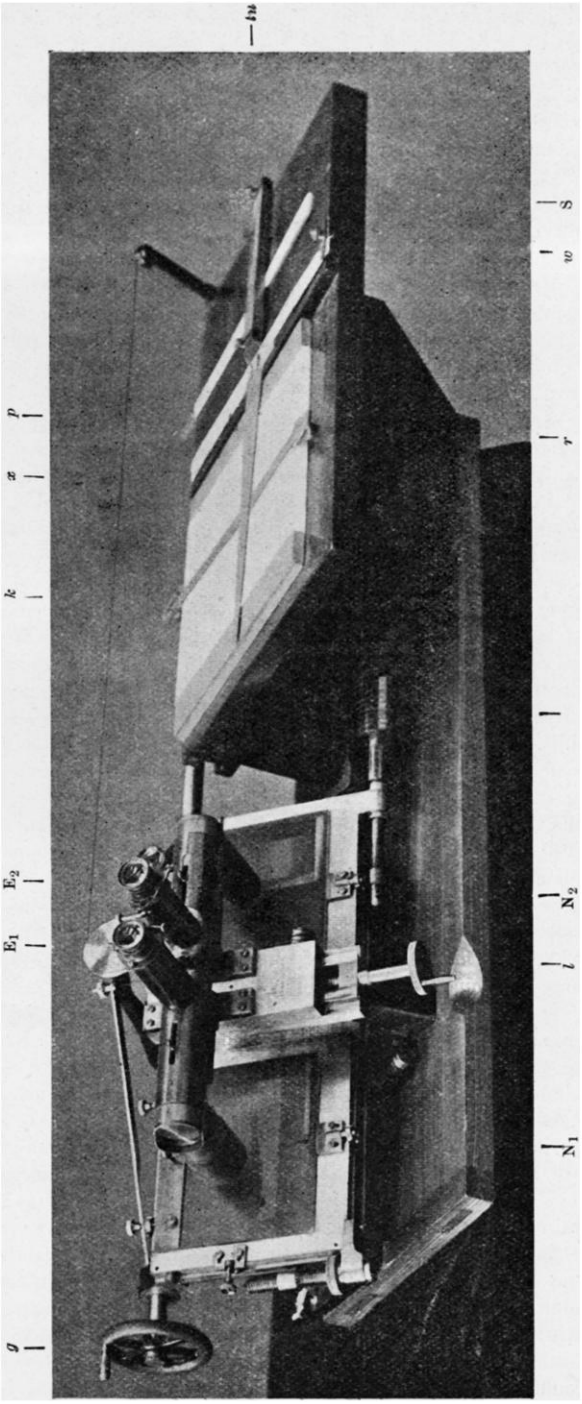


FIG. 1.—THE STEREO-PLOTTER. THE LETTERING REFERS TO FIG. 10.

is in favour of the camera, and here the degrees of accuracy would differ very slightly. In many large tracts of country financial considerations render a detailed plane-table survey out of the question, whilst political or natural considerations may render it unnecessary; but in most cases a small-scale contoured map is desirable, and in such cases the photographic method is the most economical way of obtaining it.

Other cheap methods have been tried, such as combined reconnaissance sketches executed with plane-table or sketching-board, and pieced together by means of a graphic triangulation or other makeshift. In many cases a photographic survey, run concurrently with a rapid triangulation, would probably have proved less costly and have given a more satisfactory result. The stereo-photographic method should prove particularly useful in exploration work, railway reconnaissance, colonial and frontier surveys on scales of 2 inches to 1 mile and under.

The photographic work to be done in the field has been made quite systematic, and requires very little skill; no focussing is required, and each exposure is determined by means of an actinometer. Development of plates is carried out by time. It should be easily mastered by any surveyor after a few weeks' practice. For the use of travellers and explorers the method is peculiarly suitable, as no technical knowledge of surveying is required, and any one with a fair eye for country could expose plates from which results could afterwards be plotted equal in value to a standard of plane-tabling which it might take him many years' training to attain. Another great advantage from the explorer's point of view is the small amount of time occupied in taking the views, and the extensive tracts of distant country that can be swept in from a single station. By using a suitable combination of lens, colour screens, and plate, any distant point which can be seen with the naked eye can afterwards be plotted from the resulting negatives. In this way the photographer knows exactly how much detail he may expect to obtain in the plotted results.

The feasibility of economical photographic surveying is entirely due to the state of perfection which the manufacture of orthochromatic plates and colour screens has reached during the last few years. B. J. Edwards's medium isochromatic plates were used in the Cumberland work, and are also used in Canadian surveys. The amount of detail, sharpness, and contrast compared with that obtainable on an ordinary dry plate is almost incredible. The results are too bright and the contrast too great to give an artistic effect, and for this reason orthochromatic plates and dense orange screens are seldom applied to landscape work in ordinary photography. Hence little is known of its capabilities. Climatic effects on modern orthochromatic plates are reduced to a minimum with ordinary care in packing.

Figs. 2 to 5 show four reproductions, each of which is one of a pair of stereoscopic views employed in plotting the map of the country south of Keswick (see pp. 538, 539). Contact transparencies were used, and naturally gave much more detail when magnified six times than can be seen in these reproductions.

A great amount of time and money is spent each year by explorers and others in taking photographs of unmapped country. With a very little extra expenditure in time and still less in money, better views might be obtained, and, in addition, the material for a contoured map of all the country appearing in each view, probably several square miles in extent, could be made available, and this without moving more than a hundred yards. Unique opportunities are probably missed in this way. The camera outfit would cost no more than an up-to-date Reflex camera; the additional weight would be small. Some central organization at home would be required for plotting the results. This could be done economically by a plotter and plotting machine attached to any existing photographic establishment, where plates could be developed and transparencies prepared.

II. Previous Photographic Methods.

The method of photographic surveying employed hitherto has in most cases been identical with, or some slight modification of, the method employed by the Canadians in the Dominion Lands Survey, and described at length in 'Photographic Surveying,' by E. Deville, Surveyor-General of Dominion Lands (1895).

Theoretically, the accuracy of the Canadian method is considerable, but as the method is one based on intersections, each point, before it can be plotted, must be identified in at least two views taken from points a considerable distance apart. This necessitates either much forethought in the field, or a prohibitive expenditure in plates and time. The identification of similar points and the subsequent plotting are most tedious. In spite, however, of these difficulties and the high standard of training required for the economical selection of views in the field, the Canadian Government has turned out admirable maps of the Rocky mountains by this method. It is estimated that the cost of a photographic survey under their conditions is less than one-third the cost which would be incurred in plane-tabling the same area.

III. Stereo-Photographic Surveying.

This method was first worked out on a practical basis by Dr. Pulfrich in 1903, but was suggested by Captain E. Deville some years previously (*vide Transactions of Royal Society of Canada*, 2nd series, 1902–03, vol. 8, sect. III., "On the Use of the Wheatstone Stereoscope in Photographic Surveying," E. Deville; also Dr. C. Pulfrich, "Über eine neue Art der Herstellung topographischer Karten und über einen hierfür bestimmten Stereo planigraphen," *Zeitschrift für Instrumentenkunde*, Heft 5 (Mai), 1903, xxiii. Jahrg.). Concurrently with Dr. Pulfrich, who is a member of the scientific staff of the Carl Zeiss Works, Jena, Mr. H. G. Fourcade has been working in South Africa at a modification of the same principle (*vide Journal of the Institute of Land Surveyors of the Transvaal*, No. 6, vol. 1, 1907).

In outline, the stereoscopic method consists in taking photographs in pairs, in the same vertical plane, at a measured distance apart, and viewing these negatives, or positive transparencies made from them, in a special form of stereoscope. The eye-pieces of the stereoscope are provided with exactly similar indices, which can be made to combine stereoscopically with any given point in the view by increasing or decreasing the distance between the slides holding the photographs. The amount of separation required for stereoscopic combination is a measure of the range of the point from the plane in which the plates were exposed, and can be read on a suitable scale. Azimuth and elevation or depression can also be read from scales on the instrument, thus completely fixing any desired point in the view.

The following is a brief explanation of the method :—

In the first place, the photographs of the country to be mapped must be taken in pairs, so that they may be viewed in the stereoscope, which is a part of the plotting apparatus. The ordinary stereoscopic prints seen are, of course, taken in a camera provided with lenses mounted $2\frac{1}{2}$ inches apart, which is the normal interocular distance of the human eyes. Consequently, objects situated more than a few hundred yards distant do not stand out in relief.

In photo surveying, where ranges of several miles may be required, a much greater range of relief effect is necessary. This is obtained by taking the two views from points, say, 300 feet apart. The effect seen in the stereoscope is precisely that which would be seen by an individual whose eyes were 300 feet apart, and is 1440

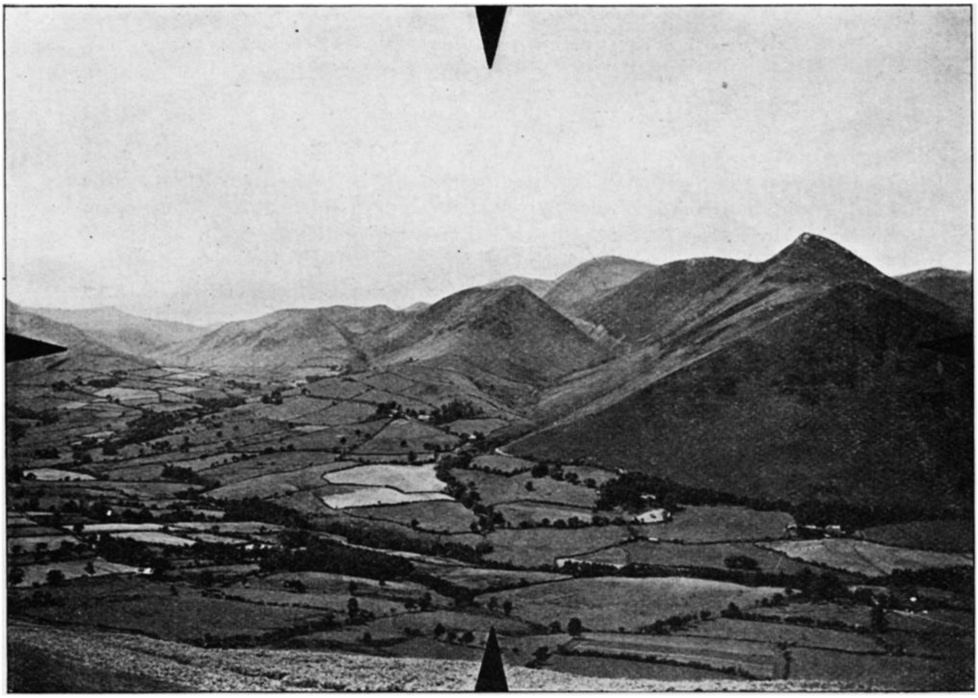


FIG. 2.—LOOKING NORTH-WEST TOWARDS KESWICK FROM NORTH.

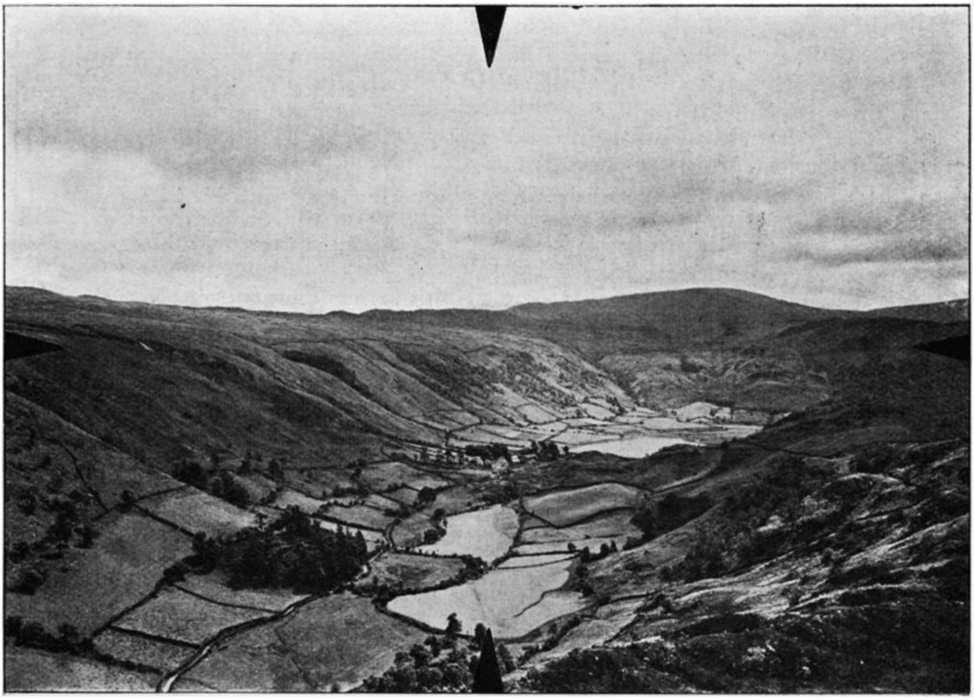


FIG. 3.—LOOKING WEST FROM CAT BELLS.

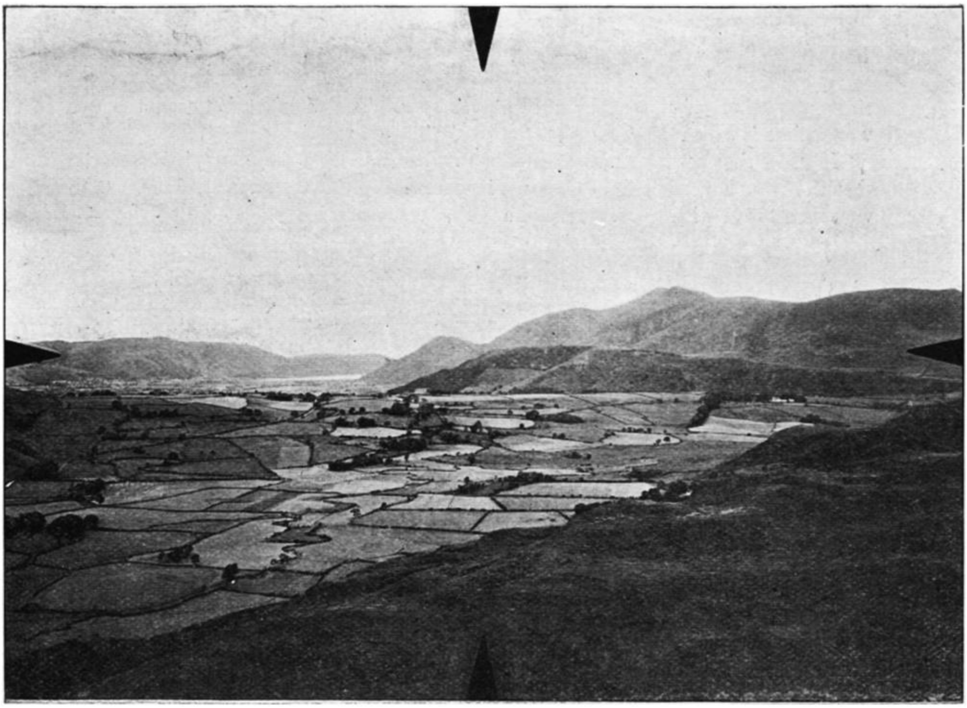


FIG. 4.—LOOKING WEST FROM GRANGE FELL.

FIG. 5.—LOOKING NORTH FROM HILL, SOUTH OF STONETHWAITE.

times the relief effect seen by the normal eyes. The distance between the two view points is called the "stereoscopic base."

In order that accurate measurements may be made from the plates, it is essential that the two plates should be exposed in precisely the same vertical plane. Both views are taken with the same camera. Fig. 6 shows the arrangement employed.

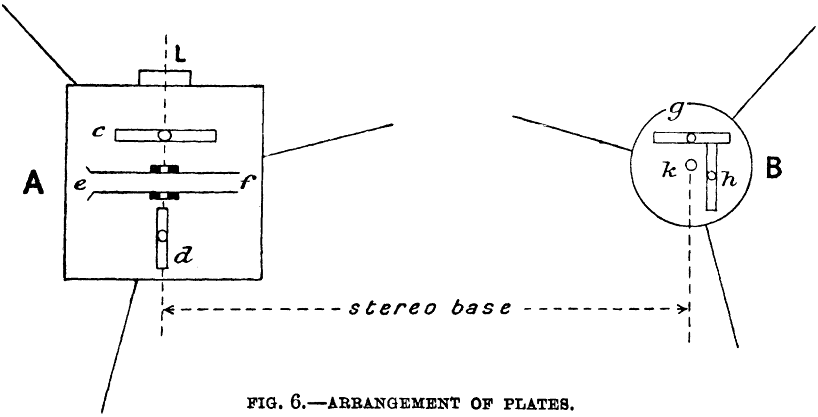


FIG. 6.—ARRANGEMENT OF PLATES.

A is the left-hand position of the camera, L is the lens, *ef* is a small telescope provided with cross hairs, and mounted in Y bearings on the upper surface of the camera. The Y bearings are carefully centred and set so that the line joining the Y's is parallel to the axis of the lens. The telescope is collimated, and can be reversed in its bearings. B is a metal plate (sighting plate) provided with a small metal upright rod sight, K, about 6 inches high and quarter inch diameter, painted white on the lower half and black on the upper half. *g* and *h* are levels, and so adjusted as to exactly correspond with the levels *c* and *d* on the camera; consequently, if the camera and sighting plate are levelled and interchanged no further adjustment for level is necessary.

In setting up in the field the following procedure was adopted:—

1. Set up camera at left station and direct it to include the view required (angle of view marked by sighting lines on upper surface of camera).
2. Attach telescope and direct assistant, who has fixed sighting plate on to second tripod 200 or 300 feet away, till he is approximately on the correct alignment.
3. Complete levelling of camera and sighting plate, and bring cross wires of telescope on to sighting rod by slow-motion screw.
4. Make exposure.
5. Interchange camera and sighting plate, reversing telescope in its bearings to eliminate collimation in setting of the Y's.
6. Bring cross wires on to sighting rod by slow-motion screw.
7. Make second exposure.

The time taken in setting up, exposing, and packing up again varies from fifteen to twenty minutes under favourable conditions, and provided the base has not to be measured.

The measurement of the base, which would be done by a subtense method or by a stretched invar wire, would only occupy a few extra minutes, as no high degree of accuracy is essential, an error of $\frac{1}{500}$ being admissible in small-scale work. The two view points need not be at the same elevation.

C_1, C_2 are the two positions of the camera, separated by the known distance L_1L_2, which is the "stereoscopic base." The axes N_1X_1, N_2X_2 are exactly parallel.

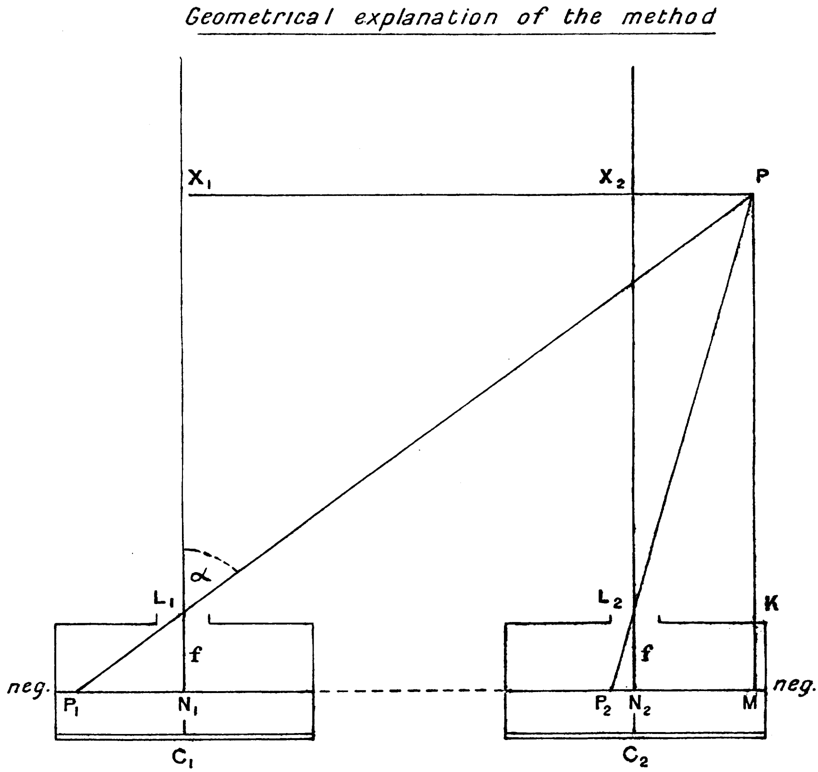


FIG. 7.

P is any distant point in the view. Images of P will be formed at P_1 and P_2 on the negatives N_1 and N_2.

Then by similar triangles—

$$\frac{P_1N_1}{f} = \frac{L_1K}{KP}$$

$$\text{and } \frac{P_2N_2}{f} = \frac{L_2K}{KP}$$

$$\therefore P_1N_1 - P_2N_2 = f \times \frac{(L_1K - L_2K)}{KP}$$

$$\text{or } P_1N_1 - P_2N_2 = \frac{\text{focal length} \times \text{stereoscopic base}}{\text{projection of range on axis of lens}}$$

Now, P_1N_1 and P_2N_2 can be measured on the negatives ($P_1N_1 - P_2N_2$ is called the "parallax" of the point P), therefore the position of P is determined. Similarly, by measuring the distance of P above or below the horizon line on the negative (say h), and knowing the projection of the range of P on axis of lens (say R), the height of P above or below the camera station $= \frac{R \times h}{f}$.

For convenience all measurements are made with respect to the left-hand camera station.

In practice these three measurements for—

(1) Parallax,

(2) Azimuth,

(3) Elevation or depression

are reduced in the recently designed stereo-plotter to a single reading, viz. parallax. Azimuth and elevation or depression are automatically indicated.

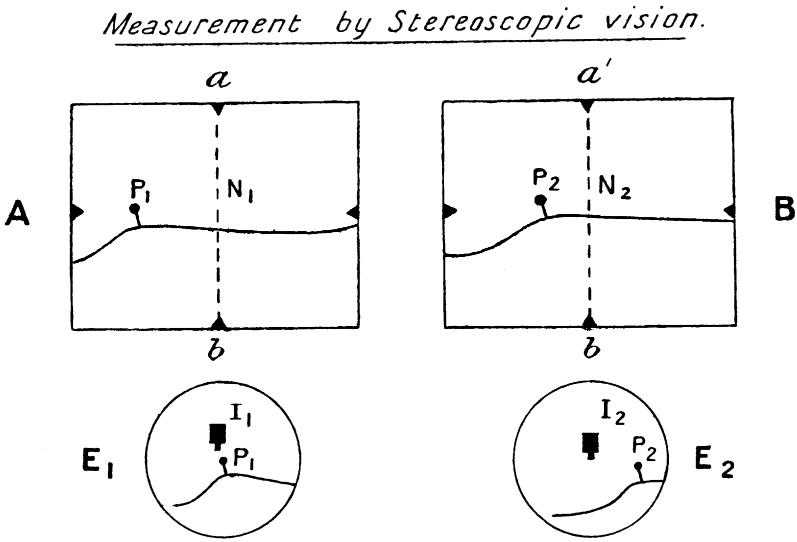


FIG. 8.

Fig. 8 shows the position on the plates of the point P in Fig. 7.

The four triangular reference marks on each plate are imprinted by projections on the inside of the camera. The plate is pressed against them during exposure, and since they are accurately set in the focal plane of the lens, all plates are exposed and marked in exactly the same relative position, and no focussing is required.

If we can measure $P_1N_1 - P_2N_2$, we have a measure of the distance of P from the plane of the plates. This measurement is effected by means of the stereoscope, in the eye-pieces E_1, E_2 of which are indices or marks, I_1 I_2, made exactly similar in appearance.

The eye-pieces E_1, E_2 are carefully set and fixed at the interocular distance of the observer; the indices I_1, I_2 then "combine" stereoscopically and appear as a single index.

The negatives are now so adjusted, by using each eye separately, that their central or principal lines coincide with the indices in the eye-pieces.

If the negatives are now moved bodily, till, using the left eye only, the index in E_1 appears to touch any object P_1 in A, then on using the right eye only, the same object in B will appear somewhere to the right of the index in E_2, unless the object were at an infinite distance, in which case it would coincide with the index.

Assuming the object selected to be at some intermediate distance, the effect transmitted to the eye senses on using both eyes, is that of an object standing out in sharp relief (much exaggerated owing to the length of stereoscopic base used), with an index suspended in space at an extreme distance behind it.

If the right-hand negative B is now slowly moved to the left independently of the left-hand one A, the sensation conveyed is that of the index advancing from the rear, until, when B has been moved through the parallax distance $P_1N_1 - P_2N_2$, the index will appear to hang exactly over the object. This amount of parallax movement made is shown on a suitable scale.

Now, this movement of the right-hand negative through the distance $P_1N_1 - P_2N_2$, or the "parallax distance," has been shown

$$= \frac{\text{focal length} \times \text{stereo-base}}{\text{projection of range on axis of lens}}$$

Assuming the focal length and stereo-base to remain constant and equal, say 6 inches and 200 feet respectively, it is clear that the parallax movement can be expressed in terms of the projection of the range, and shown as such on the parallax scale.

E.g. suppose projection of range of P = 1000 yards,

$$\text{then } P_1N_1 - P_2N_2 = \frac{6 \times 200}{1000 \times 3} \text{ inches}$$
$$= \tfrac{2}{5} \text{ inch}$$

Again, suppose projected range of P = 900 yards,

$$\text{then } P_1N_1 - P_2N_2 = \frac{6 \times 200}{900 \times 3}$$
$$= \tfrac{4}{9} \text{ inch}$$

(*Note.*—Projection of range of P is the horizontal distance of P from the vertical plane in which the plates were exposed.)

In this way the parallax scale can be graduated in yards, and in this particular case a movement from the zero to a point $\frac{2}{5}$ inch away indicates a projected range of 1000 yards and a further movement of $\frac{4}{9} - \frac{2}{5}$ or $\frac{2}{45}$ indicates a decrease in range of 100 yards. A movement of $\frac{1}{1000}$ inch can be read, and $\frac{1}{2000}$ inch estimated on the drum.

It is obvious that instead of using both eyes at the same time the measurement could be made by using each eye separately to bring the objects into coincidence with the indices, but the double observation takes longer and is less accurate than a single stereoscopic observation when both eyes are used at the same time, the accuracy of observation being approximately 3 : 5.

In cases of abnormal vision where the stereoscopic accommodation is defective, the double observation would be necessary; such cases are not uncommon, and it is advisable to select plotters whose stereoscopic accommodation is well developed. Individuals are found to vary to a considerable extent in this respect.

Fig. 9 shows the principle of Dr. Pulfrich's "stereo-comparator."

O_1 and O_2 are the object lenses, and of such a focal length as to form images of those portions of the negatives *ab*, *cd*, immediately below them at *g* and *h* after reflection at the prisms P_1, P_2, P_4, and P_3. The indices (I_1, I_2, Fig. 3) are placed at *g* and *h*. Magnified images are formed by the eye-lenses E_1 and E_2. Interocular and focussing adjustments are omitted in the figure.

The microscope may be considered as mounted on a bridge, *k*, which is rigidly connected with the base plate *mn*. The microscope can slide along this bridge in a direction at right angles to the plane of the paper, the amount of movement being shown on a scale S_2 (elevation and depression). ST is the main slide carrying the negatives *ab*, *cd*. Its movement with respect to the base plate *mn* is shown on a scale S (azimuth). RW is the parallax slide slotted into the main slide; it carries the negative *cd*. Its movement with respect to the main slide is shown on a scale S_3 (parallax).

From a consideration of Figs. 7 and 8 it is obvious that the position in plan and height of any object can be plotted from readings of the three scales S_1, S_2, and S_3,

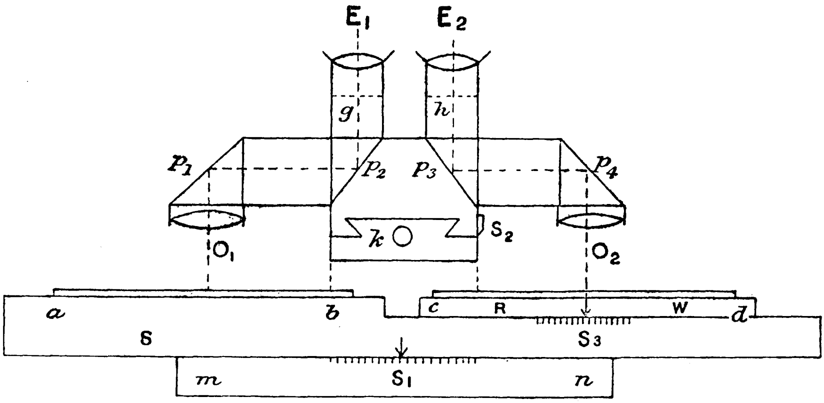


FIG. 9.—PRINCIPLE OF PULFRICH'S STEREO-COMPARATOR.

and corresponding settings on a detached plotting-board. This method of plotting is considerably more rapid than the Canadian method of intersections, but is not sufficiently rapid to enable a plotter to keep pace with a camera party.

The mental picture of the natural features in the neighbourhood of the point is apt to be lost whilst the three verniers are being read and scales are being set on the detached plotting-board.

The Stereo-Plotter.

With a view to simplifying the method and increasing the rapidity of the plotting, experiments were carried out at the School of Military Engineering early in 1907, and an instrument designed which makes the plotting of points and the reading of heights nearly automatic. To distinguish it from the stereo-comparator it has been called a stereo-plotter, as it combines the offices of the stereo-comparator and plotting board. Mr. Conrady of Messrs. Watson & Sons, who was consulted in the matter, suggested many valuable improvements in design, and worked out with much care the optical and mechanical details. In this instrument the binocular microscope is of a similar pattern to that used in the stereo-comparator (Fig. 9).

The reading of the three scales S_1, S_2, S_3 is reduced to a single reading of S_3, which is a spirally scaled drum graduated in yards, and the three separate corresponding settings on a detached plotting-board are reduced to a single setting on a plotting-board which is part of the instrument. In this manner the chances of error in reading the scales are minimized and the speed of plotting very much increased.

Fig. 10 shows the stereo-plotter in its simplest form (see also Fig. 1). MN is the binocular microscope sliding in a direction *lm* or *ml* on a bridge (omitted in drawing), rigidly connected with the base plate. N_1, N_2 are the negatives. N_1 is rigidly fastened to the main slide *abc*. N_2 is fastened to the parallax slide *de*, which can slide within the main slide.

The main slide *abc* is actuated by the handwheel *g*, and its motion transferred to the plotting-board by a screw shaft *gh* working in a sliding collar *k*. A stud or projection on *k* engages with and moves a radial arm, *rk*. As the main slide is moved, *rk* is moved correspondingly in azimuth.

The movement of the microscope is actuated by the handwheel *l*, and its motion transferred to the plotting-board by the shafting *lmn*, *mn* working in a sliding collar, *p*. A radial arm, *sp*, engages with a stud on *p*, so that as the microscope is moved up and down on the negatives, *sp* moves correspondingly from one side to the other, indicating elevation and depression.

The parallax slide *de* is moved by the spiral drum *f*, which is graduated in yards, showing projection of range on axis of lens for a given base and focal length. *wx* is a scale of yards set at right angles to *rk*, *wx*, *sp*.

If *rk* and *sp* are equal to the focal length of the camera lens, it will be obvious, from a consideration of Figs. 7 and 8, that when any object in the view is brought into stereoscopic combination with the indices in the eye-pieces of the microscope by turning *g*, *l*, and *f*, and when *tvu* is set at the range shown on *f*, then the intersection of *rk* with *tvu* gives the position in plan, and the intersection of *sp* with *tvu* along a suitable scale, *yu*, gives the height in feet above or below the camera station, which is represented by *r* in plan.

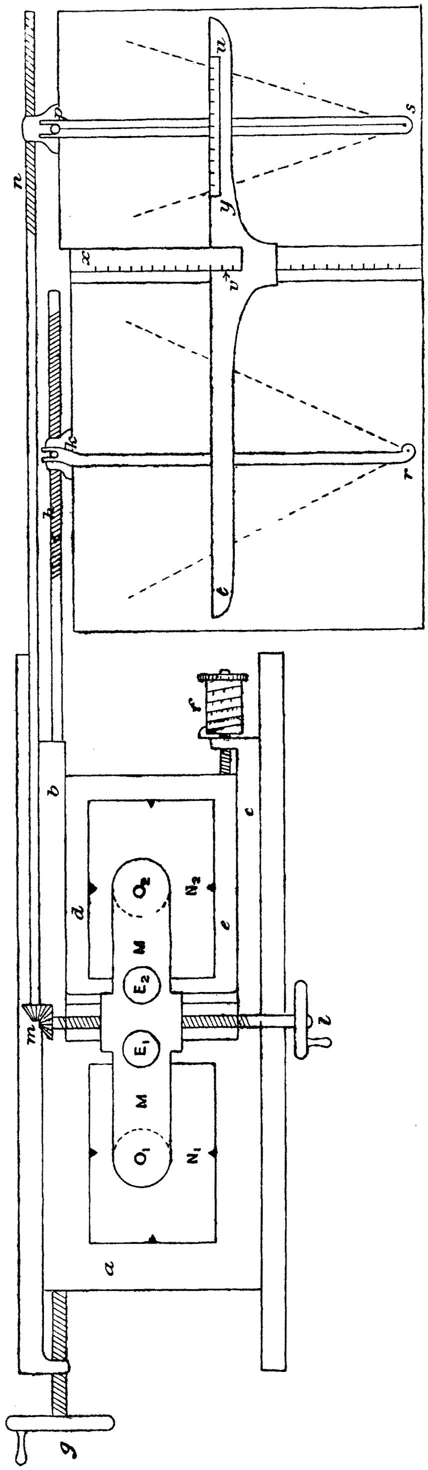


FIG. 10.—THE STEREO-PLOTTER.

In practice, so as not to obstruct the plotting-board, the arms *rk* and *sp* are made twice the focal length, viz. 12 inches, and by means of right and left handed screw threads a double motion is imparted to the travelling collars *k* and *p*. The drum *f* for convenience is graduated in yards for a base of 100 feet and focal length of 6 inches, but can be used with varying focal length and base. The scale *wx* is any required scale, usually 2 inches to 1 mile; this allows objects up to 6 miles to be plotted. Usually a 200-feet or 300-feet base is obtainable, in which case a scale of 4 inches or 6 inches to 1 mile must be substituted at *wx* to give a result plotted at 2 inches to 1 mile. For any other variation in base length a scale varying in proportion must be inserted at *wx*.

The most convenient arrangement would be an elastic scale, but as this has not been found practicable so far, a number of scales varying by small amounts have been prepared photographically, and are inserted at *wx* as required.

The great advantage of this stereoscopic method over the Canadian method of intersections is that the surveyor knows that, having taken his pair of views, every point he can see in the view before him will appear in the plotted result. Other advantages are the ease of contouring due to the exaggerated relief effect, and the elimination of time and labour occupied in identifying similar points in two views.

The chief points to be considered are—

1. The most economical procedure in field work and instruments to be employed.

2. The most rapid method of plotting the results.

An outline only of the methods and instruments can be given here, with a few practical suggestions and figures based on the experience gained in the Cumberland survey (see map opposite).

1. *Field Work.*

In the first place, an extensive survey, whether plane-table or photographic, must invariably be based upon an accurate triangulation or network of triangles. The usual method of executing the triangulation is by means of a theodolite. A series of points are thus accurately fixed, and upon them is hung the plane-table or photographic work.

The tendency in photographic surveying is to use a photo-theodolite, which is a camera and theodolite combined. These instruments are necessarily heavy and costly. The construction is unsound as far as the theodolite is concerned, and, considered as a camera, the instrument is cumbersome and excessively heavy. In practice the camera station is seldom the triangulation station—the former being chosen with a view to economical expenditure in plates, and hence in time; the latter being selected with a view to well-conditioned triangles and inter-visibility.

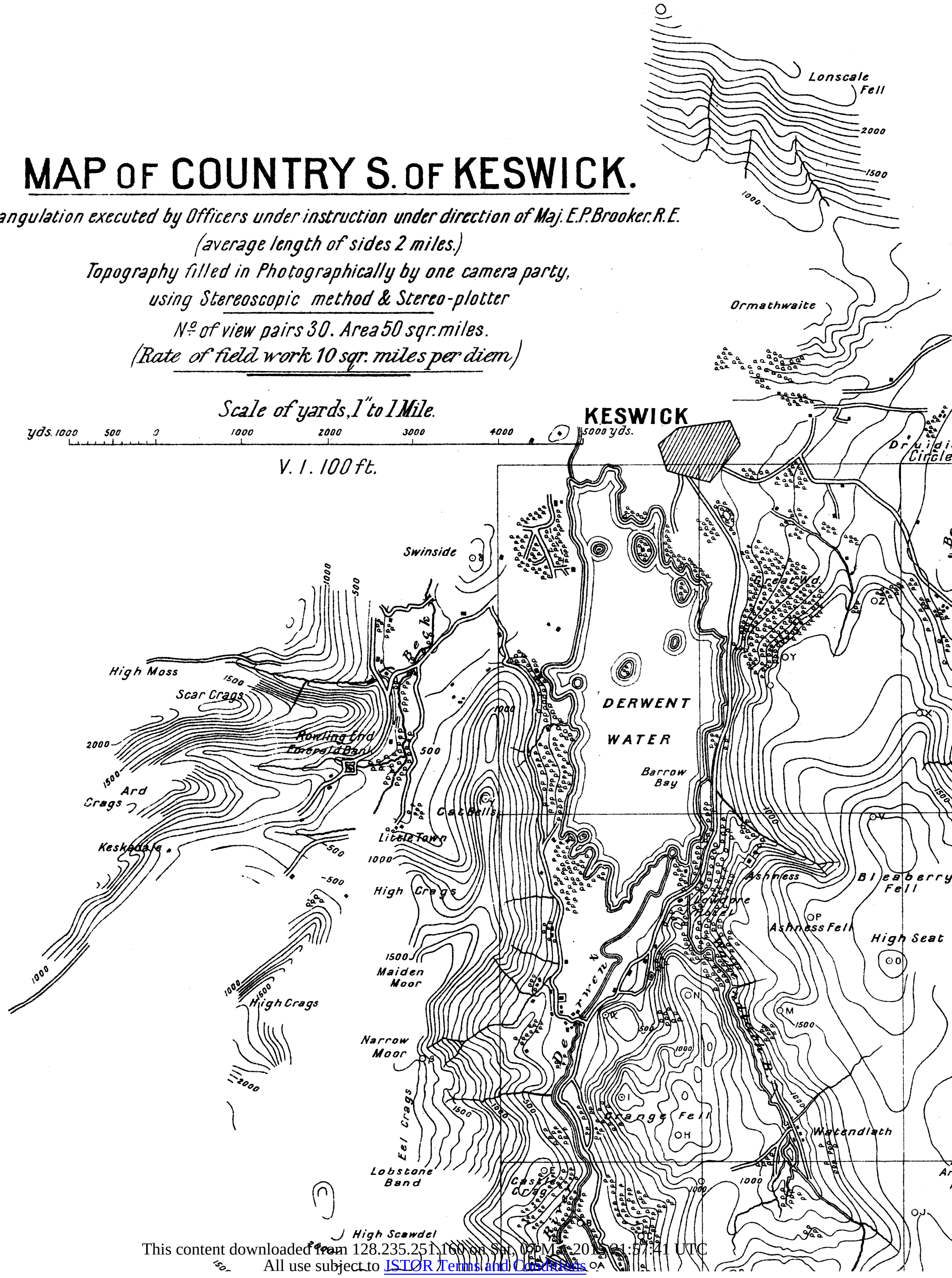
Local conditions will determine the best procedure to be followed in any particular case, but, generally speaking, a surveying camera and separate theodolite party are considered the most economical arrangement. A surveying camera with a light graduated horizontal plate, sufficiently accurate for resection purposes, would often be most useful.

The camera party would usually consist of one surveyor and one assistant (photographer). Each would carry a load of from 15 to 20 lbs. The triangulation party proper, with a 5-inch theodolite, might be a day or so in advance, or the triangulation might have been carried out some time previously. The best form of signal is a light inclined staff, with 2 yards of black or white bunting attached to its end.

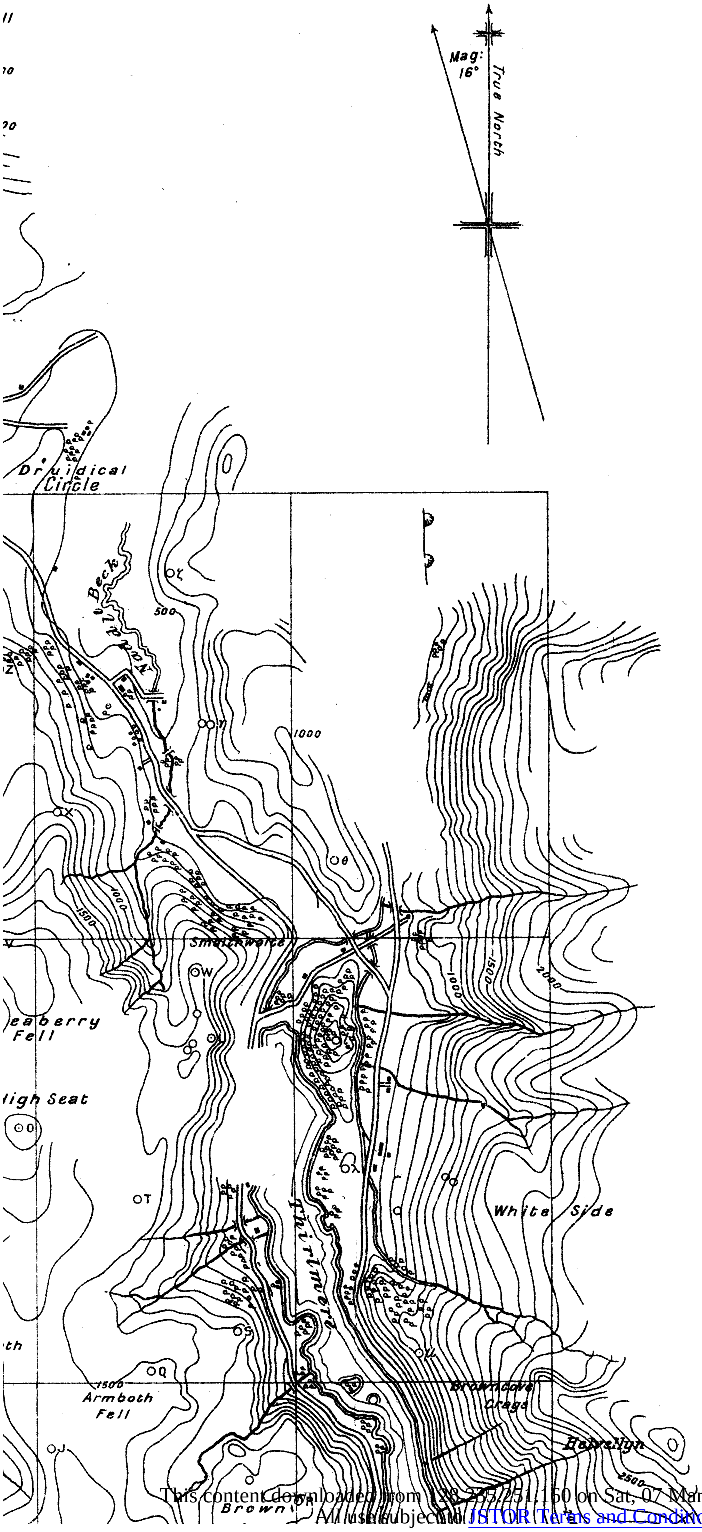
All parties traversing the ground should make notes on the topography, such

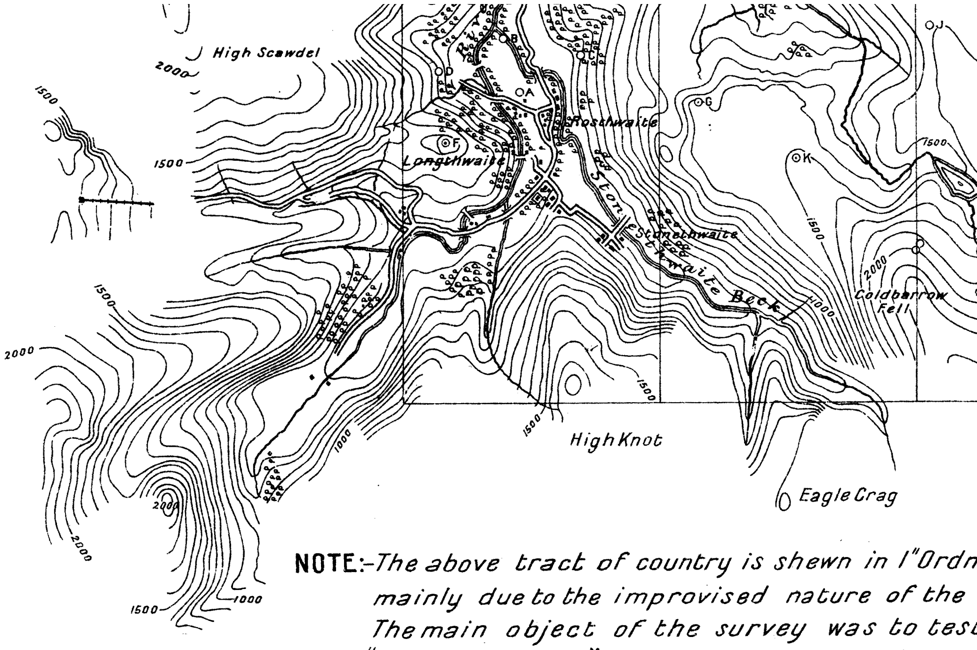
MAP OF COUNTRY S. OF KESWICK.

Triangulation executed by Officers under instruction under direction of Maj. E.P. Brooker. R.E.
(average length of sides 2 miles.)
Topography filled in Photographically by one camera party,
using Stereoscopic method & Stereo-plotter
No. of view pairs 30. Area 50 sqr. miles.
(Rate of field work 10 sqr. miles per diem)



THE GEOGRAPHICAL JOURNAL, 1908.





NOTE:-The above tract of country is shewn in 1"Ordn
mainly due to the improvised nature of the
The main object of the survey was to test
"Stereo-plotter" in particular. A considerab
graphed but not plotted as the Triangula
A portion of the topography East of High
central portion of the Helvellyn ridge.

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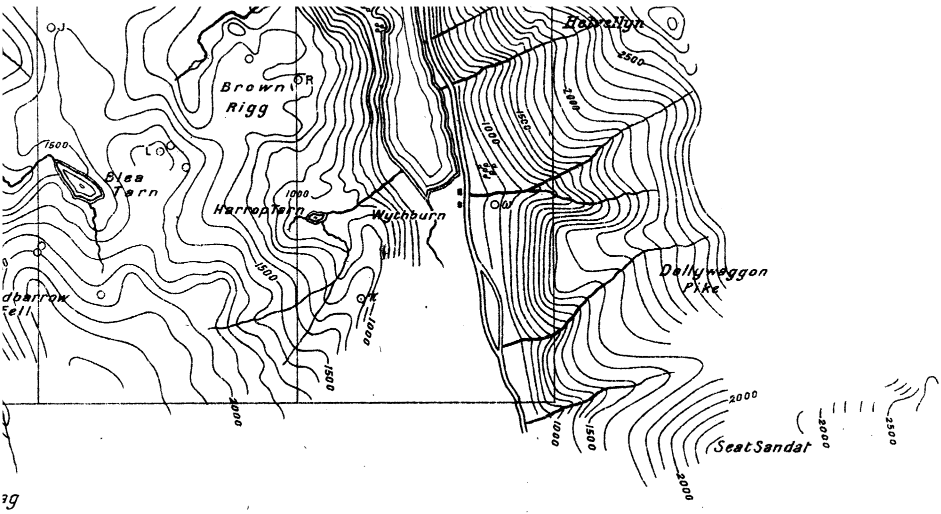

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ɑ 1" Ordnance Survey Sheet Nº 29. Any inaccuracies introduced are of the camera equipment.
to test the general efficiency of the method and of the siderable tract of country in addition to above was photo-iangulation only covered the portion within the graticules.
ᶜ High Seat is missing as time did not allow a visit to the ge.

ɔgraphical Society.

as directions of current in streams, bridges, names of farms and villages, etc. One of the great advantages of plane-tabling is that every portion of the ground is traversed, and no detail missed.

The measurement of the stereoscopic bases is always desirable, but not always essential. If the camera station is fixed, and also some other point in the view, base measurement may in rapid work be dispensed with. An experimental survey of approximately 50 square miles was carried out by the writer of this paper in the lake district of Cumberland in August, 1907 (see accompanying map). In this case there was an existing triangulation, which had been executed for instructional purposes a few days previously by a party of R.E. officers from the School of Military Engineering, Chatham. The average length of sides was approximately 2 miles. This being a comparatively close network of triangles, no bases were measured, as it was always possible to include a triangulation station in each view pair, and to resect the camera station. Development of the day's work occupied less than an hour each evening. A dark room or tent is not required. Stand or tank development is the simplest method.

The camera equipment was of an improvised nature, being a Canadian Survey camera supplied by Messrs. Sanger Shepherd, and adapted for use in the stereoscopic method by mounting a small sighting telescope on its upper surface. Slow-motion gear was added to its base plate.

Owing to its improvised nature very considerable errors in alignment were introduced, and no corrections were applied. In spite of this, however, the result approximates fairly closely to the Ordnance Survey sheet of the same area. Considerable time was occupied in experimenting with and testing the gear, which had only just been completed. The chief sources of error, so far as the field work is concerned, are—

(1) error in alignment;
(2) error in base measurement;
(3) lack of definition in the negative.

There are other minor sources of error, which may be neglected in the class of work aimed at, where the degree of accuracy required is not greater than 0·5 per cent.

Under given conditions the degree of accuracy attainable can be precisely determined and, conversely, the conditions for a given degree of accuracy can be arrived at (*vide* 'An Elementary Treatise on Phototopographic Methods and Instruments,' by J. A. Flemer: Chapman & Hall, 1906). Errors in alignment and base measurement are merely matters of instrumental refinement.

Definition of the negative may be considered to depend on the focal length of the camera lens, and the fineness of the grain of the plate. The most economical combination is found to be a 6-inch lens, covering a half-plate, $4\frac{3}{4}$ inches by $6\frac{1}{2}$ inches. It has been found by experiment that a 6-inch rapid rectilinear lens, when stopped down to *f*45, gives a definition equal to approximately one and a half times the defining power of the normal human eye, viz. approximately 40″ of arc. This introduces a parallax error in the negative of 0·0016 inch. This error could be reduced by using a lens of longer focus, but the decrease in angle of view would necessitate a greater expenditure in plates and time, or larger plates and camera, entailing considerable increase in weight, bulk, and cost of equipment.

The probable error in a single stereoscopic observation in the stereo-plotter is found to be 0·0012 inch. This includes the error in setting of plates, scales, etc. A monocular observation, on the other hand, would give a probable error greater than 0·0012.

This error 0·0012 inch in parallax reading could be reduced by greater refinements in the instrument or by using a finer-grained plate and a more perfect lens.

The following table of errors has been prepared so that the conditions for any required degree of accuracy can be ascertained. The probable errors in alignment and base measurement assumed, viz. 20 seconds of arc and $\frac{1}{400}$ respectively, are large and not likely to occur in any work of a careful nature, but might appear in rapid reconnaissance work.

Data for Table of Errors.

Camera lens, 6-inch focus.

(1) Probable error in alignment = 20 sec. arc.

(2) Probable error in reading of parallax and setting of plates and scale in stereo-plotter = 0·0012 inch.

(3) Probable error in rapid base measurement = $\frac{1}{400}$,

$$a = \text{error in range due to (1)} = \frac{(\text{range})^2 \times 20 \sin 1 \text{ inch}}{\text{base}}$$

$$p = \text{error in range due to (2)} = \frac{0{\cdot}0012\ (\text{range})^2}{\text{base} \times 6 \pm 0{\cdot}0012\ (\text{range})}$$

$$b = \text{error in range due to (3)} = \frac{(\text{range})}{400}$$

$$\text{Mean error} = \sqrt{a^2 + p^2 + b^2}$$

Table of Errors.

Range.	Base 100.			Mean error.	Base 200.			Mean error.	Error in height.	
	a	p	b		a	p	b		Base 100.	Base 200.
500	0·2	0·5	1·2	1·2	0·1	0·2	1·2	1·5	0·2	0·3
1000	1·0	2·0	2·5	3·2	0·5	1·0	2·5	2·7	0·6	0·5
1500	2·2	4·5	3·7	6·2	1·1	2·2	3·7	4·2	1·2	0·8
2000	4·0	8·0	5·0	10·2	2·0	4·1	5·0	6·8	2·0	1·4
2500	6·2	12·6	6·2	15·3	3·1	6·3	6·2	9·3	3·1	1·9
3000	9·0	18·1	7·5	21·5	4·5	9·0	7·5	12·0	4·3	2·4
3500	12·7	25·7	8·7	29·9	6·4	12·9	8·7	16·8	6·0	3·4
4000	16·0	32·2	10·0	37·3	8·0	16·2	10·0	20·6	7·5	4·1
4500	20·2	40·8	11·2	46·9	10·1	20·4	11·2	25·3	9·4	5·1
5000	25·0	50·5	12·5	57·7	12·5	25·1	12·5	30·8	11·5	6·2
6000	36·0	72·5	15·0	82·3	18·0	36·2	15·0	43·1	16·5	8·6
7000	49 0	99·0	17·5	112·2	24·5	49·5	17·5	57·0	22·4	11·4
8000	64·0	130·0	20·0	146·2	32·0	65·0	20·0	75·1	29·2	15·0
10000	100·0	204·0	25·0	228·0	50·0	102·0	25·0	116·3	45·6	23·3

Focal length of camera lens = 6 inches.
(a) *p.e.* in alignment = 20 seconds of arc.
(p) *p.e.* in reading of parallax = 0·0012 inch.
(b) *p.e.* in base measurement = $\frac{1}{400}$.
100 yds. on scale 1 inch to 1 mile = 0·057 inch.

Note.—Errors in height are calculated for points at a mean elevation or depression of 10°.

From the above table and formulæ, the degree of accuracy for any set of conditions can be determined, or any required degree of accuracy ensured by variation in the length of stereoscopic base and focal length of camera lens.

2. *The Plotting.*

The nature of the country, the scale of the map, the vertical interval of the contours, will determine the number of points to be fixed per square mile. Under average conditions, it may be taken to vary from 50 to 200. For economical work, a plotting machine should be able to keep pace with a camera party; that is to say, it should be capable of fixing in plan and altitude from 500 to 2000 points per diem.

By the Canadian method of intersections, twenty-five points plotted by at least three rays is considered a good day's work.*

Mr. Fourcade's instrument, which works on similar lines to Dr. Pulfrich's stereo-comparator, gives twenty-five points per hour in the hands of an observer who has had no practice.†

The stereo-plotter was designed with a view to increasing the speed of plotting. It has been found that with this instrument from 100 to 150 points per hour can be fixed. The present instrument is an experimental one only, and admits of several improvements which would increase the speed of plotting and its accuracy.

The procedure adopted in plotting was as follows. The triangulation stations lettered, and the resected camera stations numbered, were carefully marked on a large sheet of tracing cloth. Each piece of plotting when completed was then placed beneath the tracing and oriented by means of two fixed points, or one point and an azimuth. The detail was then traced on the tracing cloth.

In this way the map was built up, and very little adjustment was found necessary where the different portions met.

The rate of plotting of the Cumberland survey was approximately 8 square miles per diem, the rate of field work was 10 square miles per diem. From 40 to 70 points per square mile were plotted. In considering these figures it must be remembered that this was a first attempt, and executed with more or less improvised instruments. The advance made, however, is encouraging, and I am now considering the design of an improved plotting machine, or "stereo-planigraph," which will be entirely automatic, and in which contours can be traced direct on the plotting sheet without any reference to scales or settings, and without moving the eyes from the eye-pieces of the stereoscope. Preliminary drawings have been shown to Mr. Conrady, whose expert advice throughout has been of the greatest assistance. He is of opinion that the construction of the instrument offers no insurmountable difficulties. The increase in speed and accuracy of plotting should be very considerable.‡

After the paper, Sir DAVID GILL: I note with very great interest that with observations by stereoscopic methods you get twice the amount of precision that you do from measurements depending upon angles at right angles to the line of sight. That was Prof. Forbes's experience. He said that with his little balloon with the rope hanging down (which corresponds with the bottle-shaped figure in this apparatus), he found he could get the appreciation of parallactic displacement twice as accurately by the stereoscopic method as he could by the

* *Vide* 'An Elementary Treatise on Phototopographic Methods.' By J. A. Flemer.

† *Journal of the Institute of Land Surveyors of the Transvaal*, vol. 1, No. 6.

‡ Since writing the above, funds have been allotted by the Royal Engineer Committee for the construction of a new light camera equipment and an improved stereo-plotter. Experiments will probably be carried out with these instruments in the course of the summer.