For Departmental use.

Survey of India.

DEPARTMENTAL PAPER—No. 9.

# STEREO-AUTO-PLOTTING

A TRANSLATION BY

LIEUT.-COL. H. M. COWIE, R.E.

OF

## STÉRÉOAUTOGRAMMÉTRIE

BY

PAUL CORBIN.

PUBLISHED UNDER THE DIRECTION OF THE SURVEYOR GENERAL OF INDIA.



Dehra Dun:

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# AUTO-STEREO-SURVEYING.

## *I.—Historical.*

Auto-stereo-surveying is the latest development of stereo-photo-surveying, itself the result of the quite recent application of the principals of stereoscopy to photo-surveying. In this latter process, as one knows, the relative positions of objects are determined and projected on to the horizontal plane by means of data afforded by their photographic representation.

Auto-stereo-surveying as applied to topography, with which only we will concern ourselves here, is the perfected form of a method of photo-surveying, the originator of which was undoubtedly Colonel Laussedat (1819-1907).

It was actually in 1854 that Colonel Laussedat foresaw the application to surveying of pictures in natural perspective, as given by the camera lucida; and after 1859, of photography, as soon as apparatus and processes should begin to be fairly practicable. Particularly between 1863 and 1871, when with the assistance of M M. Javery and Galibardy, using his methods and his apparatus, he completed numerous plans of which the results were absolutely convincing.

But it was not till 1910, that the French Service Géographique began to make a practical study of the uses of photo-surveying, to which it had previously attached no importance, as we shall show briefly.

In 1884, twenty years after Laussedat's work, we find the following in the "Course of Topography at the School of Artillery and Engineering", the nursery of our Survey Officers. (*Method of reconnaissance survey* by Colonel Romieux, in an appendix to mapping from the perspective and the study of the Schrader *orographe*).

"Photography will give equivalent results only when it becomes possible to obtain quickly and at the station of observation itself a print, on which one can draw, that is to say when we need ask the Camera to do nothing more than that of which it is capable, namely to produce a rapid, exact and intelligible picture".

In 1899 again, in an official publication by the Service Géographique de l' Armée: *The Map of France (1750-1898). Historical Study*, by General Berthaut, we find the following expression of opinion.

"We can, then, look on photography as an *aid, servicable only on occasions*, and not as a substitute for the usual methods" (p. 321).

Now, at this time, the Institute Géographique Militaire of Austria, after having devoted the years 1891-1894 to experiments with Laussedat's method, had, after 1895, definitely adopted it for all favorable regions and had already mapped, by the method, about 400 square kilometres on the scale 1/25000, at a mean rate of 120 square kilometres a year, which after 1900, rose to 180 or 200.

In 1911, in the *Elements and Principles of Topography* by Colonel Crouzet, also published by the Service Géographique de l' Armée, this is how the author expresses himself in a chapter of *two* pages on the subject of stereo-photo-surveying.

"The great difference between photo-surveying and stereo-photo-surveying lies essentially in the fact that in the latter the bases are much shorter than in the former. In certain cases this is a great advantage, but it cannot be concealed that it is also a serious defect, in that it is a *violation of a principle of applied geometry, which prescribes the avoiding of great magnifications or what comes to the same thing, intersections at too acute angles.*

"*One serious drawback is the necessity of placing the sheets of glass in the same vertical plane and it is this which limits the length of the base.*

"One of the advocates of the use of photography has rightly drawn a parallel between stereo-photo-surveying and "the method of parallaxes with which astronomers are *forced to be content* *"; there could be no more frank admission that it is a *last resource*, which may, however, be found, in exceptional cases, to be of use" (p. 256).

And further on, in conclusion:

"We have gone into the discussion at some length, *because in France, the question of photography has been raised with an undue amount of noise on the part of certain of its supporters.*

From the depths of their offices some, "convinced that photography can be used in almost all circumstances, where a reconnaissance or a study of terrain is required", have announced that the old processes have served their time and it was only "persons out of date, sceptics, and partisans more or less disinterested" that would place obstacles in the way of this movement. These amenities, which went further in the case of opponents who were no longer able to retaliate, could only harm a cause, in support of which it would seem there were no better arguments.

"It was fortunate that others, better advised, more practical and in consequence having greater authority, set to work quietly, in contrast to these fussy manifestations, and defined exactly the sphere of efficient application of the new methods and by so doing have rendered a very real service*.

"Wherever the old methods can be put into practice, the advantage rests with them and so far, in their own sphere they have *no* † rival, *from any point of view* †, but it can be seen that there are certain exceptional cases where one would very gladly employ photography and this fact is sufficient justification for keeping in touch with the practice of this method." (p. 259).

We will show that the "drawback" of which the author speaks, has been eliminated since 1909 and also that the limitation of the length of base, far from having been imposed by this supposed drawback, as he believes, has been the *end and object striven for* by the creators of the new method, Pulfrich and Von Hubl, who to achieve this end, took advantage of the great precision of *stereoscopic* intersections.

Finally, the author is under the impression that the two stations must be at the same level which is certainly not the case. Moreover, as may be seen, he is absolutely silent regarding the really fundamental difference which constitutes a most important advance upon the old

* Laussedat. Recherches sur les instruments, les methodes et le dessin topographiques, Vol. II part 2, page 209.

* H. and J. Vallot: The application of photography to topographical surveying in high mountains. Paris, Gauthier-Villars. 1907. (note by the author quoted).

† In italics in the text.

photo-surveying, that is to say, the *elimination of the necessity of identifying points* on the photographic prints.

He would seem to have ignored all the *later publications*, very precise on these points, published by the Institut Géographique Militaire of Austria (Nos. 2, 3 and 4 of the brief bibliography given on p. 6).

It may be added that the Orel Auto-stereo-plotter has been known since 1908, through the medium of three publications by its inventor, namely; in 1908 and 1909, in the *Internationales Archiv für Photogrammetrie*, and in 1910, *in Petermann's Mittheilungen.*

Finally, in 1912, in another work published by the same service under the title *Appreciation of ground forms and the reading of maps* by General Berthaut, a work extremely interesting on other grounds besides being instructive and authoritative, we find this guarded statement: "we cannot discuss here the *very controversial* question of the use of perspective drawings and, in particular, of photographic perspectives in the preparation of maps". We may draw attention to the fact that at that moment, (May 1912), the Institut Géographique Militaire of Austria had mapped about 4,900 square kilometres by means of photo-surveying. Of this 2370 were done by stereo-photo-survey (the recent and materially improved form of photo-surveying) and the Orel auto-stereo-plotter, and that all these operations by the Vienna Institut had been made the subject of fully detailed reports, as will be seen by the short bibliography which follows:—

However in 1911, Colonel Vidal, the distinguished Head of the Topographic Section and a confirmed supporter of this method, decided to acquire for the Service Géographique de l' Armée a Pulfrich "stereo-comparator" and from that time, the new process has been subjected to continuous tests under the energetic impulse of General Bourgeois himself, the eminent Director of the Service Géographique and of his Assistant Director, Colonel Vidal. The results were absolutely convincing and now, the Service Géographique has decided to acquire an Orel auto-stereo-plotter, an ingenious apparatus which, as we will see later, truly opens up limitless vistas to photographic surveying and gives it, in every case, the first place amongst the methods of mapping broken ground in vogue amongst the great geographical Institutions.

Owing to the prolonged official ostracism, there are to be found in France few really important practical works on photo-surveying, except those by MM. Joseph and Henri Vallot, who, as a matter of fact, undertook, about 1892, the triangulation of the Mont Blanc massif as a foundation for their map of this region on the scale of 1 20000, an important work carried out afterwards to a great extent by the method of photo-surveying. This is, at present, still in progress, but M. H. Vallot has already published, in 1907, the provisional and remarkable sheet dealing with the lower portions of the Chamonix Valley.

We may draw attention also to the fine map of the glacier regions of the Grandes-Rousses massif on 1/10,000 (15 to 20 square kilometres) published in 1908 by the Ministère de L' Agriculture from compilations by MM. Flusin, Jacob, Lafon and Offner based on their surveys of 1905 and 1906. However, the old method of Laussedat was used here only for the mapping of the unapproachable glacier portions, the work being based chiefly on a regular tacheometric survey tied to the geodetic net-work of M. Helbronner (1300 tacheometric rays as against 200 points mapped by photography).

In foreign countries, on the other hand, the use of Laussedat's method has spread extremely rapidly, for it has roused keen interest in official services, particularly in Germany, Austria, Italy, Canada, East Indies etc. It would be impossible to state, even summarily, all the work, both theoretical and practial, executed in these countries; but we will see that it was in Germany and later in Austria that decided progress was effected in respect to instruments as well as to the principles themselves.

From 1893, Hector De Grousilliers, an engineer of Chalottenberg, whose French name we find with gratification at the starting point of the novel and triumphant career upon which the Laussedat method was about to enter, had been evolving the fertile principle of the stereoscopic telemetre, which became the point of departure of the efforts of Dr. Pulfrich, Scientific Assistant to Zeiss at Jena.

He, indeed, first succeeded about 1898 in giving practical shape to the "stereotelemetre" of Grousilliers and was thus led to study the use of stereoscopic negatives for photo-surveying. It was thus he arrived at the idea and, later, about 1900, at the practical materialisation of the apparatus for the precise measurement of such negatives, the "stereo-comparator", which was to assure the definite and unopposed triumph of photographic surveying. It was, thus, mainly, Pulfrich who created stereo-photo-surveying.

At the same time, after 1891 the Institut Géographique Militaire of Austria had taken up the study of Laussedat's method of photo-surveying and had very quickly recognised its value. Thanks to the keen initiative of the Chief of the Topographical Section of this Institute, General, then Colonel, Von Hubl, it definitely adopted, in 1894, this method of work amidst high mountains.

Between 1899 and the end of 1904, it had already mapped by this method 1278 square kilometres in the mountainous regions of the Austrian Tyrol.

In 1903, the Institute acquired the first specimen of the Pulfrich stereocomparator and subjected the new method to an exhaustive study which gave such convincing results that General Von Hubl decided to use stereophoto-surveying conjointly with the old photo-surveying. This was done to such purpose, that between 1905 and 1907, 1270 square kilometre were mapped by the two methods used simultaneously. We thus see that to General Von Hubl is due the great credit of having brought the new method out of the realms of theory into those of practice.

Meanwhile, on the appearance of the stereo-comparator, the Landesaufnahme of the Great General Staff at Berlin had organised a stereo-photo-surveying Section and subsequently carried out, by this method, the detailed triangulation of German South Africa.

Finally, in 1908, an officer of the Military Geographical institute at Vienna, Captain, then Lieutenant, E Von Orel devised and caused to be constructed the first specimen of a mechanical device for automatic plotting which, in combination with the stereo-comparator, constitutes the extra-ordinary Orel auto-stereo-plotter.

The latest pattern of this instrument makes it possible to construct the map automatically, no longer point by point, but by continuous lines, that is to say the pencil, linked to the binocular microscope, with which the observer studies the stereoscopic negatives, traces on the plan, automatically and without calculation, the horizontal projection of all the lines of terrain and, what is particularly marvellous, the successive level contours of all tracts seen in the two negatives, with their smallest sinuosities and at the exact interval desired by the operator and this up to a distance of 16 kilometres on the scale of 1/25000 with a precision of plotting of the order of 1/10 of a millimetre and a rapidity which varies from 2 to 5 millimetres per second.

In 1912, Mr. von Orel founded at Vienna a private Society "La Stereographik" which has already carried out by means of his apparatus numerous precise plans, either on a large scale, particularly on 1/1000 for private schemes (projects for railways, canals, pipe lines etc.) or on medium scales, e.g. the map of the Dachstein massif on 1/25,000 for the Austrian Alpine Club. Finally Brazil, the Argentine Republic and Norway have just adopted the Orel auto-stereo-plotter for the survey of their official maps and their example is going to be followed by Russia, Italy and Switzerland.

The object of this paper is to show how these extra-ordinary results are obtained, that is to say, to describe the chief elements of the method of auto-stereo-surveying, the principles involved in the instruments used, their manner of operation and their use and lastly by exhibiting practical results actually obtained to prove that auto-stereo-surveying truly constitutes an important advance in topography and cartography.

However, by reason of the limited space at our disposal, it will not be possible to go into details: we shall have to limit ourselves to a very summary description, referring the reader who may wish to go more thoroughly into the matter, to the original works of which a very complete bibliography for the period 1900 to 1911, will be found in the very interesting work of Dr. Pulfrich, entitled *Stereoskopisches Sehen and Messen* (G. Fischer, Jena 1911). It will be seen that of the 276 publications mentioned in this bibliography, only 23 are in French, 11 of which are due to Colonel Laussedat and into one's mind will come, perhaps with some astonishment, the remark of an author referred to above. "In France, far too much noise has been made over the question of photography."

We may, however, mention the following fundamental works from which we have, moreover, borrowed largely :—

(1) "Recherches sur les instruments, les methods et le dessin topographiques" (Vol. II part 2), 1903, published by Colonel Laussedat, a few years before his death. It was the first work which introduced this new method to the French reader and was very complete for that day. As we have seen, scarcely anything has been published in our country since then.

(2) "Die Stereo-photo-grammetrie" by Colonel von Hubl (*Mittheilungen des K. U. K militär geographischen Institutes*, Vol. XXII) 1903.

(3) "Die Stereo-photo-grammetrische Terrain-aufnahme" by the same author

(same periodical, Vol. XXIII) 1904.

(4) "Beitrage zur Stereo-photo-grammetrie" by the same author (same periodical Vol. XXIV) 1905.

(5) "Der Stereo-autograph als mittel zur automatischen Verwertung von Komparator daten" by Lieutenant E. Ritter von Orel (same periodical Vol. XXX) 1911.

(6) "Uber die Anwendung des Stereo-auto-graphischen Verfahrens für Mappierungszwecke" by the same author (same periodical Vol. XXXI) 1912.

*II.—Laussedat's method of photo-plotting.*

This consists, first of all, in measuring either directly or by means of triangulation, a base line disposed approximately parallel to the expanse of terrain to be mapped; and then in taking from each end of this base, and by means of a special photographic camera, the "photo-theodolite," negatives of the terrain, the optical axes of the camera being set, at each station, in the horizontal and directed approximately on the central portion of the country to be mapped.

The plotting of the map involves the following operations; preparing positive paper prints from the negatives; marking on these two prints, lines indicating the horizontal and vertical planes passing through the optical axis; identifying on both prints the images of every point to be plotted; finally, measuring the abscissa and ordinate, OX and OY of each of these two images, with reference to the two axes previously traced.

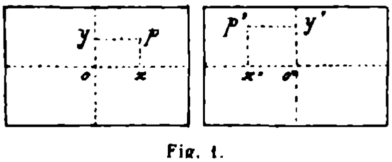



Fig. 1.

The base SS′ (fig. 2) having then been plotted to scale on the plan, we draw from its two extremities or stations, the rays AS and A′S′, in the direction in which the optical axis of the camera was set at each station and upon each of these rays, at a distance OS=O′S′ from each station, equal to the focal length of the photo-theodolite, we erect a perpendicular. Next, by means of the abscissæ, OX and O′X′, previously measured on the prints, we draw the rays from each station towards the point identified. Their intersection is the horizontal projection P of the point, whose altitude can then be calculated very easily by means of the ordinates OY or O′Y′, measured on the print, and the focal distance F.

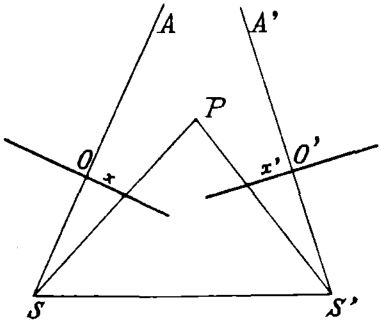



Fig. 2.

We see that the method of photo-surveying resolves itself simply into the classic process of intersection characteristic of planetable surveying, with this difference that here we work, not with points of the real landscape, but with points of photographic images.

The accuracy of the position of the point, thus obtained, depends, then, essentially on the magnitude of the angle of intersection of the rays and, consequently, on the length of the base: but we are limited here, first by the necessity of having the greatest possible extent of country common to the two negatives, secondly, and more particularly, by the very rapidly increasing difficulty of *identifying the same points* on the two prints for the reason that the images become more and more different in appearance and more and more difficult to recognise the further apart the two stations of the base are situated.

It is thus impossible to work with long bases; on the other hand, with short bases a much greater degree of precision is requisite in the drawing of the rays in order to compensate for the smallness of the angle of intersection; but this also is not possible, in the majority of cases, for we cannot identify with sufficient precision on two photographic prints taken at two stations, even close together, not merely the same object but the same point of the object. It is necessary, however, to do so, in order that we may be able to measure its abscissa to a hundredth of a milimetre or to a fraction of a minute, supposing that we are using perfect negatives and can substitute for the measurement of the co-ordinates on the print, angular measures on the original negatives, and then determine the points, not by graphic intersection, but by computation.

We have, therefore, to be content with bases of medium length, giving angles of intersection of about 30°.

As a matter of fact, the difficulty of identifying points is so great that it is very often necessary to make use, for the purposes of checking, of a third image taken from a third station, giving a third ray for each point. Lastly, this work can be undertaken only by an operator who knows the country under survey perfectly, that is to say by him who took the photographs.

It is necessary to add that, in the great majority of cases, it is absolutely necessary to work on *positive* paper prints, so as to facilitate this work of identification, and this tends to increase the inaccuracy of the plotting; it is also necessary, for the same reason, to use only negatives excellent in point of clearness and density, anything else being generally useless. It is, moreover, impossible to apply the method to terrain without well defined features, for example to prairies, woods, glaciers, snowfields, or to country which offers a very small vertical picture to the spectator, as their features are projected one behind another and defy identification from different stations.

Finally, as can be imagined, the distance of the points to be plotted must not be great, for it becomes rapidly impossible to identify them and, invariably their images become more and more blurred with distance, increasing the difficulty of making measurements, the precision of which should increase with distance since the angle of intersection is small.

In fact, the mean normal distance is about 3 kilometres and 6 kilometres is not exceeded. And so, the mean outturn at a station is, *at most*, about 2 square kilometres per station on the scale of 1/25000.

It can be seen, then, that in spite of its great advantages, especially in high mountain country, where the old processes are almost impracticable and give, even though extra-ordinary exertions be made, only unsatisfying results, the method of photo-surveying had rather serious drawbacks which restricted its application, but all these difficulties have been, as we shall see, completely removed by the method of stereo-photo-surveying.

*III.—The principles of stereoscopy.*

The stereo-photographic process is based on a faculty of the eye, stereoscopic vision, the principles of which we will allude to briefly.

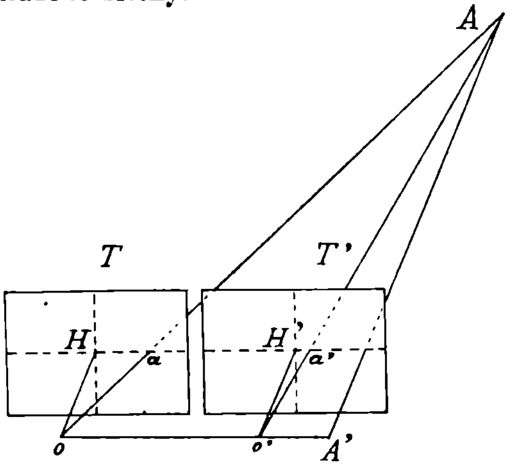



Fig. 3.

Let T and T′ (Fig. 3) be two pictures, in the same vertical plane and parallel to the horizontal line OO′ joining the eyes of the observer. Let OH=O′H′ be the distance of the eyes from the pictures; HH′ the horizon line, common to the two pictures. If A is a point in the landscape situated in the plane of the horizon, *a* and *a*′ will be the images of this point on the two pictures and it is easy to calculate the distance *aa*′ separating these two images, by means of the lengths of OO′, OH and the distance AA′ of A from the straight line OO′.

It is easily shown that all points on the vertical plane parallel to that of the pictures, (or *plan de front*) and passing through A give, on the pictures, two images whose distance apart is constant and exactly equal to *aa*′.

On the other hand, every point on a nearer "*plan de front*" gives images less widely separated than *aa*′ and points on a more distant *plan de front*, images more widely separated.

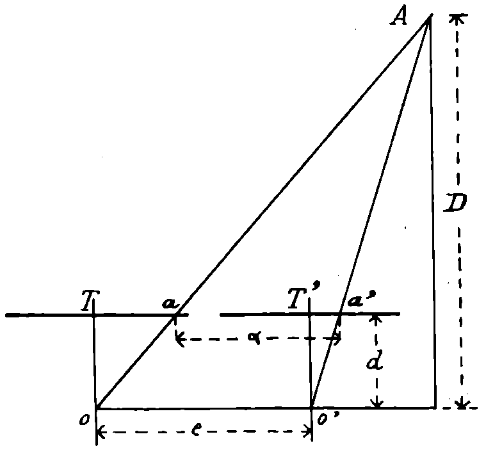



Fig. 4.

Let now T and T′ be the traces of the planes of the pictures in the horizontal plane passing through the eyes O and O′, OT and O′T′, the perpendiculars from O and O′ on these traces, and A the horizontal projection of a point. Let also D be the distance of A from OO′, *e* the distance between the eyes, *d* the distance OT=O′T′. Finally, let *a* and *a*′ be the points of intersection of the straight lines AO and AO′ with the traces T and T′, that is to say the horizontal projections of the two images of the point, and $\alpha$ the length *aa*′, which is sometimes called "the linear or stereoscopic parallax" of the point A (but we shall reserve this term to the difference T*a* — T′*a*′) we then have

$$\frac{D}{e} = \frac{D-d}{\alpha} \quad \text{and} \quad \alpha = e\,\frac{D-d}{D}$$

now *d* is nothing but the distance of distinct vision, about 0·25 metre. $\frac{D-d}{D}$ is then very nearly unity for all objects in the landscape, so that $(e-\alpha)$ is always very small and vanishes for very distant objects.

Stereoscopic effect or vision consists

in the appreciation of the value of this difference, $(e-\alpha)$, an appreciation which manifests itself in the observer having a sensation of the relative distance of the object in question, that is to say by the sensation of "depth" or "relief" in the landscape.

The angle OAO′ is termed the "angular parallax" of the point A. Experience has shown that, for normal eyes, the distance at which this sensation of relief vanishes corresponds to an angular parallax of about 30 sexagesimal seconds of arc, and does not therefore exceed, for a mean separation of the eyes $e=65$ millimetres, 450 metres; certain observers can appreciate angular parallaxes of less than ten seconds, that is to say, their perception of "relief" is still effective at 1200 or 1500 metres.

But we see that the magnitude of $\alpha$ is proportional to the value of $e$ and, at the same time, we also see that if the eyes of the observer are provided with magnifying glasses, the stereoscopic effect is increased in proportion to the magnification G of these lenses, since the images on the retina and the parallactic differences of direction are magnified in this same ratio.

It is, thus, possible to extend artificially the limits of the appreciation of relief and, above all, to make, in respect to stereoscopic images, measures of angular parallax much smaller than those indicated above.

To increase artificially the separation of the eyes, $e$, all that is necessary is to place before each eye the well known system of two total reflection prisms, as used in Zeiss stereoscopic binoculars, and which, for purposes of demonstration, may be replaced by two mirrors, as shown in Fig. 5.

Pulfrich has called the expression $G\frac{E}{e}$ the "total relief effect", G being the magnifying power of the objectives O and O′, E their distance apart and $e$ that of the eyes $o$ and $o'$.

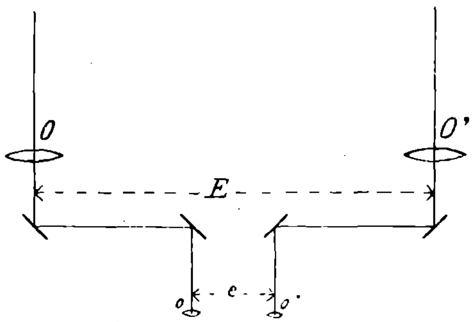



Fig. 5.

In all that has been said above, we have supposed that the actual landscape was under examination, either by eye or by a stereoscopic binocular; the same reasoning is directly applicable to the examination by the same means, of photographic images.

But in the latter case, we see at once that the sensation of relief can be extended to any distance whatever, since the separation of the eyes is now replaced by the separation of the positions of the lens of the camera at the time the negatives were taken, a separation which can be made as large as we wish. All that is then required is to examine the resultant positives with the binocular device, well known by the name of "stereoscope", to see a relief which bears to that which we would have got from the same landscape with the naked eye, the ratio of $\frac{GE}{e}$, G being the magnifying power of the lenses of the stereoscope, E the separation of the two objectives of the camera, that is to say the distance between the two positions of this camera at the time of taking the exposures, and $e$ the distance between the eyes; in short, for the observer, the relief which would have been appreciated by a giant whose eyes were separated by precisely this distance E and who had, besides, a magnifying power equal to G.

It can thus be seen that we can perceive and, if the apparatus be suitable, measure angular parallaxes of extremely small magnitude, much less than the centesimal second. Thus, by photographing the planet Saturn at an interval of one day, that is to say from the extremities of a base whose nett length is 1,730,000 kilometres, a stereoscopic view has been obtained which clearly shows the planet with its satellites suspended in space *in front* of the back-ground of the fixed stars.

It is to be noted in passing that if the width of the negatives is greater than the separation of the eyes, that is if their size exceeds 8/9 it is sufficient to furnish each eye piece of the stereoscope with a pair of total reflection prisms, filling the same role as a pair of parallel mirrors. We can, then, separate the two negatives as we please and consequently use any sizes whatever.

Having got so far, we will suppose that the two negatives have been taken at the extremities of a base of length B, and in such a position that the optical axes of the camera were horizontal, parallel to one another and perpendicular to the base. This, in stereo-photo-surveying, is termed the "normal case".

Let *oo'*, (fig. 6), be the eye pieces, OO' the objectives, FF' the focal points of the stereoscope, TT' the two transparent positives in position in the stereoscope.

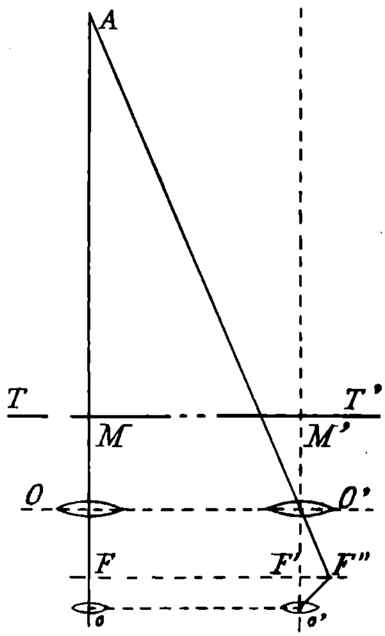



Fig. 6.

Let us suppose that we have placed at the points, F and F' two reference marks, one of which, the right hand mark F' is capable of being moved laterally in the right hand focal plane. Under these conditions we see that when the right hand mark is exactly at F' the two marks coincide with the focal images of a single point of the stereoscopic landscape, situated at infinity. Thus the observer sees, not two marks, but only one which seems to be at infinity.

If now, the right hand mark be moved laterally, so as to bring it, for example, to F'', it coincides in this position with the right hand image of a point A, in the stereoscopic landscape, still lying on the perpendicular OM, in the left hand transparency but at the finite distance AO from the objective O, or what comes to the same thing, from the base B.

The observer then always sees but a single mark, hanging in space, but at a finite and well determined distance.

Proceeding further, if, without again touching the right hand mark, we move as a whole, by means of two rectangular movements the pair of plates in their plane, we find immediately that each time that the image of a point of the stereoscopic landscape, situated at exactly this distance from the base, coincides with the fictitious image of the mark, the observer has a very clear sensation of a real material contact of the ground with the ærial mark; he feels that it *touches* the ground.

It can now be understood that by combining this general movement of the two plates with displacement of the reference mark F', that is to say by moving this "imaginary mark" in space, it can be "guided" to all points of the landscape at will. Now, if we are able to calculate the distance from the base which corresponds to the measurable displacement of the right hand pointer, it is evident that the distances from the base of different points of the stereoscopic landscape can be determined without difficulty.

It is this principle of "imaginary distance-mark", floating in the stereoscopic landscape, or the "principle of aerial scales", evolved by Grousilliers, which Pulfrich used as his starting point, first for the construction of the stereoscopic telemeter and soon afterwards for that of the stereo-comparator, briefly described below.

### *IV.—The Stereo-comparator.*

The apparatus is fitted with a horizontal frame in which the two negatives can be placed side by side in the same plane. This frame is provided with various movements which permit of

*1.* turning the negatives CC' (fig. 7) in their plane and about their centre (this movement is used only for adjusting the plates).

*2.* displacing both negatives laterally and simultaneously to right or left.

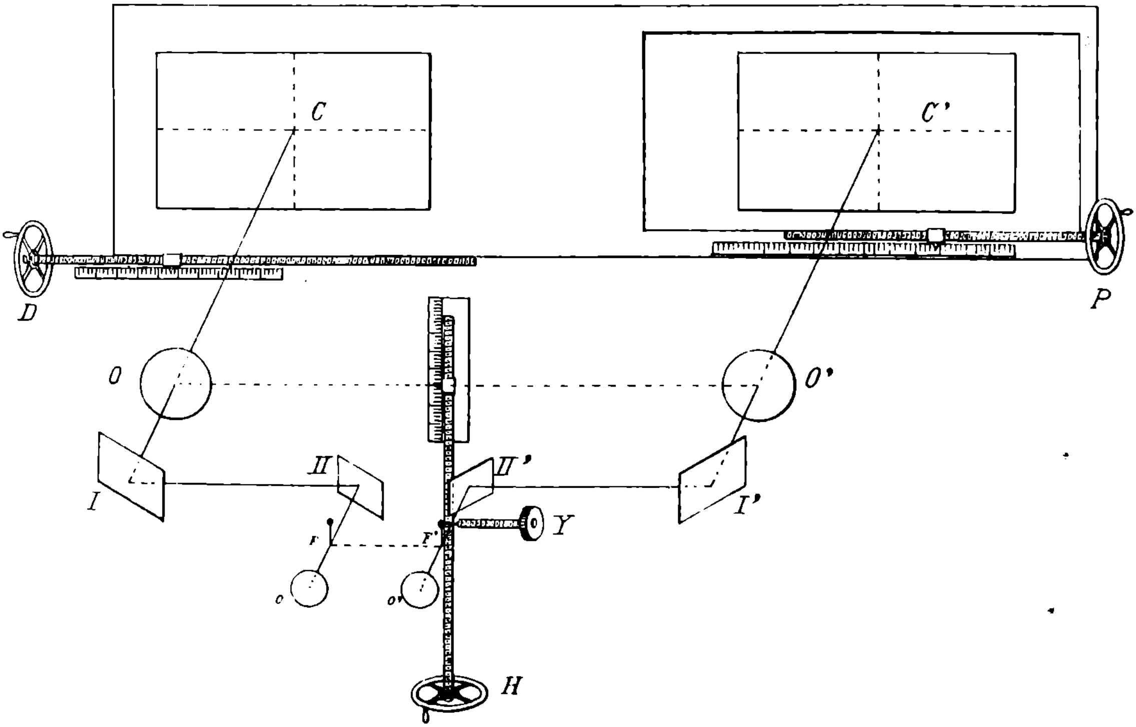



Fig. 7.

The latter movement is produced by means of the micrometer screw D, its amount being measured on an appropriate scale.

In addition, the right hand image can be moved by itself to right or to left by means of a special micrometer screw P, the amount of movement being read on a second scale.

Above the frame carrying the negatives, is placed a binocular miscroscope fitted with the usual arrangement of total reflection prisms, shown in fig. 7 by the mirrors I, II, I′, II′.

The cross wires of the miscroscopes are replaced by the two pointers F and F′ described above. In the first pattern constructed, the arrangement of fig. 7 was adopted, that is to say the right hand pointer was moveable laterally by means of a special micrometer screw Y. This screw, as we shall see, was used only to determine the distances of objects very close to a point already fixed.

By means of a micrometer screw, the whole binocular microscope can be moved towards or away from the frame carrying the plates, so as to permit of the focussing of the stereoscopic image. In addition, the eye-pieces can be adjusted to suit the operator and the objectives moved in the direction of their axes so as to vary the magnifying power from four to eight. The operator thus has in the field of view only a small fraction of the stereoscopic image, but with a relief which can be increased a hundredfold.

Lastly instead of raising or lowering the pair of plates with respect to the microscopes, the latter are moved relatively to the former by means of the micrometer screw H.

In practice, the movement of the right hand mark described above is usually replaced by the moving of the right hand plate by the screw P.

This movement, it might seem, would cause the stereoscopic image to appear to move, the image of the distance mark remaining stationary in space. But it is not so. On the contrary, it is the stereoscopic landscape which appears to the observer to remain fixed and the image of the mark to move in distance. We can then easily touch a given point in the stereoscopic landscape with the "moveable mark" by operating the screw P in combination with the two general movements (wheels D and H). Thus in the latest models, the screw Y is absent; the marks consisting simply of crosses whose four arms carry graduations, by means of which the height and width of objects can be measured *.

Now let us turn our attention to a very important device: a special micrometer screw is mounted on the frame carrying the right hand negative for the purpose of moving this plate in the direction of the principal vertical. It is this movement which makes it possible to allow for the difference of level between the right hand and left hand stations.

If the negatives are placed on the comparator simply symmetrically with regard to one another, this difference of level has the effect of doubling the image of the imaginary mark and making "pointing" impossible.

It requires only a turn of this screw to cause this duplication of image to disappear completely.

* In stereo-comparators which form part of an auto-stereo-plotter this cross itself is discarded and the two fixed marks F and F′ are of the type shown in fig. 7

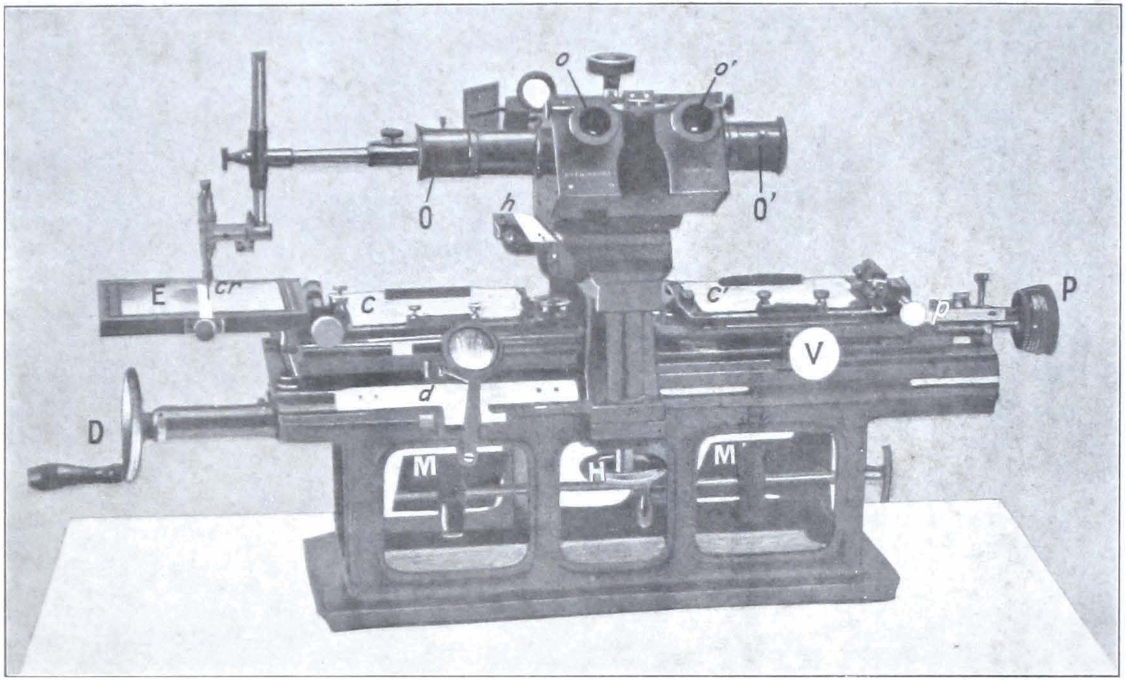



Fig. 8.—Pulfrich Stereo-comparator, model D, for plates 9 × 12 cm.—

*C, left hand negative; C′, right hand negative; E, positive print of left hand negative; o, o′, eyepieces of the binocular microscope; O,O′, object glasses of the binocular microscope; D, hand wheel of "directions"; d, scale of "directions"; P, "distance" micrometer screw and head; p, scale of "distances"; H, hand wheel of "heights"; h, scale of "heights"; V, screw adjusting height of right hand negative; c r, pencil; M,M′, mirrors illuminating the negatives.*

It can be easily realised that this movement has precisely the effect of bringing the two images of the same point on to exactly the same perpendicular to the principal vertical.

It is seen then that the use of bases on a slope does not lead to any difficulty. Experience shows that the angle of slope may be as much as 25°.

Fig. 8 represents the latest pattern of Pulfrich stereo-comparator for 6 × 13 plates. The model for 13 × 18 plates differs from this only in dimensions. The references below the fig. indicate the principal devices to which we have just been alluding.

We will not go into the details of the placing and adjusting of the negatives on the comparator before beginning the measurements, the object of the adjustment being the bringing of the point of intersection of the principal horizontals and verticals, or the principal point of each image, into the optical axes of the two microscopes, which involves the use of several other auxiliary micrometer screws to which we need make no further reference. It need only be said that these operations take much longer to describe than to carry out, occupying, as a rule, not more than 15 or 20 minutes for a pair of negatives.

The measurements proper are then carried out as follows:—

We move first the pair of negatives and the microscope by means of the two general movements, horizontal and vertical, using the screw D, or *screw of "directions"* and H, the *screw of "heights"* in such a way as to bring the point of the landscape, the position of which is to be determined, under the left hand pointer; then by means of the screw P, or *"screw of parallaxes"*, the imaginary "moving pointer" is brought into stereoscopic coincidence with this point. We can easily see that readings then made on the scales corresponding to the screws D and H will give, respectively, the abscissa $x$ and co-ordinate $y$ of the point with reference to the two principal axes of the left hand negative and that the reading on the scale corresponding to the screw P will give the difference between the abscissæ on the two negatives, that is to say, the stereoscopic parallax. All the readings are accurate to 0·01 mm, thanks to both the construction of the apparatus and the magnifying power of the microscope.*

*V.—The Method of Stereo-photo-surveying.*

This process consists, then, of the following operations:—Successively, at the two extremities of a base, always very short relatively to the distances of points of the terrain under survey, we set up a special photographic camera, the stereo-photo-theodolite, so as to satisfy the conditions of what we have called the "normal case", that is to say, that in the two positions, the optical axes are horizontal, parallel the one to the other and perpendicular to the base or briefly, the images are in the same plane. It can be shown that the essential condition to be attained is the rigorous parallelism of the optical axes and that a small error in the perpendicular-

* There is no limit to the uses to which the stereo-comparator can be put in the measurement of objects, whatever their form, size or distance, whether they are in movement or at rest. The manifold applications of this apparatus are surprising. Besides purely topographical plans, with which alone we are concerned here, we may mention hydrographic plans, battle plans, linear measurements, the study of sea waves, the study of clouds, the study of the trajectory of projectiles and their points of impact, the discovery and study of differences, of changes or of errors of images (researches connected with variable and moving stars, verification of graduations of precision, the discovery of forged bank notes etc.).

ity of these axes to the base is less serious than a fault, even a small one, in parallelism which must be correct to within about a minute.

It is for this reason that the photo-theodolites used up till now in photo-surveying cannot be utilised in any way in stereo-photo surveying for they do not enable one to attain this precision even approximately. And so we suggest the name, stereo-photo-theodolite, for apparatus satisfying this condition.

The construction of apparatus of this type is now a matter of *routine* with the firm of Zeiss. Later on we will briefly describe the most recent pattern.

In addition, it is absolutely necessary to make use of two tripods set up at the two extremities of the base and on which, in turn, the photographic camera is placed.

The length of the base is generally measured tacheometrically. Its slope is measured as well as its direction and the position of one of the two stations is determined by one or other of the known methods of traversing, triangulation or planetabling.

It is necessary for precise plotting to have in the field of the negatives one or two "check" points, easily recognisable and appertaining to a triangulation net-work. In the absence of such a net-work, it is, however, sufficient to measure at each station, by means of the telescope of the stereo-photo-theodolite, the direction and the angle of elevation of two or three points of the landscape, clearly visible and easy to identify on the negatives.

These operations complete the *field work*; including the measurement of the base and all the angular measures which have just been alluded to, they do not occupy more than an hour and a half, at most.

In the *office*, the negatives appropriate to a base are placed and adjusted on the stereo-comparator, as described above; after which we proceed with the measurements of points of the stereoscopic image without having to touch the adjustment again.

We have seen that the "sighting" on a point by means of the "moving mark" gives at once to the hundredth of a millimetre, the ordinate and the abscissa of the point, with reference to the principal axes of the left hand negative and also its stereoscopic parallax.

In fig. 9, let $f$ be the focal length of the camera and B the length of the horizontal projection of the base; S and S′, the projections of the two stations on the horizontal plane; TT′, the trace, on the horizontal plane, of the vertical plane of the two negatives; SM the horizontal projection of the optical axis of the left hand negative, cutting TT′ in T, and M a point on this axis.

If we draw M S′ cutting TT′ in T″, we see at once that $T''T' = a$ is the stereoscopic parallax of the point M, T′ being the foot of the perpendicular dropped from S′ on TT′.

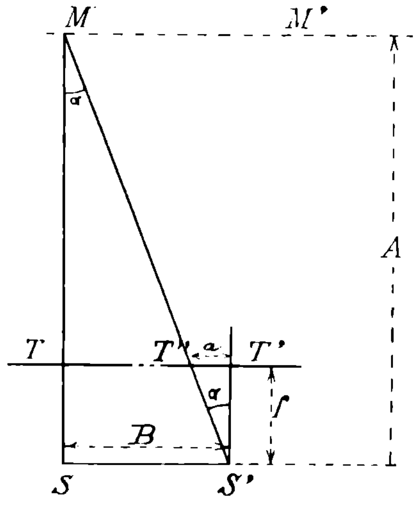



Fig. 9.

If we put S M = A and the angle SMS′ be called $a$, it is seen that

$$A = B \cot a \quad \text{and} \quad f = a \cot a,$$

$$\text{from which} \quad A = \frac{f}{a} B.$$

It can be shown without difficulty that all points on the plane MM′ at the distance A from the base have the same parallax $a$, that is to say, that if we know the parallax $a$ of a point in the landscape, the formula above will give its distance from the base.

The construction of the horizontal projection of the point on the plan is done in the following manner:

We plot on the plan (fig. 10), according to scale, the projection of the base SS′ and at the distance $f$ we draw TT′ parallel to it, and ST perpendicular to TT′. On the line TT′ and from T as origin we lay out with its proper sign, the abscissa $x$, measured on the abscissæ scale of the stereo-comparator or the *scale of directions*; we get thus the point X and draw the line SX; the horizontal projection P of the point will lie somewhere on the line SX.

The parallax $a$, measured on the scale of parallaxes or *scale of distance*, gives, by means of the formula $A = \frac{B}{a} f$, the distance A = SM of the point P from the base SS′. The required projection P lies, then, at the intersection of the line SX with the line M P parallel to S S′ at the distance A.

As regards the difference of level $h$ of the point with reference to the left hand station S, it is evident that it can be derived from the formula,

$$h = y \frac{A}{f} = y \frac{B}{a}$$

$y$ being the ordinate measured on the *scale of heights*.

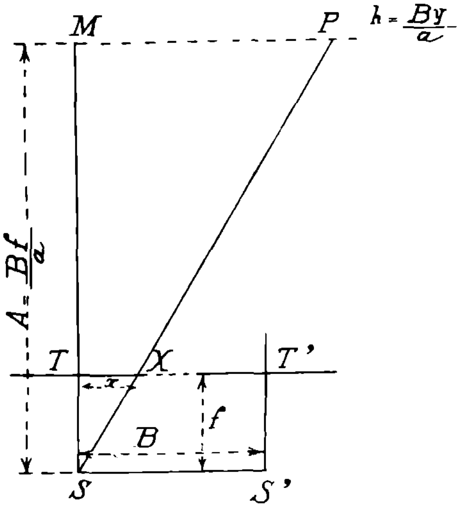



Fig. 10.

We see then that, so far as the construction of the plan goes, the method of stereo-photo-plotting is very similar to the old method of Laussedat. The former has one essential advantage however, in that it is necessary to make only a single pointing to get, *simultaneously*, the three elements required for the determination of the point, whilst in the latter, this determination requires, as we have seen, at least three *independent* measurements; two measurements of abscissæ, one of ordinate. But from all other points of view, as well, the superiority of the new process cannot be disputed. We have seen that the principal defect of the old method of photo-surveying lay in the great difficulty of *identifying the images* of the same object on the two negatives, or the two prints obtained at the two stations and that this difficulty involves one in quite a number of obligations which greatly restrict the field of applicability of the method.

These obligations are;—the necessity of drawing on positive prints; the necessity of the draughtsman in the office having perfect knowledge of the terrain under survey; the necessity, in many cases, of having to introduce a third station for the sake of a check; the necessity for negatives of the best quality; the impossibility of using bases short enough to prevent the loss, always considerable, of the field of view not common to the two photographs; the impossibility of applying the method to very receding or regular ground without detail; the impossibility of working at considerable distances and consequently a poor return in square kilometres per station and a necessity of increasing the number of stations.

On the other hand, the characteristic evil inherent in the photographic method, the difficulty of identifying the images of the same point, is entirely absent from the new method, *for indentification no longer comes into the matter.* The observer sees before him the landscape in relief; he makes the "moving mark" touch the object and, indeed, that point of this object which he finds convenient to his purpose, whatever be its shape, nature or distance; for example, any tree whatever in the middle of a wooded slope, any point whatever on a uniform surface (grass or debris slope).

He has no difficulty in selecting, along the characteristic lines (changes of slope, water courses, arêtes etc.) the points by which the terrain can be most satisfactorily defined, instead of being obliged to search arduously for the small amount of detail that can be identified on the two prints but which is often far from characteristic.*

This unrestricted choice of really useful points necessarily reduces the number of points of detail that have to be plotted.

In addition, the photographs present the same details by reason of the shortness of the base, generally from 40 to 300 metres long, and this leads to a better yield from stations and a very considerable diminution of their number. Moreover, thanks to the elimination of the need of *identifying points*, we can tackle any kind of terrain besides high mountains, including, contrary to an opinion still very wide spread, ground not only uniform but very receding, as we will show by characteristic examples later on. All that is necessary is that there should be a few stations from which sufficiently comprehensive views of the detailed forms of the ground are obtainable.

Another result of the elimination of the need of *identification* is that the operator in the office no longer need know the terrain, especially as it appears in real relief before his eyes and since his moving pointer serves him as a thoroughly intelligent *staff man*, instantly obedient and capable of moving in a moment to the most distant or the most inaccessible points.

As for the negatives, they are used directly in the comparator, the transposition of lights and darks not affecting the facility of making pointings with the "moving pointer" and there thus results a considerable increase of precision. Moreover, we can make successful use of negatives which would have been rejected under the old method, for the reason that they were thin or the opposite, very dense, but which give good relief in the stereo-comparator.

* One has no idea of the extent to which the drawing, even on the most modern maps, of heavily wooded spurs in high mountains can be incorrect as a result of this, in spite of all the care of the most conscientious, experienced surveyors.

As regards the distance up to which the negatives are practicable, this is of considerable extent and, on a scale of 1/25000, it is possible without difficulty and with sufficient accuracy to plot ground 14 or 15 kilometres from the base.

Finally, the principle itself, of the presentation *in relief* of the ground to be mapped constitutes a substantial and inestimable advantage of the process. The field of view of the microscope of the stereo-comparator does not exceed 1 centimetre in radius, but for the examination of the negative, *as a whole,* we can use, instead of the microscope, a stereoscope provided with mirrors, which presents to the observer a view of the ground in relief showing a wealth of detail and extraordinary modelling, irrespective of the altitude of the station above the landscape, so that a stereoscopic view taken from a high summit does not appear at all flattened or crushed as in the photographs taken for the old method; this enables us to make use of stations of this kind with great advantage by reason of the considerable extent of ground displayed, whereas formerly it was recommended that such stations should be carefully avoided because terrain seen from above appears without relief, flat and featureless: the valley forms disappear and slopes are no longer appreciable.

We cannot do better than quote here from General von Hübl, to whom stereo-photo-surveying owes so much.

"The apparent size of this image in relief depends on the distance between the two camera stations and the interval between the observer's eyes.

If the latter, for example, is 65 millimetres and if the length of the base is 65 metres, the landscape appears as a model reduced in the ratio of 1/1000.

A single glance through the apparatus, even at a bit of country strange to you, gives you your bearings at once and those particular points of detail whose positions should be determined for the representation of the forms are at once obvious and unmistakable. The steepness of the slopes, the changes of slope, the depth of each hollow are easy to see and considerably more easy to appreciate than *in nature.* Thanks to these circumtances, the reproduction on a horizontal projection, showing the exact character of all the forms, is greatly facilitated. We are dealing no longer with Nature with its massive, impressive forms of which our eyes can take in but the smallest part, and whose representation on a sheet of paper requires great practice and experience but with a model, rich in detail, giving us a comprehensive view in which accessory details are suitably subordinated to the main forms.*

* It is interesting to draw attention here to the small number of persons, even among those constantly practising stereoscopic photography who have any idea of the *modelling,* the *relief,* that in the case of a big landscape, is given by stereoscopic negatives taken on a sufficient base. The greater number of them, indeed, take *stereoscopic* photographs of a landscape, only by operating *simultaneously* the two shutters of their apparatus, in other words from a base equal in length to the interval between their objectives; but negatives thus obtained give the same degree relief as that presented by the same landscape when observed with the naked eye, a relief which disappears, as we know, at distances greater than a few hundred metres. These operators, in the majority of cases at all events, know nothing of the beauty of stereoscopic landscapes which, for simplicity's sake, we will qualify as "of large interval", or at any rate they imagine that it is necessary to use complicated apparatus and, in all cases, *stand cameras.*

Now, nothing is more easy than to obtain these effects with a simple *hand* apparatus, provided it is furnished with a cap which permits of each objective being uncovered *in succession.*

The procedure is otherwise most simple; placing himself, squarely facing the landscape, at one extremity of the base, chosen so as to be *approximately* parallel to the expanse of landscape, the operator places the cap on the objective

"*The advantages we gain by using the comparator rather than the present method of determining the positions of points by rays and intersections are so considerable that we should not be deterred by any trouble or expense that the work on the ground may entail.*"*

It is thanks to the ardent belief which the author of these *prophetic* lines placed in the value of the new method that not only have all the difficulties of the field work been overcome but the method itself has led to still more marvellous results, which remain to be described, and has acquired an elasticity which places it absolutely without rival.

It is of interest to note the difficulties to which General von Hübl refers and which were pointed out first by him to the makers.

It is first necessary that the objective of the stereo-photo-theodolite be perfectly made and corrected so as to give images free from defect and distortion, since the precision of the reading of the parallaxes amounts, as has been mentioned already, to 1/100 of a millimetre. Now, this precision is essential, for it can be easily shown that for a focus of 193 mm, for example, this amount of parallax, equivalent to a difference of parallactic direction of from 8 to 10 seconds, approximately, corresponds to a difference of "*depth*" of 10 metres at 6 kilometres, for a base of 200 metres. It is, for this reason that we cannot use paper prints which are always distorted.

which corresponds to the other station; then noting the position in the field of view, of a distant, clearly visible point, as close to the intersection of the cross wires as possible he takes, in this position, the negative corresponding to the station. After which, the objective in front of the negative which has just been taken is covered by means of the cap and the other station is visited, the shutter being reset. From this second station, the observer picks up again the reference point, placing himself so as to bring it *approximately* into the same position relative to the cross wires as before, so as to get *approximate* parallelism of axes at the two stations, that is to say, the "normal" case in stereo-photo-surveying. The exposure from this point of view is then made and the operation is completed.

It goes without saying that one should endeavour to have the nearest picture planes suitably distant so that they shall not differ too greatly in the two negatives, to introduce no objects in movement and to avoid a base at too great a slope.

After a little practice, these operations, which appear complicated, do not take up more than two minutes at each base.

Small stereoscopic apparatus of the size of the Richard Verascope (4, 5/10. 7) is admirably suited to this rough method.

One can scarcely imagine how extraordinarily interesting collections of diapositives of this kind can be, even when the regions are completely unknown to him who studies them under the stereoscope.

The prolonged indifference to stereo-photo-surveying, exhibited by the majority of technical men, is due, certainly in part, to their ignorance of the undreamt richness of these "models" and of the great ease with which they can be obtained as much as to the fact that, on most occasions those few who practised stereoscopy "of large intervel", worked on foot and on elevated summits. Now it is practically impossible to find there bases sufficiently large and suitable for the "normal case", which alone is applicable, except with special apparatus; views obtained thus, from bases of a few metres, of massifs generally several kilometres distant, present a relief entirely insufficient and almost without interest, merely suggesting the effect of theatre scenery, of *planes* one behind the other. There is no "*modelling*" in the proper sense of the word.

This depends mainly on the magnitude of the base; which may be varied with advantage from a twentieth to a thirtieth of the distance to which it is desired the sense of relief shall extend, a *distance to be determined, of course, on the ground;* this length of base can be measured on the ground, simply *by pacing.*

It is scarcely necessary to state that this procedure can be carried out equally well with apparatus having but one objective, that is to say non-stereoscopic; all that is necessary is to pack away the exposed plates at the one station before going to the other.

Finally, the process is further simplified in the case of photographs taken on board a ship moving along a coast; for the base is provided by the progress of the ship itself and the parallelism of axes is got quite simply by adjusting, for each exposure, the apparatus in the same position on the deck. The whole operation is thus reduced to loading and exposing twice.

Astonishing "models" can be obtained thus of a coast line, 8 or 10 kilometres distant.

* Colonel Von Hübl: Die Stereo-photo-grammetrie (Mittheilungen des K. u. K. Militärgeogr. Institutes, Vol. XXII, p. 15).

The sensitised plates used must also be true planes, for it can be shown that if the divergence from the plane amounts to 1 millimetre at the edges, not uncommon in the case of ordinary plates, this defect leads to errors of parallax in these parts of the plate of from 3 to 4 tenths of a millimetre.

Again, the plates must be as exactly as possible in the same plane and, in especial, parallel at the two stations, for an error of parallelism of only one minute causes an error of parallax of from 1 to 2 tenths of a millimetre.

It can be shown, however, that if the axes, while remaining parallel to one another, diverge slightly from the perpendicular to the base, this defect leads to far less serious consequences than the former, as regards the precision of the measurement of parallaxes, and that we can tolerate a *common* deviation of the two plates of from six to eight minutes.

Lastly the plates should be as nearly vertical as possible, an error of one minute in the position of the horizon resulting in an error of parallax of 3/100 of a millimetre.

As regards the measurement of the base, this should be carried out with high precision, that is to say to at least 1/1000. It can be shown, in fact, that an error in the base has a proportional effect on the distances of points.

For all these reasons and more specially on account of the effect of errors of base measurement and of perpendicularity of the two optical axes to the base, it was considered, about 1905, to be absolutely necessary to have on the negatives from *six to ten* "control" points which would make it possible, with the help of formulæ and construction of somewhat complex nature, to eliminate these two errors before commencing observations with the stereo-comparator.

So far as the method itself was concerned, there were, even in 1905, the following objections:—

It was practically obligatory to use nothing but negatives obtained in the "normal case", that is to say with the optical axes perpendicular to the base; it was impossible to use axes oblique to the base, but parallel *inter se*, and still more so, convergent axes. These two cases, especially the latter, called for extremely slow, complicated operations, in spite of all the simplifications introduced especially by General von Hübl, by the eminent Prof: Dolezal of Vienna, by Prof: Fuchs of Presbourg, etc. So much so, that, putting on one side the "normal case", one could foresee *dimly* in the future practically only the case of two axes, parallel one with the other, and inclined at 30° to right or left of the perpendicular to the base, extending the field of view from 40° to about 100°. This constituted a serious defect and a want of flexibility of method for it is often very difficult to find amongst high mountains a site for a base of sufficient length, suitable for the "normal" case, especially on high crests, otherwise particularly favorable, in that they offer an extensive view.

And so, in 1904 General von Hübl decided provisionally, to use the old photo-surveying simultaneosly with the new method.

In the matter of office work, even in the "normal" case, the stereo-comparator enabled one to plot only point by point, very slowly and laboriously, the level contours in every case being drawn only after there had been placed on the plan a sufficient number of spot heights to permit of the curves being interpolated by the old method.

*VI.—The Stereo-photo-theodolite.*

The instrument required for the field work is the stereo-photo-theodolite. With the firm of Zeiss of Jena the making of these instruments is now *a matter of routine.* We will describe the 1913 model of which fig. 11 gives a general view, and which is designed to take 13×18 plates.

For convenience of transport, the apparatus is made in three separate parts, *the tripod* provided with a centring device, the *photographic camera* and the *theodolite.* The particularly compact construction of instrument is to be noticed. This, while giving great stability, facilitates the reading and manipulation of the different verniers.

The camera rotates on its *tribrach* about its *centre* and can be set to any position by a clamping screw. It is fitted with a lens which can be raised or lowered by 30 millimetres with respect to its central position.

The frame carrying the object glass is furnished with an arm inside the camera, moving with it and terminating in a horizontal index with a very fine point *a.* This point moves along and very close to the right hand vertical edge of the sensitised plate (fig. 12).

The point of this index is, in consequence, in the same horizontal plane as the optical axis *o.* Its image on the plate thus registers, very simply, the position on the negative of the principal horizon.

The frame against which the sensitised plate rests has four reference marks 1. 2. 3. 4. arranged as shown in fig. 12. These marks are formed of small metallic projections which lie very close to the sensitized

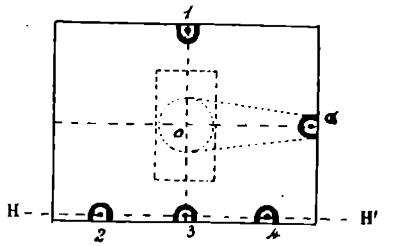


Fig. 12.

film and have at their centres a hole which, being of a diameter scarcely greater than the thickness of a hair, gives a very precise black point on the negative.

The marks 1 and 3, define the principal vertical of the negative; the marks 2, 3, 4 are on the same straight line H H'. parallel to *Oa.* It follows that if the image of the mark 1 is badly defined on the negatives, as sometimes happens since this part of the plate is generally very dark, we can always find on the stereo-comparator this principal vertical since it is the perpendicular dropped from 3 on to the straight line *Oa,* itself parallel to 2, 3, 4.

The dark slides are devised so that, at the time of exposure, the sensitised surface presses directly against the frame at the back of the camera and the focal distance is thus rigorously constant from plate to plate and unaffected by variations in the thickness of the slides.

On the sides of the frame and inside the camera are three drums having series of perforated numerals which print automatically on to the negatives, the serial number, up to 24, of the base, the distinguishing number of each negative at each station and lastly the focal distance of the lens.

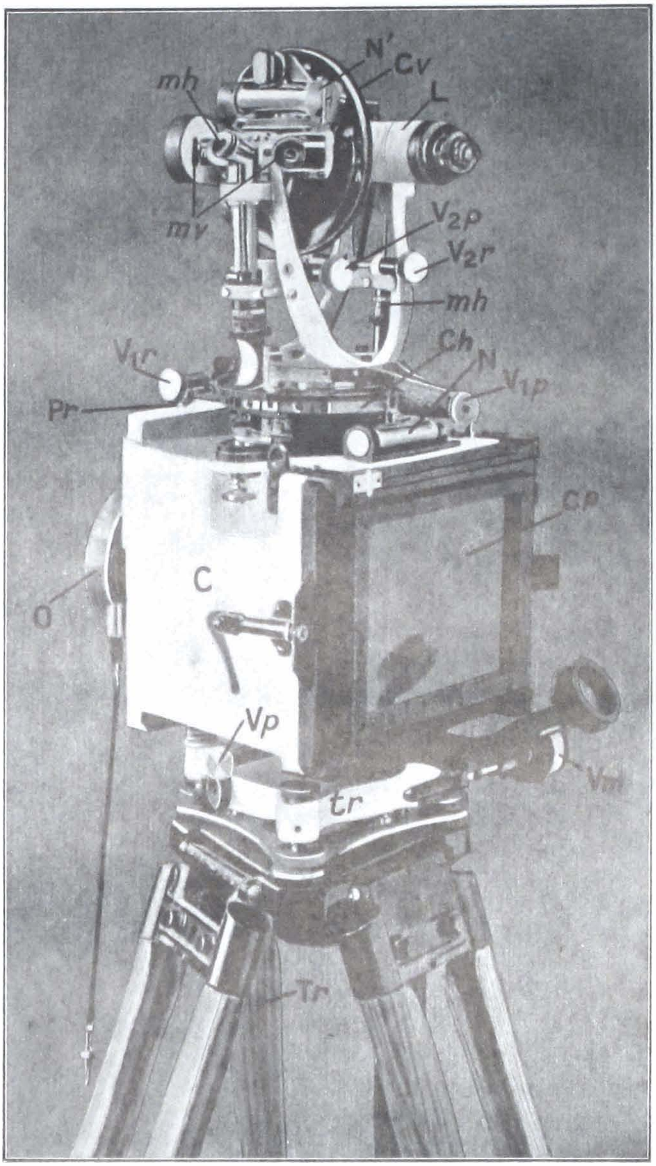



Fig. 11.—Zeiss Stereo-photo Theodolite, 1913 model, for plates 13 × 18 c. m.—

*Tr, tripod; C, camera; tr, tribrach; Vm, micrometer screw for measures of distance; Vp, clamping screw; O, camera objective; Cp, plate carrier; Ch, horizontal circle;* $V_1r$, *Pr, slow motion screw and stop controlling rotation of theodolite on the vertical axis;* $V_1p$ *clamping screw on horizontal circle; N, N′, bubble tubes; L, telescope of theodolite; Cv, vertical circle;* $V_2r$, *slow motion screw of vertical circle;* $V_2p$, *clamping screw of vertical circle; mh, horizontal microscopes; mv, vertical microscopes.*

Photo.-engraved & printed at the Offices of the Survey of India, Calcutta, 1921.

On the top of the camera are placed two levels at right angles to one another, the value of their divisions being fifteen seconds.

The theodolite is mounted at its *centre*, on the top of the camera, in such a way that a specially constructed *catch* allows of the diameter, 0°—180°, of the horizontal circle being set with perfect exactness in the same vertical plane with the optical axis of the camera. A special "spur" device of the horizontal circle enables the telescope to be placed *exactly* at right angles to the optical axis or to deflect it, equally exactly, by 30° to right or left. These three positions give, at the station, a total field of view of 105°. The readings on the horizontal circle, which is 120 millimetres in diameter, are made to about 30 seconds.

A special micrometer screw, placed horizontally below the camera, provides a means of measuring the length of the base. This is done by directing the telescope by means of this screw, successively to the two extremities of a horizontal metal scale, 1 metre in length, placed on a second tripod at the other extremity of the base and by reading on the micrometre head the number of divisions which correspond to this movement of the telescope. One division of the micrometer equals 1/30,000 of its effective distance from the vertical axis of the instrument.

A mark of special design, fitted on the tribrach of the tripod at the second station, provides a point on which observations are taken for the purpose of setting the optical axis of the camera, either in the "normal" case or in any other.

Carefully prepared plates, worked as for mirror glass, are used for the negatives. It has been recognised as absolutely useless to "work" them "optically" as was thought possible at first. The fineness of the grain of the emulsion is from one to two thousandths of a millimetre which certain manufacturers have succeeded in producing as a stock quality.

This fineness of grain allows of an eight fold magnification in the stereo-comparator and of attaining, normally, a precision of eight or ten seconds in measures of direction or slope.

We will not refer again to the method of using the stereo-photo-theodolite in the field, that is to say to the stereo-photo-survey method already described.

We have shown what degree of precision has been reached in the design of the stereo-photo-theodolite and how this has led to a reduction of *instrumental* errors; the process, however, which enables us to set up the negatives on the auto-stereo-plotter with great ease and to get rid of all the complicated corrections which had to be carried out formerly, consists in determining for each stereo-photo-theodolite with extreme care and at the outset before it is taken into use, what are called its *characteristic constants*, which we will enumerate briefly.

*As regards the camera.* Focal distance, projection on the plate of the nodal point in front of the objective, distance between the horizon defined by the movable point *a* on the negative and the real horizon of the negative (fig. 12), distance between the vertical defined by the marks 1 and 3 and the real principal vertical (fig. 12), value of the micrometre screw, error of the zero of graduations of the micrometer.

*As regards the theodolite.* Error of parallelism of the vertical axis of the theodolite and the vertical axis of the camera, error of perpendicularity of the axis of rotation of the telescope to the vertical axis of the theodolite, difference of height between the axis of the objective of the camera and the axis of the telescope of the theodolite, error of collimation of the telescope.

A previous, precise knowledge of all these characteristics of a given apparatus, enables us to determine, in advance and once for all, a set of corrections to be applied to the stereo-comparator which enables *immediate* use to be made of all negatives produced by this particular apparatus. All that remains now is to correct for errors of *operation* which only affect, unless they are very gross, the length of the base and, very rarely, the angle between the optical axis and the base.

These several points constitute an important, though on the whole but little known, advance.

*VII.—Office work and the Orel auto-stereo-plotter.*

We have seen that office work with the Pulfrich stereo-comparator had still to contend with several radical defects. By its nature, it admitted inevitable causes of error, the consequences of which were that from 5 to 10 °/₀ of the points were incorrect. Besides, the map could be built up only point by point and these points were determined by means of calculations and construction which were still of considerable length, in spite of all the improvements introduced, so that about five or six minutes were taken up in calculating and plotting each point.

Another result was that the contours, the essential elements of slope, could be got only by the antiquated process of *interpolation* between spot heights.

Now, though, by reason of the nature itself of the old methods, it was impossible to define ground forms exactly and precisely or to produce anything but interpolated contours, simply and of necessity approximate, the veritable model of nature, of such emphatic relief, conjured up by the stereo-comparator was a very different thing, of which a simple examination gave, even at the first glance, an extremely precise and complete knowledge of the most complicated terrain.

After starting with this vision in such high relief, to finish with a plan so rough and crude in modelling as that given by interpolated contours was truly, as Von Orel remarked, a failure to take full advantage of the method.

Finally, as we have seen, the stereo-comparator enabled us to make practical and easy use only of negatives obtained in the "normal" case, and this greatly reduced the applicability and the elasticity of the method.

And so, in a very short time, efforts were made to improve matters, first, by getting rid of all calculations and all construction of points, that is to say, by making the plotting on the map automatical.

Without referring to the experimental work, now obsolete, of Deville, the eminent Director of the Geographical Service of Canada, whose "graphic stereoscope" was really only a demonstration apparatus, Thompson in England had made experiments in this line. More recently, Dr. Pulfrich had worked on the design of the "stereo-cartographer" with a view to attaining automatic construction, point by point. But these apparatus have been so greatly surpassed by the Orel "auto-stereo-plotter", an earlier creation than the stereo-cartographer, that we will deal only with this which is, moreover, the only one in use at the present time.

It was in 1907 that von Orel, then a Lieutenant at the Institut Géographique Militaire at Vienna began his investigations. A first model, constructed by the firm of Rost in Vienna, was used experimentally in this year for the automatic mapping of the region of the Ortler from stereoscopic negatives obtained in the preceeding year.

The apparatus could still plot automatically only point by point but it got rid of all graphical errors. Heights had still to be calculated and two operations were necessary. Nevertheless, one point was determined and plotted in a minute, some five or six times quicker than with the stereo-comparator.

This first work, rigorously checked on the ground during the summer of 1909, exhibited surprising accordance with all the verificatory measurements.

Efforts were therefore redoubled, and in 1909, the firm of Zeiss in Jena delivered to the Institut Géographique a new model, in which von Orel had succeeded in effecting the automatic construction, no longer of isolated points, but of contour curves with a graphic precision of two-tenths of a millimetre. The plan board had also been enlarged and allowed of the automatic plotting, on the scale of 1/25,000, of points situated twelve kilometres from the base.

It was subjected in this year to a detailed test on the musketry ground at Hajmasker (Hungary). The ground was surveyed tacheometrically on a scale of 1/10,000 with a precision absolutely abnormal to this scale (800 to 1000 points to the square kilometre) and the contours were drawn in by interpolation at one metre vertical interval. Then the stereo-photo-survey method was applied and the negatives, thus obtained, were "worked" on the auto-stereo-plotter, the automatic tracing out of the level contours being done directly on the tacheometric plan, mounted on the plan board.

The agreement was extraordinary and it was even obvious that the "model" given by the auto-plotter was much more complete and exact than that defined by the tacheometric contours.

Faced by these results, the Institut Géographique Militaire definitely adopted the apparatus and a third model, that of 1911, was built by Zeiss.

The 1909 model was still capable of plotting, only point by point, negatives on axes parallel though not perpendicular to the base and it could not deal with convergent axes. The 1911 model effects the automatic construction, not only of level contours, but of any curved lines whatever (roads, water courses, boundaries of forests, limits of rocky ground etc.) with the axes oriented *in any way whatever*, provided they lie in the horizontal plane. The plan board has been still more enlarged.

Three instruments of this pattern are actually in use. At this moment, Zeiss is constructing a new series of Orel auto-stereo-plotters, namely, the 1913 model in which the improvements affect merely details.

Lastly, a pattern allowing of the use of axes out of the horizontal has been designed and studied in all its details.

It is to stereo-photo-surveying combined with the use of the Orel auto-stereo-plotter that we apply the term *Auto-stereo-surveying*.

1. *Description of the Auto-stereo-plotter*. We will describe, but only very

summarily, the 1911 pattern, and deal only with principles (fig. 13).

The apparatus consists of a Pulfrich stereo-comparator for plates 13×18 fitted in prolongation and to the left of the long lower edge of a solid plan board of very large dimensions.

It differs from the ordinary stereo-comparator, in that the two frames to carry the negatives are independent, the one of the other.

The frame of the left hand negative is, besides, extended to the left so as to carry a print on card, quite flat, parallel to the left hand negative. The binocular microscope carries, toward the left hand, a rod terminated by a pencil *cr* adjusted over the print, the object of which is to draw automatically on this print and in ***perspective*** the contours, traced out at the same moment in horizontal projection upon the drawing paper. (see fig. 8 representing the stereo-comparator and fig. 1 of plate VI).

A little above the drawing board and parallel to the long side, that is to say, to the principal horizon of the negatives, is placed a rigid metallic bar EE′, carrying two screw threaded blocks capable of being made to travel by means of two solid endless screws ***st*** and ***uv***, parallel and coupled by means of bevel wheels on a shaft ***tu***.

These rods turn in plummer blocks fixed to the bed plate of the machine. The screw ***st*** terminates in a hand wheel, called the "***distance wheel***". It can be seen that by turning this wheel, we control the movement of the rod EE′ over the whole surface of the drawing board.

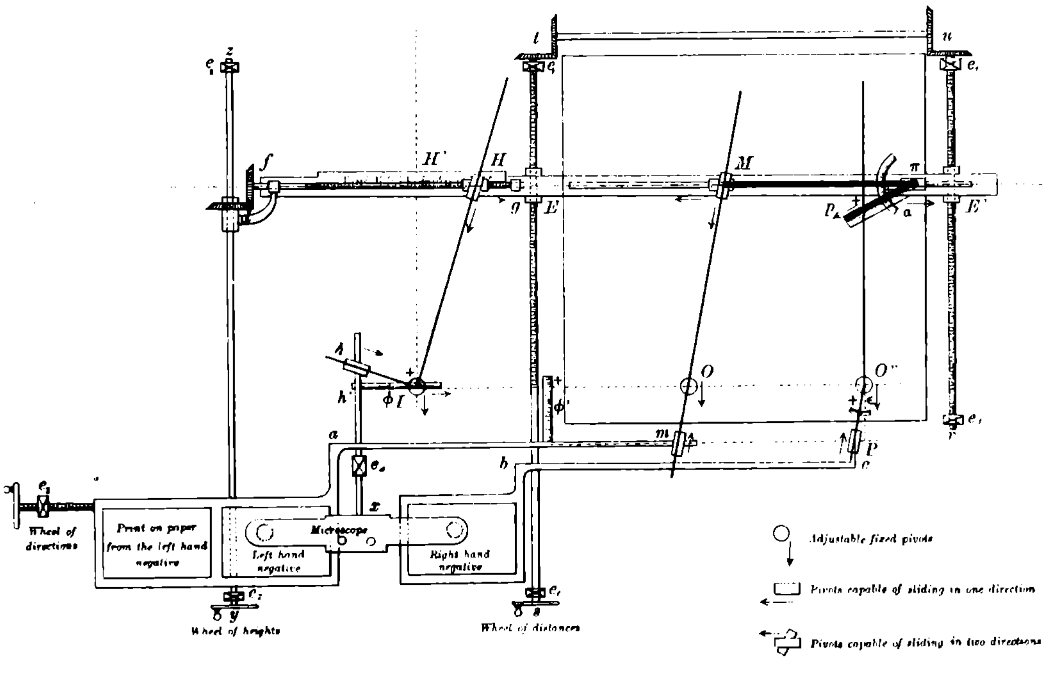



**Fig. 13.**

The binocular microscope is carried by a horizontal rod *hx*, perpendicular to the principal horizontal of the negatives, that is to say to EE′.

This rod controls at *h*, by means of a pivoted sleeve, the rotation of the arm *h*I of the right angled lever *h*IH. During this rotation, the pivot *h* slides on the arm *h*I. The point I is fixed. The point H is a joint connecting the lever *h*IH to the rod EE′ and consists of a double movement pivot, that is to say it is capable of movement along EE′ as well as along HI. The rod *hx* slides in a plummer block $e_4$ carried by the bed plate.

The movement of H along the rod EE′ is got by means of an endless screw *fg* mounted on EE′ and connected to a lateral shaft *yz* by means of a bevel wheel *df*, carried by the bar EE′. In addition, the hub of the pinion *d* of this bevel gear is able to slide along *yz* by means of a feather sliding in a canelure cut in this shaft. This latter is carried in two bearings $e_2$, fixed to the bed of the machine, and terminates in a hand wheel called the "*height wheel*".

It can be seen that if we turn this wheel without touching the distance wheel, the point H is moved along EE′ which remains fixed while, at the same time, the binocular microscope moves parallel to the plane of the negatives in a direction perpendicular to the principal horizontal. If the distance wheel be turned without touching that of height, it will b eseen immediately that the microscope will perform the same movement, but the point H will remain fixed on the rod EE′ during the movement of the latter.

The frame of the left hand negative carrier is connected by a rod, *am*, parallel to EE′, to a lever *m*M, capable of turning about the fixed point O. The connection is effected by means of a sliding pivot such that, during the rotation, *m*, fixed on *am*, moves along OM. The point M consists of a pivot joint with two sliding movements, connecting the arm of the lever OM to the rod EE′, in such a way that the pivot M can slide along either EE′ or M*m*. It is the point M which carries the pencil which automatically draws the map.

The turning movement of the lever OM is produced by rotating a wheel, termed the "*wheel of directions*", fixed to the frame of the left hand negative carrier and having a screw thread bearing in the thrust block $e_3$, carried by the bed plate of the machine. It is seen that by turning this wheel without touching the other two, the left hand negative is moved in a direction parallel to EE′.

The lever OM will turn about O and in this movement, the pencil will trace out all the points of EE′, which remains fixed, as do the microscopes.

The results of turning the other wheels can be just as easily appreciated and it will be thus seen that if all three be turned simultaneously, the microscope can be brought over any point whatever of the left hand negative and the pencil M to any point whatever of the drawing board.

Lastly, the frame of the right hand negative carrier is connected like that of the left, by a bent rod *bc*P, which carries a sliding pivot P, to the lever PO″*p*, capable of rotating round the third fixed pivot O″. This lever is connected to the pencil carrying joint M, of the rod EE′ by a special piece M$\pi$*p*, formed of two rods jointed at $\pi$. The rod M$\pi$ has only one movement, that of sliding along EE′; the rod $\pi p$ carries a pivot $p$, with two sliding movements, connecting it to the lever $pO''$ and capable, in consequence, of sliding along both $pO''$ and $p\pi$. Consequently, if we turn the direction wheel without touching the other two, the effect of which is, as we have seen, the movement of the left hand negative parallel to EE′, the movement of the piece $M\pi p$ will produce a similar effect on the right hand negative.

Summarising, the movement of the three wheels permits of the "movable mark" of the binocular microscope being brought on to any point whatever of the stereoscopic view and to move the pencil to any point whatever of the drawing board.

The rod EE′ carries a micrometer scale HH′, graduated outwards from zero at the point H′, the foot of the perpendicular dropped from I on EE′.

It is on this graduated scale that is read the differences between the heights of the points observed and that of the left hand station.

The distance of the point I from the rod $xh$ can be varied at will by means of a micrometric scale $\phi$. The rod $\pi p$ also carries a micrometer screw which allows of the length $\pi p$ being adjusted exactly. In addition, the angle $p\pi M$ also can be altered at will, by means of a micrometric graduated arc $a$. The part $O''P$ of the lever $PO''p$ can likewise be bent at O″, so that $PO''$ makes any angle whatever with $O''p$, measured on a micrometric graduated arc $\epsilon$.

Finally, the three fixed points I, O and O″ are on the same straight line parallel to EE′, but all can be moved simultaneously in a direction perpendicular to EE′, by any amount whatever with reference to the straight line $a\,m$ P, this amount being measured by means of a micrometric scale $\phi'$. On the scale $p\pi$ is set off the length of the base. The scale $\phi'$ gives the distance of the line IOO″ from the line $am$P, equal to $f$, the focal length of the stereo-photo-theodolite. By means of the scale $\phi$ the same value is given to the length I $h$ and on the graduated scale $a$ is set the value of the angle $M\pi p$, the angle between the optical axis of the left hand negative and the perpendicular to the base. (In the "normal case" $\pi p$ coincides with $M\pi$). The graduations $\epsilon$ are used to give to the angle, supplementary to $PO''p$, the value $\epsilon$ of the angle between the two optical axes in the case of convergent axes. Clamping screws allow of the "travellers" being securely fixed in position on these different scales.

Figure 13, it should be understood, is purely diagramatic, for instance, the "height" wheel is in reality duplicated by a pedal, so that the operator is enabled to put in movement, absolutely simultaneously, the three mechanisms of height, direction and distance.

Fig. 14 is a view of the 1911 model.

2. *The Principle of operation of the Auto-stereo-plotter.* The extraordinarily simple and ingenious geometrical and mechanical principles on which the operation of this marvellous apparatus is based can be described in a few words.

Let O X and O′ X′ be the horizontal projections, on the plane of the map (fig. 15), of the optical axes of the camera in its two positions at the extremities of the base OO′. We will suppose we have to deal with the case where the axes are parallel to one another, but oblique to the base, $a$ being the angle between the base and the normal to the two axes.

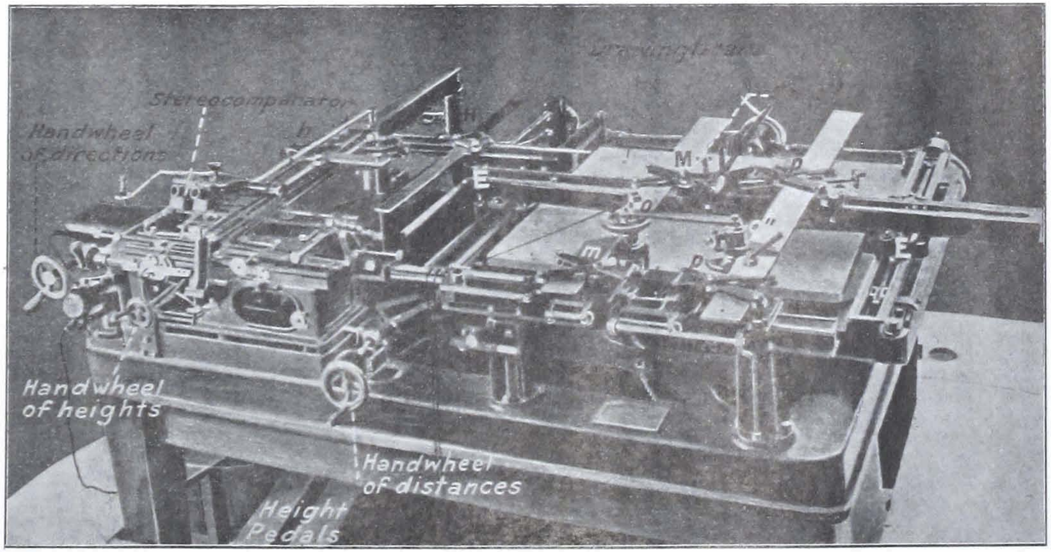



Fig. 14—Orel's Auto-stereo-plotter(*1911 model*).(*The reference letters correspond to those of Fig. 13.*)

Photo.-engraved & printed at the Offices of the Survey of India, Calcutta, 1921.

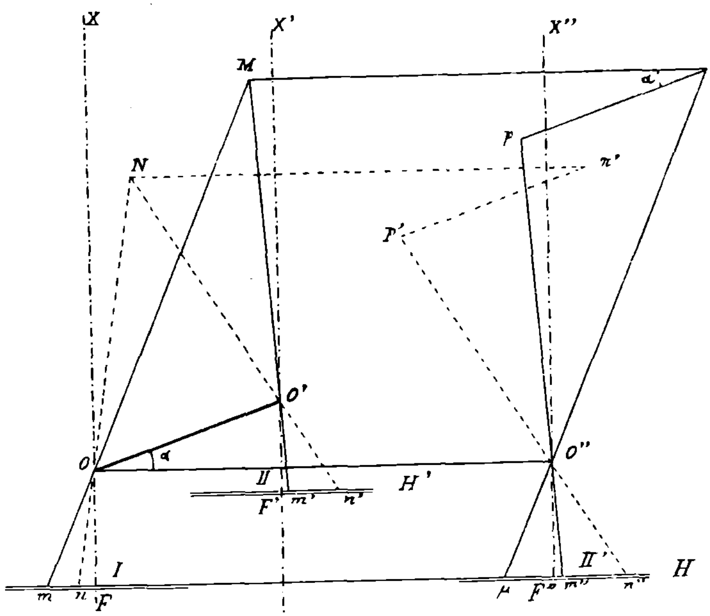



Fig. 15.

Let OF and O′F′ be, to natural scale, the focal length of the objective and, consequently, FH and F′H′, perpendicular to FX and F′X′ will be the traces, on the horizontal plane, of the negatives, supposed vertical.

Let M be, on the scale of the plan, the horizontal projection of a point of the terrain. The points of intersection, *m* and *m′* of the straight lines MO and MO′, respectively, with the traces FH and F′H′ represent then the projections, on the principal horizontal of each negative, of the image of the point M on each negative, that is to say, F*m* and F′*m′* are the abscissæ of these images measured, on this horizontal, from the centres F and F′ of the negatives (see Figs. 1 and 2). It is seen, then, that the construction of the point M could be effected by means of the abscissæ F*m* and F′*m′*, as primal data. But it will be at once realised that the position of the negatives shown in the diagram is absolutely opposed to their use in a stereoscope and, much more so, in the stereo-comparator.

Let us draw OO″ parallel to FH and let us take on this straight line a point O″ at an arbitrary distance from O. If we now move there the point O′, the straight line O′X′ remaining parallel to itself, we see that the trace of the right hand negative F′H′ will coincide with the prolongation of the trace FH of the left hand negative, in such a way that the focal point F′ coincides with F″ and the optical axis F′X′ with F″X″.

In this position, the two negatives lend themselves to stereoscopic examination and, in consequence, to the use of the stereo-comparator.

Let us take on F″H and with their appropriate signs, the lengths F″$\mu$ and F″*m″* respectively equal to F*m* and F′*m′* and draw the straight lines $\pi$O″$\mu$ and *p*O″*m″*; these are respectively parallel to M*m* and M*m′*.

Draw $M\pi$ parallel to $OO''$ to its intersection $\pi$ with $\pi\ O''\mu$. We see that $M\pi$ is equal to the arbitrary length $OO''$. From the point $\pi$ draw $\pi\ p$ parallel to the base $OO'$. It can be shown without difficulty that $\pi\ p$ is equal to $OO'$. In addition, the angle $M\pi p$ is equal to the angle $a$.

One gathers from this, that the determination of the point M, instead of resulting from the simple intersection of the straight line $m$ O M with the straight line $m'O'M$, as in the first position of the negative II, is easily obtained in the position II′ by the intersection of the same straight line $m$OM with the side $M\pi$ of the figure $M\pi p\ O''m''$, for it is evident that, for a given position of $Om$ and $O''m''$ (that is to say for a given point M) there is only one position of the figure $M\ p\ \pi$ defined by the construction given above.

It will then be easy to construct any other point N corresponding to the images $n, n', n''$ by merely causing the figure $M\pi p$ to move, unaltered in shape, parallel to itself, so as to arrive in the position $N\pi'p'$.

If we now compare the preceding figure to fig. 13, which gives diagrammatically the design of the auto-stereo-plotter, we see at once that it is just these mechanical connections and this method of plotting that are achieved mechanically by the latter, by means of levers pivotted about the centres O and O″. The only difference is that the two negatives are placed to one side so as to clear the drawing board and close enough together to permit of examination under the binocular microscope.

Their movements, in the sense of the principal horizontal, are simply conveyed, in direction and true magnitude to the points $m$ and P which correspond to the points $m$ and $m''$ of fig. 15.

In the general case where the axes are convergent at an angle $\epsilon$, let, in fig. 16, OX and O′X′ be again the two optical axes and I and II the traces of the two negatives.

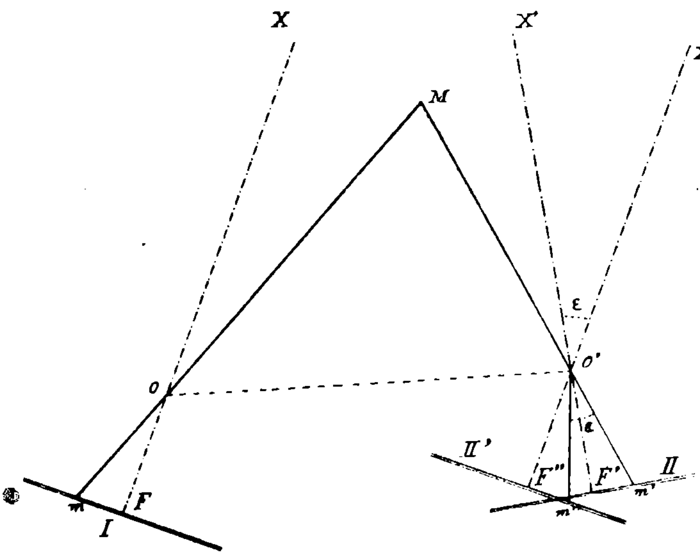



Fig. 16.

If we turn the axis O′X′ about the point O′ by an angle equal to $\epsilon$, the negative II arrives at II′ parallel to I. An examination of fig. 16 shows we have now resolved the problem into that of the preceding case of parallel axes, subject only to the condition that we no longer have to deal with the rectilinear ray MO′*m*′, but the bent ray MO′*m*″, such that *m*″O′ makes with MO′ exactly the angle $\epsilon$.

The examination of the diagram of the auto-stereo-plotter shows, again, that this condition can be realised by means of the graduated scale $\epsilon$.

3. *Contour tracing.* We have just studied the operation of the mechanism in respect to *distances* and *directions*. We still have to examine it in regard to *heights*.

We have seen, (fig. 10), that the difference between the height $h$ of a point on the left hand negative and that of the left hand station can be obtained by means of the formula

$$h = \frac{Ay}{f}$$

where A is the distance of the point from the base, $f$ the focal length of the camera object glass and $y$, the ordinate of the image of this point, as measured on the left hand negative, that is to say, its distance in millimetres from the principal horizontal of the negative.

It can be easily shown that, in the case of a base oblique to parallel optical axes, the length A, which enters into this formula, is the distance of the point not from the base but from the projection of this base on the perpendicular to the axes.

It is this formula that is given effect to, geometrically, by the two similar triangles $h'h$ I and H′H I, (fig. 13), in which we have

$$\frac{hh'}{h'I} = \frac{HH'}{H'I} \quad \text{or again} \quad HH' = \frac{H'I}{h'I} hh'.$$

Now we know that $h'$I is equal to $f$ and $hh'$ is equal to the displacement of the binocular microscope, that is to say, to exactly the value $y$ of the ordinate of the point "spotted" by the "movable mark". Finally, it is easily seen that H′I is just the distance of the point M from the projection of the base on the perpendicular to the optical axes. It follows that HH′ is then equal to $h$ and that we can at once read, on the scale HH′ and with the point H′ as zero, the difference of level for each automatically plotted point M.

If now, we fix by means of a clamp the slide H at any point whatever of the scale HH′ and we then turn the wheels of "distance" and "direction", the bent lever $h$ IH, controlled by the rod EE′, will slide in the pivoted sleeve H without the length, to which HH′ is set, altering; but, as we have seen, its short arm I$h$, in its turn and by means of the sliding sleeve $h$, will move the whole binocular microscope. It is evident then, that under these conditions the imaginary "movable mark" cannot move except in a horizontal plane, since the difference of level HH′ will remain constant. Consequently all the points of the terrain which the operator "touches" with this "mark" will be points on the level contour corresponding to this difference of level HH′ and as we can keep this "movable mark" uninterruptedly in contact with the ground, the pencil will thus trace out on the drawing board the corresponding level contour, not by interpolation, nor even by widely spaced points, as in the least imperfect of the old methods that were applicable to only very large scales, but in an absolutely continuous manner, recording the slightest sinuosities, and this without the least difficulty, since all that is necessary is that the operator should keep turning the "direction" and "distance" wheels while maintaining the contact of the "movable mark" with the ground. The out-turn of line traced in this way will be from 2 to 5 millimetres a second, according to the distance, the scale, the nature of the terrain and the quality of the negatives.

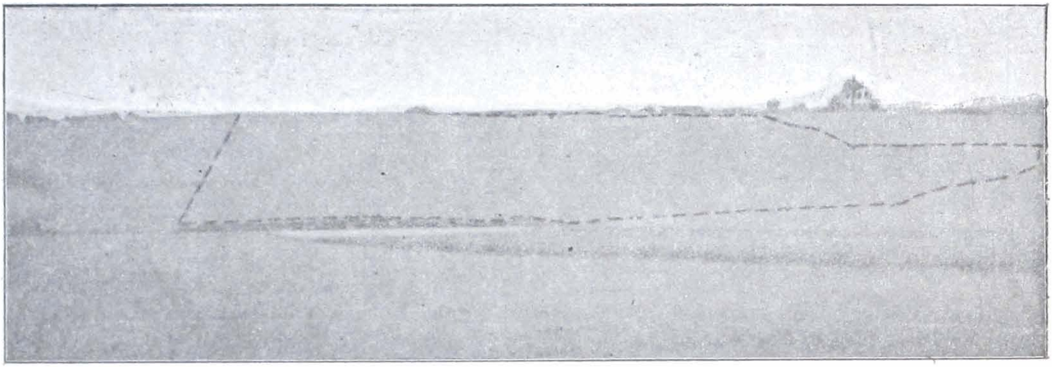


Fig. 17.

*VIII.—The results actually attained and the future of auto-stereo-plotting.*

### § 1. *The advantages.*

In the following lines will be shown that wherever it is applicable auto-stereo-plotting is overwhelmingly superior to the older methods.

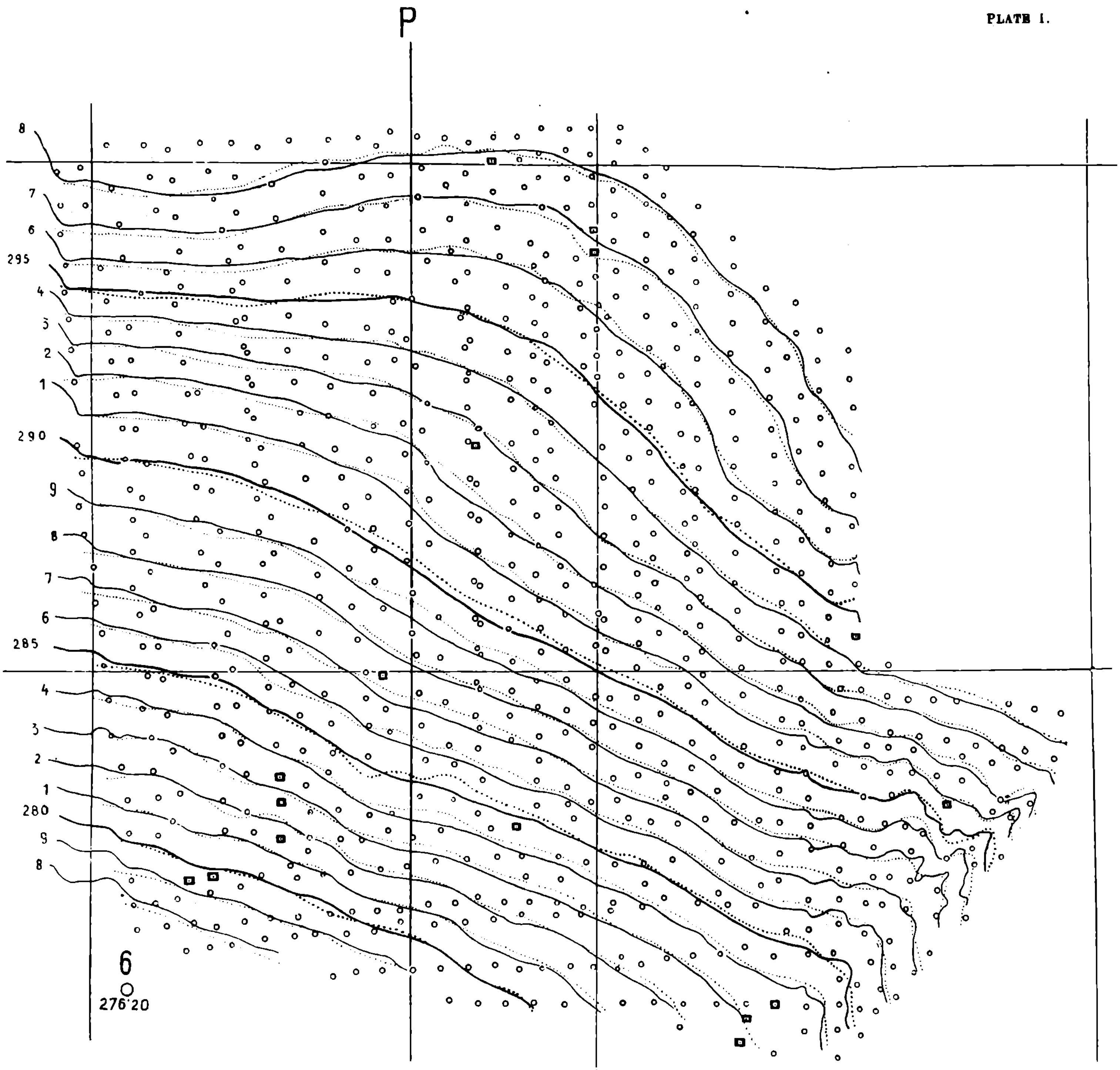
1. *Rapidity.* Firstly, the rapidity of both field work and office work greatly exceeds that of any of the old methods, scale for scale.

Thus, on the scale of 1/20,000, a skilled surveyor will turn out, per month, scarcely 10 square kilometres of regular plane-table survey in mountains, that is to say 0·3 kilometre per working day. This is the normal figure for surveyors of the Service Géographique de l' Armée in the survey of the Alps, which is to serve as a basis for our new map on 1/50,000.

On the other hand, the Austrian Institut Géographique Militaire turned out normally, in its surveys of the Tyrol on 1/25,000, 2 square kilometres per day per operator (150 square kilometres, on an average, for six weeks field work, two sections being employed) when using Laussedat's method of photo-plotting; about 1,418 square kilometres have been surveyed by this method from 1,167 stations.

After 1909, as we have seen, this method was entirely abandoned, giving place to that of auto-stereo-plotting. From that time, the normal out-turn has been 800 square kilometres during each annual field season of six to eight weeks, only a single section being employed, that is, about 10 square kilometres per day per operator. By the end of 1912, 2,880 square kilometres were mapped in this way from 334 stations.

The difference between the two last methods is shown by the marked difference of out-turn in ground mapped per station (1·2 km² approximately in the first case and about 8·6 km² in the second).




Comparison between a tacheometric map, and the same as produced by the method of auto-stereo-surveying.

Scale. $\frac{1}{1000}$ Contour Interval 1. metre

Contours given by the auto-plotter.

" " " tacheometer.

Tacheometric points found correct.

" " " incorrect.

In 1913, in the twenty days between 10th July and 1st August, the Austrian detachment mapped 390 square kilometres from 26 stations, or about 10 km$^2$ per station.

The map of the Dachstein massif on the scale of 1/20,000, produced by the Viennese company, the "Stereographik", founded by M. von Orel, covers 362 square kilometres. The undertaking involved 35 bases and occupied 30 working days in 1912, about 12 square kilometres per day and 10·3 square kilometres per base. The terrain was, moreover, somewhat unfavorable owing to the number of high plateaux with few culminating points, a formation which necessitated more than the normal number of stations.

On the scale of 1/1,000, the rapidity of auto-stereo-surveys, as calculated from numerous technical plans executed by the "Stereographik", is, in the case of the most difficult terrain, from 50 to 60 hectares per working day per detachment. Now it is only on easy, very gently sloping terrain that a third (10 to 20 hectares) of this out-turn can be attained with difficulty, with the tacheometer, and that with a much lower degree of precision; in very broken country the out-turn and the accuracy fall very rapidly.

As regards the cartographic work, no comparison is possible, since the old methods were unable to produce anything similar to the plans given by the auto-stereo-plotter with their continuous curves. We can only say that, in a year, a single apparatus can map at least 3,000 square kilometres on a scale of 1/20,000, excepting, be it understood, the "blanks" corresponding to tracts or to small details invisible from the stations and which have to be completed on the ground during a following field season and generally by old methods, their extent being always very small if the bases have been judiciously selected. It is in this second season also that the "nomenclature" has to be collected.

One can easily imagine, thus, what economies the new method enables us to effect in the execution of maps in general and, in particular, of *Cartes d'État*, economies in expenditure, in personnel and especially in time.

2. *Accuracy.* The accuracy of plans obtained by the new process has, for long, been looked on with suspicion by poorly informed scientists although a guarantee of its precision was afforded by the mere fact of its adoption, to the exclusion of all others, by the Austrian Institut Géographique Militaire, after 1908, for terrain at all favorable and this after sixteen years of experiment and continuous work on a very large scale (2,870 square kilometres of mapping).

Nevertheless, several proofs may be adduced here.

Let us call to mind, first, that in 1911 the Service Géographique de l' 'Armée' began to experiment in the Oisans massif with the method of stereo-photo-surveying and later to plot the map on a scale of 1/20,000 by means of the Pulfrich stereo-comparator. Now with a view to furnish a check, twenty-three points appearing clearly in the photographs were, in the course of the work on the ground, fixed by theodolite observations from the principal stations. The positions of these points were then computed trigonometrically.

Now, the official report on the results of this check is couched in the following terms:—"The comparison of the positions and altitudes of the check points as given by the photo-survey, with those derived from the trigonometrical computation, gives a measure of the precision of the operations. *The differences are inappreciable in regard to position and do not amount to 2 metres in respect to altitude.*"*

Further corroborative proofs, in 1912 and in 1913, led to the decision to acquire an Orel auto-stereo-plotter, as has already been said.

Plate I represents comparative plans, on 1/1,000, executed near Vienna

(i) by means of the method of auto-stereo-plotting (curves in continuous lines).

(ii) by means of the tacheometer (curves in dotted lines and isolated points).

The tacheometer plan which was to serve as the means of appraising the new method was naturally executed with extreme, and exceptional, care, *315 points being fixed per hectare.*

It was thus possible to define the ground by contours at 1 metre interval with particular accuracy. We can say that these curves represent the maximum accuracy, compatible with the scale, attainable by the tacheometric method.

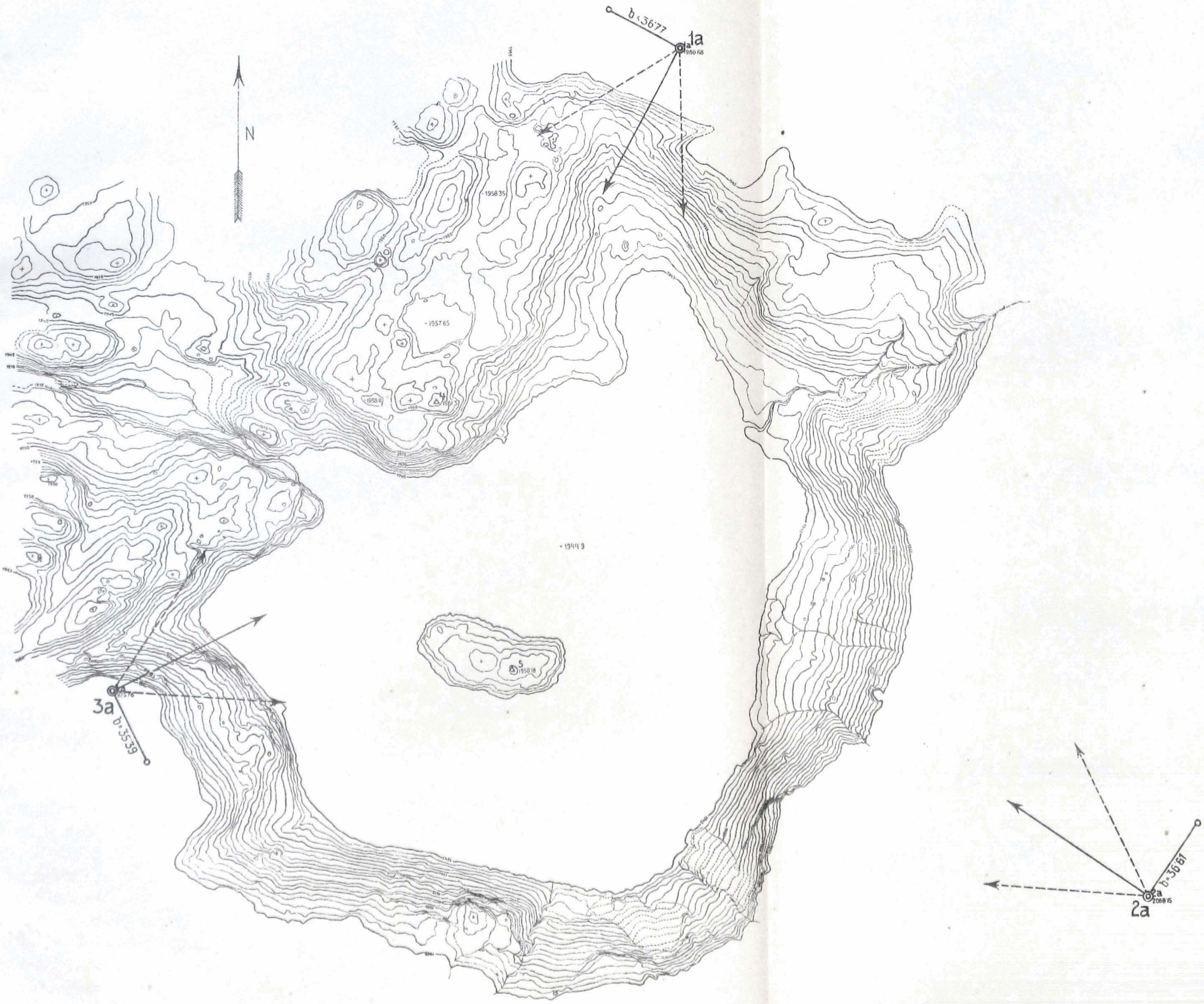
The drawing by the auto-plotter was effected on the same sheet of paper as the tacheometric plan. Now to begin with, the auto-plotter gave accordant values of height in the case of all the tacheometric points, except sixteen, which are indicated on the plan by a special symbol, and these sixteen points were found, after verification, to be burdened with errors in the tacheometric calculation.

In the second place, it is seen that the interpolated tacheometric contours are not quite exact and differ appreciably from reality towards the right of the area, where they are too systematic and show none of the minor undulations of a small drainage channel, which on the other hand is perfectly rendered by the continuous curves of the auto-stereo-plotter, the superior accuracy of which is clearly shown here.

Finally, it will be noticed by examining fig. 17, a print from the negative at the left hand station of the base, how very favorable is this terrain, regular and without "accident", to a precise and easy tacheometric survey and it will also be seen at once that Laussedat's old method would have been ineffective. The negative shows nothing on this bit of ground, uniformly sloping and absolutely without appreciable detail, which would lend itself to any graphical construction. This is a pertinent answer to such scientists as still believe that the new method, like the old, is applicable only to terrain of amphitheatre type and it is, at the same time, proof that the old method of photo-surveying has no longer reason to exist and should disappear.

Plate II reproduces, but on the scale of 1/2,000, that is to say, on half reduction, the plan, on 1/1,000, of the lake of Pormenaz in the neighbourhood of the col d' Anterne (Haute-Savoie) which was executed by the "Stereographik" at our request last August, to serve as the subject of special technical study. The work occupied half a day on the ground and at the auto-stereo-plotter, twenty-three hours. At our request, the curves were drawn, only up to the 20-metre level above the lake and there was no plane-tabling. The directions and lengths of the three necessary bases are shown and also the field of view of the three negatives taken at the left hand station of each base.

* Papers of the *Service Géographique de l' Armée* No. 34 Vidal. Report on the work carried out in 1911, page 44.




*Map of the Lake of Pormenaz produced by the auto-stereo-plotter. (Contour interval 1 metre)*

Now, during the work with the auto-stereo-plotter it was possible to show that the "imaginary mark", having been once adjusted by the operator to remain in a plane which, if the apparatus were accurate, ought to be horizontal and to correspond to the surface of the lake, could then be made by the operator to follow with precision the smallest sinuosities of the edge of the lake and the central islet (fig. 1, plate VI). This is a striking proof of the precision of the instrument, for here we are dealing with a continuous level contour traced on the ground by Nature herself.

Again, one more fact may be alluded to; this is that different traces of the same contour, made by different operators, in succession at the stereo-plotter, coincide with one another so closely that the trace simply thickens up.

It is seen, then, that, scale for scale, the accuracy of the process is at least equal to that of the most perfect of the old methods and, what is still more astonishing, that it depends only in a small degree on the field work, that the accuracy is, in a way, constant, and the maximum compatible with the scale of the plan given by the auto-stereo-plotter.

3. *Richness of modelling.* We may lay stress on another important advantage possessed by plans produced by the auto-stereo-plotter, and that is the richness and infinite delicacy of the model of the terrain which is afforded by the *continuous* curves. From this point of view, no other method is capable of giving anything at all approaching it. We can say that models of terrain of such truth have never been even thought possible. The old fashioned contour, for the most part interpolated or, in exceptional cases and for only very short distances and on very large scales, "traced" by means of several points ***on the ground***, was generally only an approximation to the truth, more or less coarse, merely a diagram. What can be said of contours, interpolated ***in the office***, from several heights scattered, the least unfavorably possible, over the paper, and themselves derived from uncheckable figures taken from the observers' field books. This, however, is the case with most plans of so called precision, executed by the tacheometer and as we have seen above, even in a plan of extreme precision, there are still errors which escape detection.

The appearance of a map with auto-stereo-plotted contours is such a novelty to the eye of the specialist by reason of the undreamt of richness of modelling, that some of them have complained that this richness itself would militate against the appreciation of the general form of the terrain. For our own part, we have never felt this, very much the reverse. However, as von Orel has remarked, nothing is more easy than, in the final execution of the map, to omit the small sinuosities of nature which might be considered as disturbing in this respect. But the essential difference from other methods which give contours, no point of which is exact, except very occasionally, is that in this case by far the greatest part of the final contour is absolutely accurate and besides there always remains, and this is important,—the original curve of the auto-stereo-plotter as a basis for simplification in the drawing of the final contours.

In present practice, there is nothing to equal it: everything depends on the work of the surveyor on the ground (I do not speak of tacheometric plans, generally very inferior in the matter of level curves) and consequently on his personal equation, his training, his experience and his eye for country,—in a word on his "topological" attainments.

Now, we can say that it is only during the last few years (less than 15) that this new science, "topology", has been diffused amongst the best surveyors, sufficiently to ensure that maps of irregular ground, executed with the planetable, on 1/20,000 and generally serving as foundation for the compilation of the *cartes d'Etat* are not veritable caricatures of the terrain.

The existing maps of a large country have to satisfy wants ever more and more varied and consequently are always having to meet increasing demands. In particular, the researches into physical geography or geology require on the part of the modern surveyor a thorough, comprehensive knowledge of the principles of these sciences if he wishes to produce a map which will provide a sound datum, a thing indispensable to such research and yet, at the same time, what difficulties does the ground not present in the way of producing such a map.

As was said in 1868 by Colonel Goulier, undisputed master of the old French topographical survey, "The surveyor covers the ground, pace by pace, like the gnat which circles round the model of the sculptor. He sees the surface only element by element and when sometimes, he does succeed in getting, for a somewhat limited area, a general view, the surface is often unfavorably illuminated and often the observer is so distant that his binocular vision is unable to reveal to him with accuracy, the slopes that he has to represent."

In the new method, on the contrary, the operator on the ground has no need of these generally somewhat rare qualifications; he is not even, properly speaking, a surveyor; he need only be careful, conscientious and accustomed to use instruments of precision and photography. The only experience he must have, and this he acquires very quickly, is that he must be able to place his bases in the most favorable positions so as to include in his negatives as much as possible of the terrain, and this consists, on most occasions, in getting on high as possible. He need not study the terrain, he has nothing to *interpret*, to understand, even to draw, and in the office again, there need be no surveyor at the stereo-comparator, merely an operator possessing normal eyes, as regards stereoscopic vision, and hands accustomed to manipulate instruments of precision.

The result, almost instantaneous, of the purely mechanical operations is a map with contours of marvellous richness of modelling and which is so much the more faithful to nature, that nothing is easier than to trace, in much broken up ground, all the intermediate contours that one may require for the more complete analysis of accidents of terrain which may have escaped *representation* by falling between two contours at the normal interval of the map, intermediate contours which are every bit as true as the others.

Here we have, as von Orel has said, the suppression of all personality in the innumerable details that go to make up the map of a large region instead of the present accumulation of veritable *personal manuscripts*, the value of each of which depends on the ability of its author. It is this that explains the variations in the quality of the modelling one sees so frequently in large maps not only as between sheet and sheet but in one and the same sheet.

There is, finally, the complete and extraordinary reversal of even the order of execution of the essential parts of a map: outline, determination of heights, construction of contours.

The new process provides the cartographer *from the start and before every thing else*, with the *contours* which formerly were for him the *crowning* of his work.

Let us turn to the work of "generalisation" which has to be taken up subsequently for the preparation of the properly called *cartes d'Etat*, usually on a smaller scale than that of the component originals.

(Thus for the new map of France, on 1/50,000, the sections were surveyed on 1/20,000 and for certain areas even on 1/10,000).

Here, only, will it always be necessary, whatever the method, to employ a first class topographer, since it is a matter of simplifying, of generalising and this mostly, by the deletion of contours to allow space for the outline detail and the lettering, the relative importance of which increases as the scale decreases. Such work calls for consummate experience, as here it is necessary to know how to bring out and give emphasis to the characteristic features of a country, of which in all its details it is generally impossible for the operator to have first knowledge; the detail sections form his sole source of information and he is obliged to draw inspiration from his experience and topological knowledge, and so, very often, as General Berthaut said, "One feels the necessity of going to the ground itself to see how it is made". One has, nevertheless, to be content to accept a conjectural position for a line for the simple reason that it appears to be the most probable.

With the new method, the matter is simple; all that the topographer in his office, need do is to turn to the mirror stereoscope carrying the pair of transparencies which represent the region to be generalised; to find there, immediately before his eyes, the ground itself, not merely a little corner of it, but the whole expanse for some 15 or 20 sq. km, in marked relief, giving a clear and immediate revelation of the modelling of the large forms.

How vastly superior are we to the miserable gnat described by Colonel Goulier!

The task of the "generaliser" will be still more simplified if the field operators, the photographers in fact, are provided with a small pattern (4, 5/10, 7) of hand stereoscopic apparatus and will take the trouble to collect, in the course of marches executed for their regular operations, small stereoscopic negatives with "big separation", after the simple and rapid manner indicated in the footnote on pages 17 and 18 every time they reach a point offering good comprehensive views of the region to be mapped.

By so doing there is gained a very great advantage, easily appreciated by specialists.

The examples which follow will enable the reader to appreciate this superiority of modelling of auto-stereo-plotted maps. Plate III is taken from the map of France, *(carte de l' Etat-Major)* on 1/80,000 (Annecy sheet, N.E.). The continuous blue line shows the limits of a map on 1/20,000, executed and mapped for us, during last August by the "Stereographik", the mapping being based on the very accurate triangulation carried out by MM. Vallot, who very kindly placed it at our disposal. The area is about 140 sq. km. The broken blue line shows the whole ground covered by the negatives, that is to say, the area really " surveyed " and which could, as easily, have been mapped. It amounts to 237 sq. km. The arrows show the directions of the axis of the left hand negative *normal* to the different bases. The finished map of the limited area was delivered to us at the end of January 1914, but it is of too large dimensions to be shown here.

It only remains to be said that a large part of this map on 1/20,000 falls in the territory of the Canton of Saint-Gervais (Haute-Savoie) where, fifteen years ago the cadastral survey was revised with a very great deal of care. The Directorate of the Cadastral Survey of the department of Haute-Savoie was kind enough to provide us with a very accurate copy of the " mosaic ", on the scale of 1/20,000, of this Cadastral Survey, showing thereon, its own trigonometrical points as well as those of the triangulation of MM. Vallot. It was thus easy exactly to superpose this copy of the mosaic on the original contoured plan given by the auto plotter. The accordance was absolutely astonishing, for all the smallest rivulets of the copy were found to fit into the channels of the contoured plan.

It was another remarkable proof of the accuracy of the new method.

Plate IV is a reproduction of part of the complete contoured map drawn by the Orel auto-plotter from another survey, carried out by the " Stereographik ", on its own account, of the opposite flank of the Chamonix valley up to the crests of Mont Blanc, from a single base in front of le Brévent.

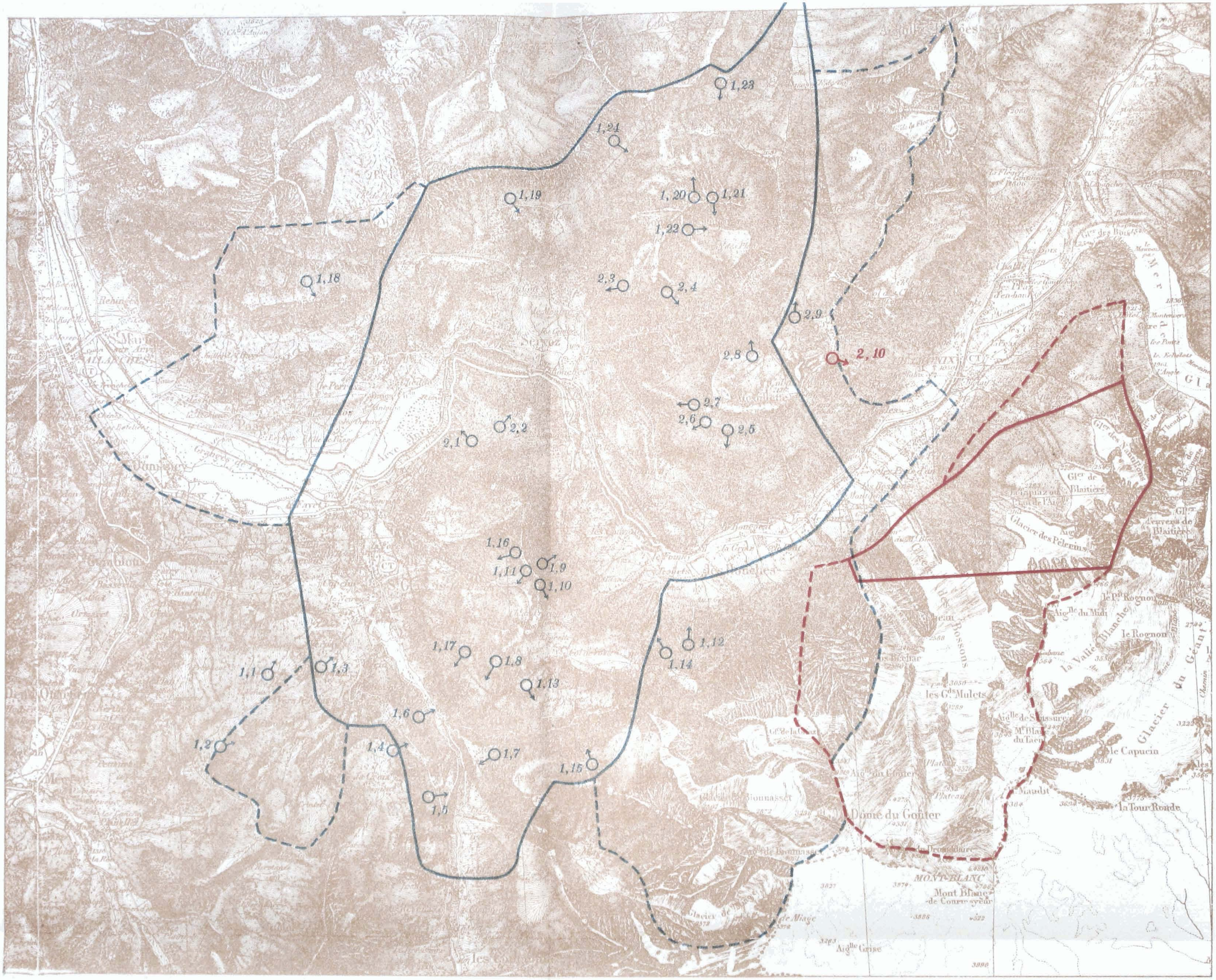
The five control points are derived from the triangulation carried out and very kindly placed at our disposal by MM. Vallot. At one operation and by means of the auto-stereo-plotter, the three negatives were thus productive, of a contoured map of 30 sq. km. of regions to a great extent absolutely inaccessible (see the red line in plate III).

Our thanks are due to M. von Orel for permission to reproduce this still unpublished work, of special interest as it includes all the ground it was possible to discern on the negatives and to draw with the auto-plotter.

Fig. 2 of Plate VI. shows the general panorama seen from the left hand station of the single base, at which the work on the ground occupied about $1\frac{1}{4}$ hours. We would draw attention to the importance of wooded surfaces where, as we know, the identification of points was almost impossible with the old Laussedat method.

Let us point out, to begin with, the representation of the " wall " of vertical arêtes which bounds the plan on the S.E.,—a wall where the tracing of contours at 20 metres interval had not to be interrupted, a fact which gives the plan the value of a scientific document, instead of the purely convential diagram, more or less artistic, with which we have always had to be content in such cases, up to the present time.

One will also notice the unusual completeness of modelling of the glacier surfaces, showing clearly and accurately the large crevices, the very interesting detail of the small scarped ravines, the beds of old sub-glacier torrents, and of

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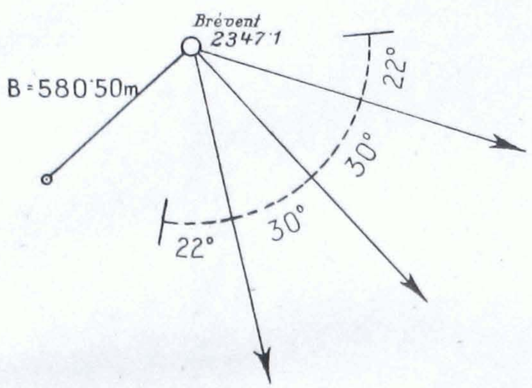
Limits of terrain surveyed stereo-photographically from bases other than those of Brévant.

Limits of terrain mapped by the auto-stereo-plotter.

Limits of terrain surveyed stereo-photographically from the Brevant base (2,10).

Limits of terrain shown on the auto-stereo map in Plate IV.

2,10 1,19 Position of the left hand station, direction of the "normal" axis, and designating number of each base.

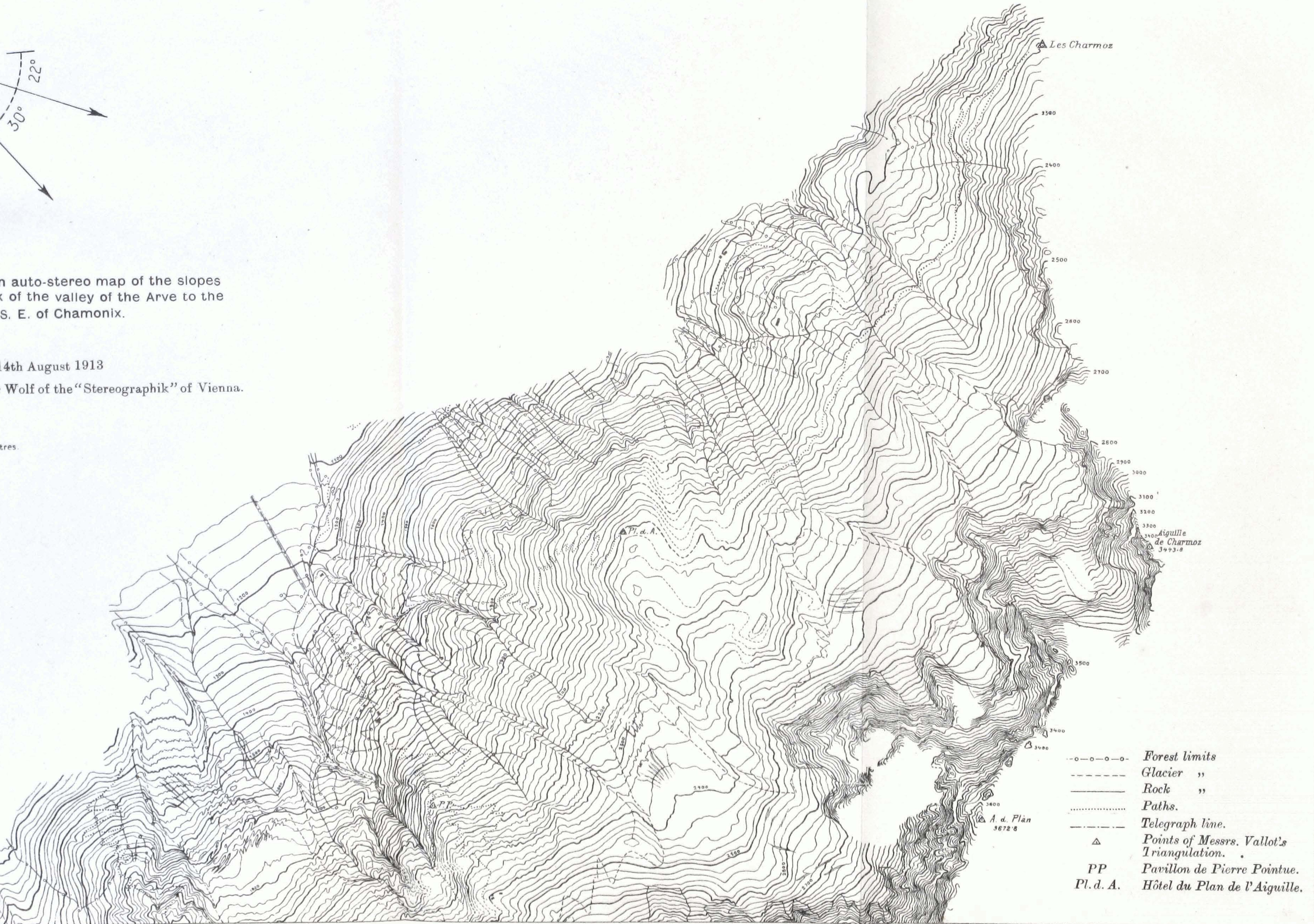



**Extract from an auto-stereo map of the slopes of the left flank of the valley of the Arve to the S. E. of Chamonix.**

Surveyed on the 14th August 1913
by M. l'Ingenieur Wolf of the "Stereographik" of Vienna.

Scale $\frac{1}{20,000}$

Contour interval 20 metres.



the highly complex form of the summit of the great wooded buttress separating the glacier of Bossons from that of Taconnaz.

It is very interesting to compare this plan, contoured by the auto-plotter, with the beautiful provisional map of the same region, already referred to and on the same scale, published by M. H. Vallot. This comparison shows at once the extraordinary accuracy of the plan, for the two systems of contours, as a whole, coincide almost everywhere as well as at the moraine crests; as for the streams of the map, they fall exactly in the channels of the plan. But the contours of the plan are infinitely richer in detail and in the *wooded*,* inaccessible regions, where the old photo-plotting was able to give only a roughly approximate diagram, the differences are very considerable (see in particular, the buttress between the Bossons and Taconnaz glaciers, as well as the steep slopes to the S.E. of Pierre-Pointue). The superiority of the new method is clearly evident.

Lastly, Plate V. is part of a technical plan, on 1/1,000, of a rocky, very much scarped bit of ground in the environs of Fiume (Croatia) of which the accompanying photograph gives an exact idea.

* As touching the applicability of the method to wooded regions, a study of the panorama from which this plan was constructed is not without interest, for it shows clearly that, on medium scales, the existence of forests of tall pines presents no difficulty to the construction of the contours. This is easily comprehensible; on the one hand, the modelling of the upper surface of the forest is, in fact, on such scales, very perceptibly the same as that of the ground below; on the other hand, it is almost always possible to see, and to make a pointing on, the ground itself in several parts of the forest, so that control heights are obtainable.

As regards plans on large scales, the parts of the forest where the ground is clearly visible and determinable are, naturally, more numerous and important by reason of the short distances (100 to 700 metres) at which the negatives are taken. In fact, experience has shown that on plans at 1/1000 or 1/2000 the contours are indefinite only over very short stretches; here they are drawn through plotted points just as in the case of tracts which are not as completely visible as might be desired (see plates II, IV and V)

It can justifiably be said that no known method would have been able to produce for such terrain, and on such a scale, anything but a rough and formless representation, so that the "model" produced without the slightest difficulty by the auto-stereo-plotter, contoured at *one metre* interval, is truly astounding and constitutes a highly precise scientific document of a type absolutely unknown up to the present.

In short, in point of view of richness and accuracy of the details of modelling of the terrain and also of the incomparable facilities which it secures for the necessary generalisation of the model for the preparation of the map proper on a smaller scale, the new method presents an indisputable superiority over all the old processes.

Let us draw attention to still one more advantage, and that is the limitless possibility of checking an auto-stereo-plotted map. It is only necessary to "re-work" the negatives to assure oneself of the accuracy of the earlier work.

Finally, in the majority of cases it is perfectly easy to derive from the negatives, by "re-working" them with the auto-stereo-plotter, a plan on a larger scale, and this is a valuable advantage, for one can thus obtain of any particularly interesting region a more detailed map, with contours at closer interval. At present, there is nothing to be done in such cases, but content oneself by enlarging the first map with all its errors and in the enlargement nothing more will be found than was in the original. The only other alternative is to "re-do" at great cost, all the work on the ground.

What it amounts to, is that the new method enables one to preserve, so to speak in the office, the terrain itself instead of storing in the archives as at present, only the sections, per-force incomplete, afforded by the planetable or the bulky and uncheckable tacheometer field books.

### § 2. *The uses to which the method may be put.*

The advantages of the new method from all points of view, rapidity, economy, precision, richness of modelling, absence of personal equation, the ever-present possibility of checking, are so great that one is justified in considering its advent not as simply a step in advance but as a veritable revolution in topography and cartography, and the uses to which auto-stereo-plotted plans may be put are bound, in a short time, to become both important and varied.

In the matter of *cartes d'État*, we have the possibility of obtaining much more rapidly and economically, general maps of a quality and uniformity of style far superior to those in present use. This consideration is especially important in the case of newly opened-up countries, the colonies in particular, where the execution of precise work on the ground is usually slow, very costly and very arduous.

Concerning official plans on large scales, it would seem that *cadastral* plans on 1/1,000 or 1/2,000 might, in the majority of cases, be produced by this method, especially in broken country. We need not dilate on the special interest which plans of parcels of land, with accurate contours at intervals of from 1 to 5 metres, would have for the general public. These would open up to administrative bodies, possibilities, not existing at present, but which will certainly be considerable in the future.

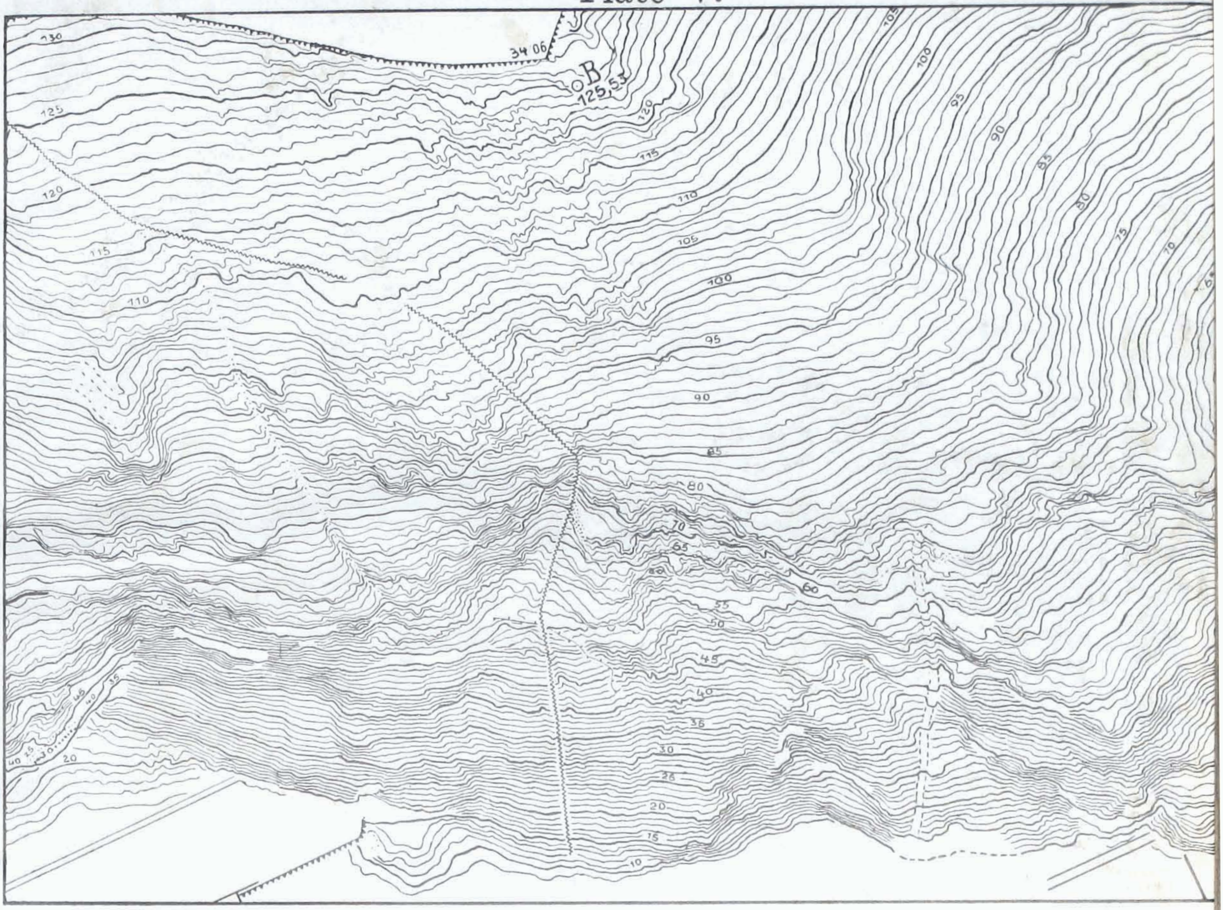
From the point of view of *science*, a new field is opened up to investigations into *physical geography* and *geology*. It is undoubted that specialists find most profitable the careful study of these new maps, so extraordinarily rich in modelling and at the same time so scrupulously exact. We may mention, in particular, the study of erosion phenomena in their very varied manifestations, or of those relative to vulcanism, to glaciology, concerning which many problems are still keenly disputed*, hydrology and even botanic geography.

As for the geologist, what satisfaction must it not be to him, to have at his disposal for the showing of the outlines of geological formations, in brief, for the preparation of geological maps, topographical maps where the modelling, the shape of the ground is no longer, as is so often the case, so untrue and inaccurate, or so badly represented that he is forced to resort to systematic "fudging" of his proper outlines in order to avoid inserting apparent improbabilities on the map or even to omit altogether certain important phenomena, because they will not fit the incorrect topography.

*Scientific Expeditions*, well equipped,—will also find a valuable auxiliary in the new method of rapidly producing maps of the country traversed, maps far superior to any thing that it has been possible to achieve up to the present, seeing that

* In this connection, the comparison of the contoured map of plate IV with the provisional map of M. H. Vallot, already referred to, is most instructive. It gives evidence very clearly of the general and very pronounced retreat of the four glaciers which appear on this terrain (Bossons, Pélerins, Blaitière and Nantillons) a retreat effected in the course of the short period elapsed between the dates of execution of the two maps (1896 and 1913). The shrinking has taken place in length as well as in width. We see, accordingly, how much more easily periodical large-scale plans, executed so easily by this method, would enable variations of glacier masses to be studied, than the slow, complicated processes in use at present.

# Plate V.




Part of an auto-stereo map of environs of FIUME (Croatia) Scale $\frac{1}{1000}$. Contours at 1 metre interval.


General view of the terrain of the map.

# Plate VI.

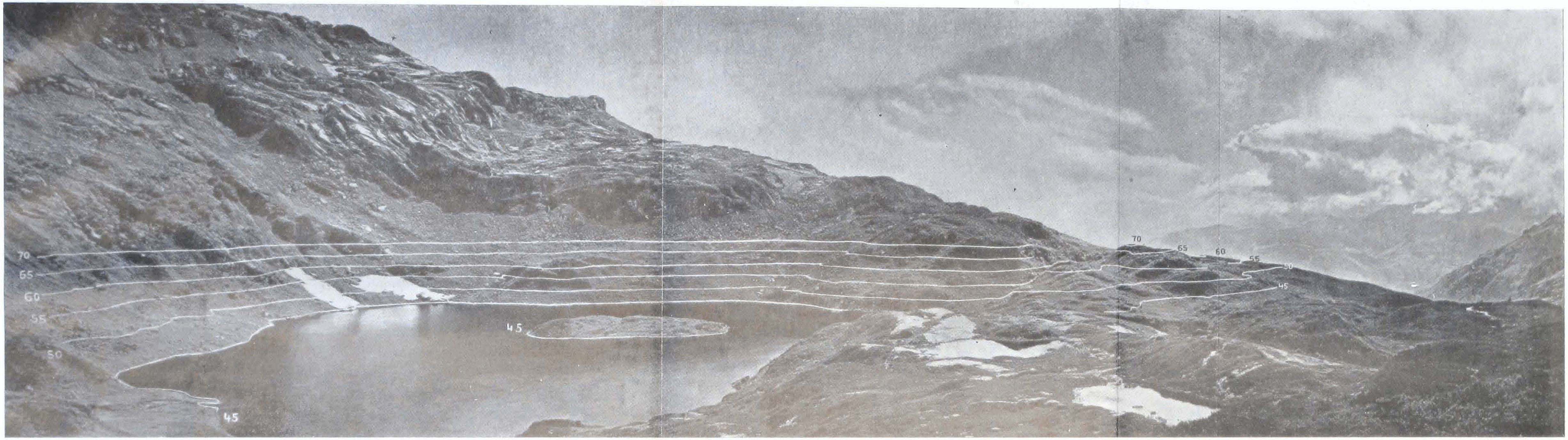
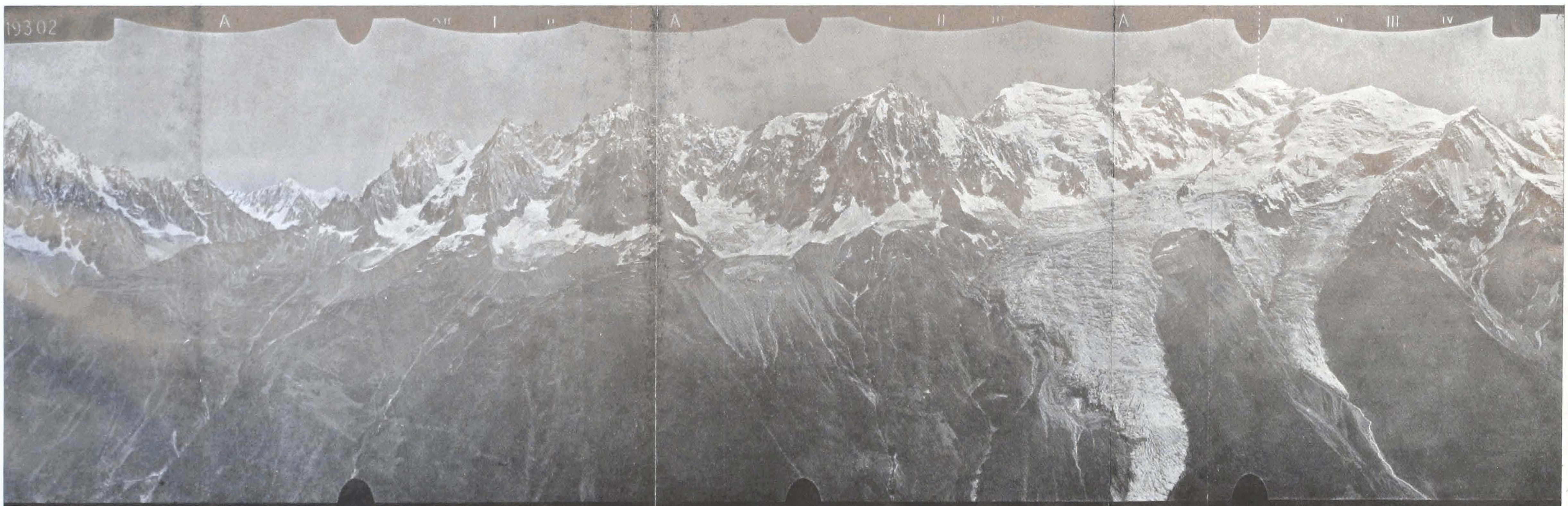



FIG. 1. Auto-Stereo map of the Lake of Pormenaz (H^te Savoie) Panorama from Base 1, (Left-hand Station.) with the perspectives of the 5 metre interval contours traced out automatically by the Auto-Stereo-Plotter.




…G. 2. Auto-Stereo map of the left flank of th… …lley of the Ar… to the S. E. o, Chamonix. Panorama … om t… … si… … s … …nt (Left-hand Station…

a range of 10 to 20 km. can be covered from selected bases.

Also, and for the same reasons, maps of little known coasts are most easily made from the bridge of a vessel, equipped with stereo-photo-theodolites fixed at its two ends and fitted with shutters operated simultaneously by electricity. *

In connection with *military science*, one interesting use to which these new maps could certainly be put is as plans for the "war game". These at present are only enlargements to 1/10,000 and even 1/5,000 of the 1/20,000 detail of *cartes d' Etat* and one can obviously find on them only such modelling, as there was on the original. Now, on 1/20,000, a ravine 20 metres wide, corresponding to only one millimetre on the map, can not be represented; it is however, tactically, a serious obstacle. In fact, much information in the shape of cover or of obstacles of small and medium size is entirely absent from these maps, where, however it would be of great importance. The possibility of deriving, from stereographic photographs, plans on a larger scale, *more detailed* as regards modelling, enables the student to provide himself with maps far more instructive than the coarse enlargements in present use.

In particular "*Plans directeurs*" of the surroundings of fortified places, executed by the auto-stereo-plotter will possess, for the same reason, enormous advantages over the present type of map in which, in most cases, the rendering of the shape of the ground is very unsatisfactory and too much generalised for the requirements of defence.

Here, the possession of a large scale map showing a finely detailed model of the possible zones of attack, will confer a considerable advantage on the artillery of the defence. It goes without saying that such special maps would be prepared only for portions of ground, usually of small extent, which are really practicable to the enemy and would not, as is now the case, be extended uniformly all round the fortified place and also, that they would not be available to the public.

Again, the engineer on his part is interested to an equal, if not greater degree in the new, exact details of *cartes d' Etat*, a first class foundation for preliminary projects, (railways, roads, canals, irrigation &c.) in irregular country.

One particular case, occurring frequently, is that of the study of schemes for utilising the power of high falls in mountains where, usually, the details given by existing *cartes d' Etat* are too inaccurate to permit of a serious preliminary examination of the project, making it at once necessary to undertake a costly survey of the ground. Now, by reason of the cost and particularly of the great amount of time required for such a survey, the engineer nearly always contents himself with selecting, on the ground itself, a trace which *appears* to him to be the most favorable and has this single trace mapped by the surveyor. This precludes the possibility of discussing an alternative, often perhaps more interesting, there being no complete, comprehensive map of sufficient accuracy.

The new method, on the other hand, makes it possible to obtain, much more rapidly and at less cost, a plan of high precision on a medium scale, (1/5,000 to 1/10,000), embracing *all* the terrain on which the possible alternatives *can* be worked out free from preconceived ideas.

* An Austrian war-ship, a Russian and three German have been, for several years, equipped in this manner.

Then again, consider the value of detailed plans on a large scale (1/1,000 to 1/2,000) in connection with big works, the execution of which is so difficult on steeply sloping ground, for example mountain railways and more particularly power pipe lines which are often brought down amidst impracticable cliffs. Here the problem is insoluble in so far as it concerns the surveyor's work and so it is necessary to be content with estimates of the cost of the work, arrived at solely "by eye" until the "*construction*" workmen, suspended by ropes in front of the vertical faces, have been able to measure by means of line and wooden template the lengths and bends of the pipe. Then only can the engineer form an idea of what he has to face.

The auto-stereo-plotted map will now provide him with plans on 1/1,000 or 1/2,000 representing the most rugged cliffs with extraordinary accuracy and detail and this, merely by undertaking a few hours of easy work on the ground. This is one of the cases where the new method can be applied with the greatest ease. The great majority of power conduits are, naturally, to be found in topographical surroundings such that the whole of the site, as well as all the alternatives, can be covered by the single "normal" photograph from a base, whose siting is always perfectly easy.

The method is of equal value in the case of projects for the construction of large retaining barrages, across valleys or on the sills of lakes. Here again the rapid and cheap production of a really accurate plan on a large scale (1/1,000) is of the first importance in framing an estimate of masonry and the cost of accessory works, if the constructor wishes to avoid being confronted by disagreeable surprises.

In the easily obtained accurate plans, the working of large quarries or mines or big embankment schemes (canals, trenches, dykes etc.) will also probably find a valuable auxiliary in the carrying out of their big periodical "*états de lieux*".

### § 3. *The future.*

The short description of this new method, so full of promise for the future, is finished. Let it be said, however, that its final perfect development has not yet been reached; its practicability still depends on the ground being suitable, on the terrain affording certain points from which sufficiently extensive views can be obtained: it is necessary, in short, that there should be stations from which the photographic objective can "see" the ground to be mapped. Now, though indeed all the inconvenient and cramping conditions which existed in the beginning have disappeared, in particular the "normal case" condition, we still have to reckon with the fact that the disposition of the ground may be unsuitable. This is indeed generally the case in plains or in country, gently undulating and covered with forest, as in the Gascony heaths where it is practically impossible to find an open space.

The solution in this case would be mapping from the air, not by means of ordinary photographs, taken from a balloon either free or captive, but by auto-stereo-surveying which we will call stereo-ærial, effected from either a free or captive balloon or from a train of kites.

In this case, all the old-standing, justifiable objections that have been raised against ærial surveying, fall to the ground.

It has been pointed out that from a balloon, one cannot appreciate the folds of the terrain and that even given numerous photographs, taken from a balloon, (and this entails extraordinarily arduous and difficult processes) it is possible to determine the positions of only a few elevated points the which give a model no better than that forthcoming from the soundings of submarine depths.

This is quite correct in the case of the old photo-surveying but it no longer holds good when we come to consider stereoscopic photographs, for the impression of relief is equally good, whatever be the "dip" of the objective towards the ground. The examination of stereoscopic photographs—taken from an adequate base at 1,000 or 2,000 metres above the ground photographed with, if need be, the optical axis inclined at 60° or more, is sufficient to convince one of this. The effect is as striking as in the case of ordinary stereoscopic photographs, though, if the observer closes one eye so as to see only one of the photographs, all sensation of relief disappears instantly and the flattened terrain becomes perfectly unintelligible.

The objection to the principle of the method is then without weight and there only remains to be considered the possibility of putting it into practical shape. To dilate on this point would be straying outside the limits of this memoir: let us remark only that the solution of this important problem appears less distant and fanciful than did that which the auto-stereo-plotter has just effected so completely, and marvellously in the case of photographic surveying.

It would have been, at least, as an utopian if not as a lunatic that the world less than 15 years ago would have treated the bold person, who dared to predict that a day would shortly arrive when anyone would be able to draw, automatically and continuously, up to a distance of 10 or 15 km. or more, all the level contours comprised in a simple stereoscopic photograph, without having even seen the terrain and this with unfailing precision and astonishing rapidity.

The distance which remains to be traversed before auto-stereo-surveying is entirely freed from conditions of ground, by the opening up of the pathways of the air and from that time, becomes absolutely universal in application, indeed appears to be not great and even now the problem is being earnestly attacked from diverse sides.

We hope that this important and decisive advance in photographic surveying may be finally achieved in our own country, the fatherland of its illustrious creator, Col. Laussedat.

# ADDENDA.

1. There appeared quite recently in the "*Conférences sur les Méthodes et les Procédés de Cartographie en usage au service Géographique de L'Armée (1912-13)*" published by the *Service Geographique*, a memoir which may be studied with profit, namely the Lecture by Commandant Bonnet under the title of "Photogrammétrie". This work describes very fully not the old Laussedat method, but rather that of stereo-photo-surveying in respect to both the work on the ground and that in the office, with all desirable theoretical and practical details.

It is, undoubtedly, by far the best work on the method that has appeared in the French language. One can even say it is the only one. Unfortunately, as it was brought to a conclusion before the appearance of the Orel auto-stereo-plotter, this is not mentioned and the conclusions as to the necessity for the "normal case" and thus of the want of adaptability of the method are no longer correct.

2. It is perhaps of some interest to note briefly, how the operator determines, on the ground, what the length of his base should be, in order to attain the degree of precision prescribed for the scale of survey. He makes use, for this purpose, of a special abacus with three variables, established once for all for the focal length of the objective of the camera of his photo-theodolite; these three variables are, the length of the base, the distance of points from the base and the probable error at this distance.

This abacus gives at once, by a simple reading, the length of base required to determine with a certain degree of precision, the distances of the points most remote from the station.