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THE USE OF THE PANORAMIC CAMERA IN TOPOGRAPHIC SURVEYING

WITH NOTES ON THE

APPLICATION OF PHOTOGRAMMETRY TO AERIAL SURVEYS

BY

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PREFACE.

By Alfred H. Brooks.

The plate camera has been used for many years in topographic surveying in the United States and Canada, as well as in many European countries, and since 1910 J. W. Bagley, a topographic engineer of the United States Geological Survey, has been employing the panoramic film camera in conjunction with the plane table in surveys in Alaska. Mr. Bagley has devised some new instruments and methods and has proved conclusively that the panoramic camera is extremely valuable in certain kinds of topographic work. Some of the results of his phototopographic surveys are presented in the maps accompanying this bulletin. These maps give conclusive evidence of the refinements that are made possible by the use of that instrument.

The methods and instruments here described have thus far been used only in Alaska, but they promise to have a wider application in topographic surveys; hence this bulletin has been prepared. As the camera is used in conjunction with the plane table the bulletin includes also a brief account of the uses of the plane table.

Mr. Bagley shows clearly that the field cost of surveys made by the use of the panoramic camera and plane table is far lower than that of surveys made by the plane table alone, and though the compilation of the field data in the office is more laborious the final cost of the completed map is nevertheless lower. The methods here described are especially applicable to regions where the field season is short, the field cost high, and the climatic conditions adverse to topographic work.

In view of the present interest in aerial surveys, Mr. Bagley has appended to the volume a discussion of the use of the camera in such work. This discussion, which is largely based on French treatises, presents briefly the principles and some of the methods of photogrammetry in its application to aerial surveys. The subject needs further study and experimentation.

THE USE OF THE PANORAMIC CAMERA IN TOPOGRAPHIC SURVEYING.

By James W. Bagley.

INTRODUCTION.

The purpose of this bulletin is to describe the field and office instruments used in topographic surveys of certain parts of Alaska in which the ordinary plane-table instruments were supplemented by the panoramic camera, to show the way they were used, and to present some of the results obtained.

In view of the increasing importance of photography in surveying and the rapid strides that are being made in the art of navigating air craft it has seemed desirable to include also some notes on the application of photogrammetry to aerial surveys. These notes have been gathered chiefly from the publications of the two eminent French authors Laussedat and Saconney, whose volumes are mentioned elsewhere in the text. Though it is impracticable to treat this subject here in even an approximately complete manner, it is hoped that the matter presented will interest many to whom the original sources are not readily available. In acknowledging the credit that is due to Laussedat and Saconney, the writer wishes to state that though the methods they suggest seem practicable he has not had the opportunity to test them. It is hoped that by the inclusion of even so brief a summary a stimulus may be given to aerial surveying, either directly or by drawing attention to what is being done in this field in other countries.

Photographic methods have been employed in various forms for many years by surveyors in foreign countries, but the use of the camera in surveys in the United States was, until the commencement by the Geological Survey of the work in Alaska here discussed, confined to certain surveys carried out by officers of the United States Coast and Geodetic Survey, in connection with the survey and location of the boundary between the United States and Canada by the International Boundary Commission, to a survey of the Pribilof Islands, and to a few other surveys of less importance. The slight use of the camera in topographic surveying in the United States is due largely to the character and size of our part of the North American Continent. The progress of settlement in extending westward over enormous areas of timbered and prairie lands of relatively small relief called for a development in surveying methods which brought out the plane table as the most serviceable instrument for the work. As no better means were available, thought and energy were concentrated upon adding to and improving the plane table. The consequence was that a relatively large body of topographers became highly trained in this method of surveying, so that when, in more recent years, surveys were extended farther into the mountainous regions of the West not only was little thought given to taking up other methods, but there was, in fact, little need for other devices, because of the skill and rapidity with which the surveys could be executed by use of the plane table. This was true of a very large part of the West that has been mapped. There were exceptions, however, which must have inspired the topographers with thoughts of improved methods of work, for in the desert mountains of the Southwest and in the northern Rockies there are large areas of rugged and bare ranges which consist of an almost bewildering number of peaks, spurs, pinnacles, saddles, and slopes—details which must be located on the map in order that the topography may be properly represented. The Grand Canyon of the Colorado is a field so tedious to survey with the plane table, so extensive in length, in relief, and in wealth of features, that it alone, in the writer's opinion, would justify the employment of the camera in its topographic survey.

Alaska contains a greater proportion of mountains favorable for phototopographic surveying than the United States proper, and the method here described was there first tried out. Most of the surveys made in Alaska have been of either exploratory or reconnaissance character, and travel has been accomplished almost wholly by the use of pack animals and boats. In all these surveys, owing to the expense and limited means of transportation, it was necessary to reduce the camp equipment and supplies to that amount which careful estimation and experience proved to be needful. The great weight of photographic plates presented an obstacle to the use of plate cameras which, in the opinion of the writer, scarcely left a sufficient margin of gain to warrant their adoption for these surveys. Plate cameras also carried the objection of a field of view so narrow that seven or eight exposures were necessary to photograph the entire horizon.

Where extensive surveys are to be carried across mountains and valleys account must be taken of the variety of topographic forms likely to be encountered, and the method for the surveys should be chosen accordingly. Of all methods in which transportation must be overland that of the plane table is most serviceable for many varieties of topography. But the panoramic camera enables the topographer to retain the plane table and at the same time to employ photography in its simplest and most satisfactory form, for the one may be used to supplement the other to whatever extent the type of country demands. It also appears certain that a combination of the two methods will form a surveying equipment superior to either alone if it is effected without loss to either. These are the chief reasons why the panoramic camera gave promise for improvement in topographic surveying.

The use of the panoramic camera is not confined to surveys where a small scale is employed, but in some mountainous areas the instrument is adaptable to surveys on a scale of a mile to the inch or even larger, and in general the gain on the side of speed increases as the scale increases.

In testing a new method for topographic surveying it was necessary to keep pace with the general trend toward better quality in topographic maps. In the results here discussed the writer is satisfied that in control, location and representation of features, and expression—all the essential factors—improvement has been made. In attempting to reduce the results to a basis for satisfactory comparison with results from other methods it has been found that conditions of work vary so greatly in different fields and the personal equation plays so important a part in topographic surveying that it was impracticable to present a completely comprehensive table, but Table 1 (p. 16) gives a comparison of results obtained by the writer with the plane table alone and with the plane table supplemented by the panoramic camera. A large number of items have been embraced in this table in order that it may, in a measure, permit comparisons by others who may wish to make them with data of their own.

The expense of equipping topographic parties and of producing contoured maps is great, and much endeavor has been made to get the results more cheaply. In pursuing this object it is necessary to keep certain recognized standards in view lest unfortunate errors lead to a weakening of the framework of the map. Whatever improvement may be made in gathering the information necessary to map topographic forms, there will remain the necessity of control in base maps, and there seems to be little chance for reduction in the work as now executed to obtain that control. Already some very noteworthy beginnings have been made in the use of aerial photography for topographic surveys, yet in this work, too, control must be established by exact measurement on the ground in many places. Such considerations lead to the conclusion that though we may expect photography and other means to reduce the cost of topographic surveys and to lessen the time required for them, yet it is doubtful whether the processes of those surveys can be simplified.

The writer wishes to acknowledge the aid received from the Bureau of Standards, which was essential to the construction of a panoramic camera of the precision desired for surveying, and especially to express his appreciation of the advice received from Messrs. P. G. Nutting and E. D. Tillyer, formerly of that bureau. Acknowledgments are also due to Mr. W. H. Boyd, of the Geological Survey of Canada, for much information that led to improvements in office instruments; to Mr. C. H. Au, a mechanical engineer, of Washington, D. C.; and to Mr. F. H. Moffit, of the United States Geological Survey, for miscellaneous assistance in photography.

HISTORY OF THE USE OF PHOTOGRAPHY IN TOPOGRAPHIC SURVEYING.

The value of perspectives to engineering had been recognized many years before the advent of the photographic camera, and when in 1839 the facts of the discoveries that had been made by Niepce and Daguerre were presented to the French Chamber of Deputies the aid which photography promised to bring to the construction of topographic maps was forecast. It is noteworthy that even before Laussedat had published the results of his first experiments with cameras that had fixed objectives Martens, another Frenchman, had devised a cylindrical camera that employed a revolving objective. To Laussedat, however, falls the credit for the first practical work of adapting the camera to surveying. His work, begun in 1849 under the engineer corps of the French Army, was carried through many years of great activity. Accounts of his progress published from year to year established him at the head of topographic engineers in the use of photography. In 1901 part 1 of the second volume of his treatise on instruments and methods of surveying placed much of his material on photography in convenient form for use by others, and this was followed by part 2 in 1903.[1]

Though France led in this field it was not long before scientists in other European countries began to experiment with the camera. In Germany Meydenbaur was the leading spirit in adapting photographic methods to engineering needs. His work consisted of devising original methods of his own as well as of introducing those that had been developed in France. The interest which he and others aroused led to the employment of photography for a great variety of scientific purposes. One of the most significant developments was the adoption by the Prussian general staff of photography for military surveys. Before 1870 a corps had been organized and trained in photographic methods, and it assisted in the military operations of the Franco-Prussian campaigns.

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[1] Laussedat, Aimé, Recherches sur les instruments, les méthodes et le dessin topographiques, Paris, Gauthier-Villars, pt. 1, 1901; pt. 2, 1903.

The first period of activity in applying photography to engineering practices is characterized by the development of the plate camera in connection with the theodolite. Instruments of considerable precision resulted, and these were mainly phototheodolites of various forms and arrangements. This period extends to about 1900. About that time E. Deville, surveyor general of Dominion lands, Canada, took up the idea of using stereoscopic photographs instead of single photographs. He experimented with a Wheatstone stereoscope, but abandoned these attempts on learning of the progress being made in the same direction by C. Pulfrich in Germany. Though the idea seems to have been first presented by Deville, Pulfrich [1] worked out a method of stereophotogrammetry which has probably had more influence in photographic engineering than all other devices since Laussedat's announcements. Pulfrich's method immediately engaged the attention of many engineers in Germany and Austria, with the result that his devices have there been elaborated and his methods employed in many branches of scientific work. The stereoautograph of Von Orel and, more indirectly, the optical instruments for aerial photography of Scheimpflug and Kammerer, in Austria, are notable evidences of the stimulus given to photographic engineering by Pulfrich.

The use of the camera in topographic mapping, though possibly more highly developed in France, Germany, and Austria, has by no means been confined to those countries. Porro, Paganini, and others in Italy and Thilé in Russia made early and profitable use of photography. Photographic surveys have been made in most of the European countries and in several of the American countries. Accurate data as to the extent of these surveys is lacking, but the total area of the North American Continent that has been mapped by the camera probably forms a considerable percentage of the total area of like surveys over the entire globe. The use of the camera in surveying on this continent is due primarily to the efforts and influence of E. Deville,[2] who in 1886 began systematic phototopographic surveys in western Canada. More than 30,000 square miles of territory has been mapped photographically by the Canadian Government bureaus, including the International Boundary Commission and the Geological Survey of Canada. The regions in Canada where the camera has been used are the rugged portions of the western and northwestern provinces. Deville's general type of camera

[1] Pulfrich's method of stereophotogrammetry is described by Otto Lemberger (Stereophotographic surveying: Eng. News, vol. 69, pp. 602-612, 1913). The principles of this method are given in a very excellent treatise by J. A. Flemer (Phototopographic methods and instruments, New York, John Wiley & Sons, 1906). See also Dock, Hans, Photogrammetrie und Stereophotogrammetrie: Sammlung Göschen, Berlin and Leipzig, 1913. This work is profusely illustrated with views of forms of phototheodolites and stereoscopic instruments used to make measurements on negatives and to reduce the data to the map.

[2] Deville, E., Photographic surveying, including the elements of descriptive geometry and perspective, Ottawa, Canada. This book is a standard publication on the subject.

designed for use in rugged mountains, and a light theodolite, each of which may be mounted on a single tripod, have been employed in the Canadian surveys.

Definite information as to the progress made with phototopographic surveys in other American countries is lacking, but reports indicate that photographic methods have been employed in surveys in the Andes and in Argentina. As most of the South American and Central American states contain considerable mountainous areas it is the writer's opinion that photography would prove a valuable aid in surveys of those countries.

In the United States phototopographic surveys, which were commenced by officers of the United States Coast and Geodetic Survey [1] in connection with the International Boundary Commission, have since been continued until at present somewhat more than 12,000 square miles has been so mapped. Two classes of surveys were included in this work—reconnaissance surveys on a small scale and detailed surveys on a scale of approximately a mile to the inch. The camera used is a modification of Deville's, and it is supplemented by a separate theodolite which may be set up on a common tripod.

A topographic survey of the island of Tutuila, Samoa, has lately been completed by the Hydrographic Office of the Navy Department. For these surveys a plate camera of Deville's general type was employed to obtain stereoscopic views, and the negatives were worked up in the office at Washington by means of a stereocomparator. It is reported that the method gave satisfactory results.

The panoramic camera was first employed in topographic surveying in Alaska by C. W. Wright [2] in 1904, and he was associated in this work with his brother, F. E. Wright. Both were at that time members of the staff of the United States Geological Survey engaged in geologic work in Alaska. The instruments now in use are developments from that beginning. The first panoramic cameras used by Mr. Wright were improvised from commercial instruments by fitting level bubbles and arranging internal scales which formed images upon the negatives. Although these cameras were not constructed primarily for the purpose of surveying, Mr. Wright reports that satisfactory results were obtained with them.

In 1907 Mr. Wright had a new camera made according to specifications which he had drawn up, but it did not become available for use for that season, and soon afterward this work was interrupted

[1] Flemer, J. A., Phototopographic methods and instruments: U. S. Coast and Geodetic Survey Rept. for 1897, pts. 1 and 2, Appendix 10, pp. 619–735, 1898.

[2] Wright, C. W., The panoramic camera applied to phototopographic work: Am. Inst. Min. Eng. Trans., vol. 38, pp. 482–497, 1908.

by his transfer to another field. Little was then done with the panoramic camera until the writer had an opportunity to use it, to a small extent, in 1910. His experience at that time was convincing as to the merit of the panoramic camera, and since then the extent of its employment in Alaska surveys has steadily increased until at present four instruments have been constructed for that purpose, so that two parties may each be equipped with two cameras when engaged in favorable fields.

With the rapid development of the airplane and dirigible balloon in European countries came a corresponding development of aerial photography for military reconnaissances and an awakening to the value of aerial photographs for surveys other than those of a military character.[1] French engineers indorse the aerial methods of photographic surveying as both rapid and economical, and the same opinions seem to be held by engineers of other countries who have had the opportunity of drawing careful comparisons between the various methods of surveying. In the opinion of the writer aerial photography will in the future not only have a prominent part in military reconnaissances in this country, but quite certainly will also have a direct and important bearing on the practices of civil engineering. The notes on the application of photogrammetry to aerial surveys appended to this volume indicate procedures that may be useful in pursuing the development of aerial surveying.

Available records concerning the panoramic camera fail to indicate that the earlier patterns were actually employed in topographic surveying, although it is probable that the "cylindrographe" designed by Moëssard was used to a small extent, for it was constructed for that purpose. This instrument, to judge from drawings of it, seems to have been well conceived and constructed, so that it is difficult to understand why it did not find more favor among topographic engineers in France. The only explanation that occurs to the writer for this failure to attract the attention of those interested in phototopographic methods is that probably when the camera was brought out the films available were much inferior to those procurable at the present time. Besides Moëssard's camera a very novel instrument, called a "planchette photographique," devised by Chevallier in 1858, deserves mention. This camera recorded the entire horizon on a horizontal plate, the light rays being turned at right angles by means of a prism. The "périgraphe" of Mangin is a similar instrument, which permits an instantaneous exposure of the entire horizon, the image being likewise recorded on a flat plate.

[1] Saconney, J. T., Métrophotographie, Paris, 1913. This volume contains very complete material on the use of aerial photography in surveying and presents it in concise and admirable form.

COMPARISON OF THE PANORAMIC CAMERA WITH OTHER METHODS OF SURVEYING.

PLANE TABLE.

In reconnaissance surveys of mountainous regions the factor which ordinarily has the greatest influence upon the progress of the survey is the time required for travel between stations. The most striking feature of the panoramic camera is that it greatly reduces the time necessary to be spent at stations. Only about one-fourth of the time required at stations by the plane-table method is necessary with the panoramic camera. The advantage gained by this reduction, however, is largely offset by the dead work of travel. Furthermore, the rate of progress is often governed more by the speed of the pack train than by the time necessary to occupy stations. It is true that a topographer who is skillful in the use of the plane table can generally keep his survey abreast of the movements of his pack train while covering a strip of territory from 10 to 20 miles wide. In doing so he will commonly occupy a single station a day and seldom more than two stations a day. If his rate of progress is 4 miles a day and the average width of country he covers is 15 miles he must sketch from 30 to 60 square miles from each station. In most mountains the average radius of work from a station will be the same for the camera as for the plane table, for this limit is determined by the amount of detail necessary for the scale of the map, and the panoramic cameras supply photographs which have the necessary range. Therefore, in surveys of this kind, as indicated in Table 1, the final advantage which is gained from the use of the panoramic camera comes from an increase in the number of stations rather than from an increase of area surveyed per day, and the result of this increase in stations is an improvement in the map.

In surveys of relatively small areas on a larger scale the time required for traveling between stations, though of considerable amount, does not have so great importance as it does in reconnaissance surveys, because the stations are placed closer together, and consequently a large number can be occupied in a working day. In surveys of this class the value of the panoramic camera will depend more on the average contents of the photographs. It is obvious that the usefulness of photographs increases with the number of points that can be located from them, so that the more intricate the topographic forms the greater will be the value of the photographs. In contrast to the resulting gain in reconnaissance surveys the value of the method in surveys on the larger scale is in an increased output. The extent of this increase, compared with plane-table surveying, will depend on the character of the mountains and the scale of the map. The largest scale of surveys in which the panoramic camera has been

TABLE 1.—*Summary of topographic surveys by plane table and by plane table supplemented with panoramic camera.*

Survey.	Year of survey.	Field scale.	Contour interval (feet).	Relief (feet).	Personnel of party.	1 Percentage of area timbered.	2 Area (square miles).	3 Field season (days).	4 Miles of traverses.	5 Number of days of station work.	6 Number of stations.	7 Square miles mapped per field work-day.	8 Square miles mapped per field station.	9 Cost of field work per square mile.	10 Total cost of field work per work-day.	11 Relative costs of plane table and panoramic camera surveys.	12 Square miles mapped per office day.	Method of survey.
Eagle River........	1909-1910	1: 48,000	50	2,000 to 5,000.	1 topographer, 1 traverseman, 2 recorders, 1 packer (30 days), 1 cook.	85	190	189	410	91	86	2.09	2.21	$33.53	$70.00	$15.25	2.04	Plane table.
Port Valdez........	1911-1912	1: 48,000	50	3,000 to 6,000.	1 topographer, 1 traverseman (35 days), 2 recorders (1 for 35 days), 1 cook.	12	320	127	135	50	148	6.40	2.16	13.97	89.40	4.81	1.64	Panoramic camera and plane table.
Moose Pass........	1911	1: 48,000	50	3,000 to 4,000.	1 topographer, 1 recorder, 1 packer, 1 cook.	30	86	46	47	19	36	4.53	2.39	18.56	84.00	11.92	1.46	Do.
Tanana............	1908	1: 180,000	200	1,000 to 2,500.	.....do................	60	1,725	79	....	29	36	59.48	47.92	3.15	187.75	.752	35.2	Plane table.
Bonnifield.........	1910	1: 180,000	200	2,000 to 9,000.	1 topographer, 1 recorder, 2 packers, 1 cook.	25	2,870	78	....	53	56	54.15	51.25	2.46	133.30	.732	....	Plane table (panoramic camera used to small extent).
Broad Pass........	1913	1: 180,000	200	2,000 to 4,000.	1 topographer, 1 photographer, 1 recorder, 2 packers, 1 cook.	16	2,500	50	....	24	101	105.0	24.75	3.28	344.20	.696	37.8	Panoramic camera and plane table.
Nelchina-Susitna...	1914	1: 180,000	200	...do...	.....do................	65	4,600	104	....	65	214	70.77	21.5	1.54	109.20	.678	30.3	Do.

used was 1 : 48,000. This is by no means the limit for its use, for horizontal angles can be turned from the photographs with all the precision necessary for a scale as large as 2 or 3 inches to the mile. The limit of the camera's usefulness will be determined by the degree of accuracy necessary in determining elevations—that is, roughly, by the contour interval.

Table 1 gives a summary of results obtained from the use of the plane table and from the plane table supplemented by the panoramic camera. It should be understood that the figures show results of work in a region where wages and cost of provisions and transportation are very high—probably higher than in any other civilized quarter of the globe—so due allowance should be made for this condition.

The Eagle River and Tanana surveys were executed by the plane-table method alone. In the Bonnifield survey a panoramic camera was employed to a small extent. For the Port Valdez and Moose Pass surveys a single camera was employed and in the Broad Pass and Nelchina-Susitna surveys two cameras were used.

The gain from the use of a panoramic camera is expressed in columns 6, 7, and 8, as well as in the columns of costs, because the advantage lies as much in increasing the number of stations, and thereby limiting the range of field to be covered at each station, as in a direct reduction of cost. The column of costs per square mile (9) should be read in connection with columns 3 and 5 in order that the influence of the weather and the cost of transportation to and from the field may be taken into account. In order to eliminate these two factors column 11 has been added. In arriving at the figures there shown only those percentages of the total costs which were chargeable to salaries on workdays, subsistence on workdays, equipment, and transportation in the field were used. The figures therefore represent only approximate unit costs of the various surveys and thus merely show the relative value of the panoramic camera in comparison with the plane table.

It will be seen that the relative cost of the Port Valdez survey is less than one-third that of the Eagle River survey. In order that these figures may not be misleading it is necessary to explain the conditions under which the surveys were made. Both of the districts are adjacent to the coast, and they presented similar difficulties to travel. The proportion of timbered areas is very much greater in the Eagle River district than in the Port Valdez district, and large glaciers cover much of the Port Valdez district. It would be a very difficult if not impossible task to equalize all the many factors that would have to be taken into account to reach a common basis for the two surveys, but by estimating roughly the effect of the timber and ice and eliminating the expense of traverses necessary for both surveys the resulting ratio of costs was approximately three to four in favor of the Port Valdez. This result gives a ratio nearer that between the costs of the Moose Pass and the Eagle River surveys, which, the writer believes, indicates with a fair degree of accuracy the relative values of the two methods in country of average favorable type. The areas covered by the Eagle River and Moose Pass surveys show a difference in amount of timber. It has been estimated that this difference was about balanced by the increased cost of transportation for the Moose Pass survey, which was effected with pack horses, requiring the additional services of a packer. The Port Valdez and Moose Pass surveys were made with the aid of only one panoramic camera, and by the employment of an auxiliary camera a further reduction in cost could have been reasonably expected.

Column 12 has been included in the table to show the time spent in office work in the several surveys. Roughly, the figures indicate that the photographic method requires about one-fourth more time for the detail surveys and only slightly more for those of the smaller scale. In the photographic surveys a large portion of the contour sketching is done in the office, whereas in the plane-table surveys, especially those on the larger scale, the contours must be sketched on the ground. This difference accounts for the increased amount of office work necessary for photographic surveys. But where the difference in amount of field sketching involved in the two methods diminishes, we should expect a corresponding change in the relative time necessary for the completion of the office work, and as in surveys on the smaller scale the amount of field sketching in the two methods is more nearly equal, a smaller difference of time for the office work results.

PLATE CAMERA.

In reconnaissance expeditions, where extensive areas are to be surveyed, broad valleys of low relief are certain to constitute a considerable portion of the region. The camera alone may be inadequate to gather the data necessary to contour the slopes and to trace the drainage in these valleys. The plane table, having been continuously employed to establish the positions of the stations and other points of control, becomes immediately available for obtaining details which can be put on the sheet without the inconvenience of improvised control and with but slight delay in progress. The topographer who is prepared for both rugged and rolling country can pass from one to the other with all the advantage that both the plane table and the camera offer. This usefulness in all types of country is the chief point of superiority which the panoramic camera, combined with the plane table, has over methods of surveying in which plate cameras are used in combination with the theodolite.

Another advantage is the locative nature of the negatives, which, by supplying data for their own control, permit great freedom of movement in auxiliary cameras. This quality practically eliminates all uncertainty of the camera's position, whether or not the stations have been sighted in the plane-table scheme. It is only necessary that the panoramas include the required number of control points properly disposed around the horizon.

The third advantage is gained by the use of film cartridges instead of plates. The cartridge of four exposures packed in a waterproof case weighs 5 ounces. Three exposures complete the horizon, so that the cartridge has a scope of 480° with necessary overlap. In the prevailing type of plate camera used in surveying, nine plates would be required to embrace 480°. These would weigh 20 ounces packed, four times the weight of the film. Two hundred rolls of film, weighing less than 70 pounds, have been used during a season of about three months. The equivalent weight in glass plates is close to 300 pounds. Such an additional load would require a considerable increase in outlay for transportation.

The dependable accuracy of results in determining elevations from film negatives is indicated in Table 8 (p. 61). Doubt of the reliability of such determinations seems to have been the only argument against the use of the panoramic camera in topographic mapping. An allowance must be made for accuracy of measurement of films as compared with plates, and when the amount of this allowance has been determined a comparison can be made of the relative values of the panoramic camera and the plate camera. For the panoramic camera there is greater ease and rapidity in field operation, more freedom in selection of stations, marked reduction of weight in negatives, greater safety in the transportation and care of exposed and developed negatives, and increased facility in the office compilation. The plate camera has the sole advantage of supplying negatives that permit greater refinement in establishing elevations, a refinement which becomes necessary only in large-scale work that has a small contour interval. As this refinement would not be needed for general service maps on the smaller customary scales, there is no justification for the time and expense necessary to obtain it. The balance therefore is greatly in the favor of the panoramic camera.

STEREOPHOTOGRAMMETRY.

The attention which stereophotogrammetry is receiving demands a comparison of this method with that of the panoramic camera. In stereophotogrammetry the plate camera is employed to obtain stereoscopic views from points whose distance from each other is carefully measured. This distance is known as the base. In accordance with principles of descriptive geometry, instruments have been constructed by means of which the field covered by such a pair of plate negatives can be rapidly converted to a map. The base and the focal distance for the negatives are known quantities from which the desired quantities, distances to points and differences of elevation, are obtained. Measurements are made upon the plates by means of microscopes and micrometers, which supply results with considerable precision. This application of stereoscopic photography is striking. The ingenuity manifested in the instruments of Pulfrich must command the respect of all who acquaint themselves with what he has done. The field which these instruments have opened or made more accessible to photography is wide and varied, and it is probable that work can be done with them which could not have been done without them. It is, however, as a means for general topographic surveying that the method concerns the present discussion. In this work there is no need to go beyond the single consideration of the base. In order that the stereoscopic negatives may have a considerable range the bases must be from 50 to 300 feet long. The kind of country in which it would be possible to select positions for stations where room could be found to lay out these bases is not ordinarily the kind in which photography is best adapted for topographic surveys. It is obvious that the pointed and commanding peaks, which offer the most advantageous positions for the camera, could not be occupied in stereophotogrammetry. Because of this fundamental feature it seems improbable that this method can be satisfactorily employed at the tops of rugged mountains.

AERIAL PHOTOGRAPHY.

It is not commonly realized that a photograph of a plane surface taken with a plate camera directed perpendicularly toward that plane is a map of the area which the photograph embraces. In other words, it is possible to use the camera to produce charts, in the form of negatives, of level ground, provided the camera can be placed in a position directly above the ground. Here the camera will merely be doing on a small scale what is done on a very much larger scale in map reduction by photography. It is essential that the lens give a true perspective and that the plane of this perspective be parallel to the plane of the ground or its angle of inclination be determinable. Upon this basis Theodore Scheimpflug,[1] of Vienna, devised a camera consisting of eight lenses arranged in such a manner that one of them is directed downward and the other seven lenses are disposed around the first with axes inclined at 45° to the optical axis of the central lens. The eight plates are exposed simultaneously. The

[1] Scheimpflug, Theodor, Die Herstellung von Karten und Plänen auf photographischem Wege: K Akad. Wiss. Wien, Math.-naturw. Klasse, Sitzungsb., Band 116, Abt. 2-A, pp. 235-266, 1907. See also Kammerer, G., Th. Schiempflugs Landvermessung aus der Luft: Internat. Archiv Photogrammetrie, Band 3, Heft 3, pp. 196-226.

central negative, if parallel to the plane of the ground, is a correct chart of the ground it covers, but the seven inclined negatives are distorted charts which require correction in order that they may be joined to the central or true chart. To make this correction, Scheimpflug designed an optical instrument which he has called a photo-perspectograph. By means of this instrument photographs taken of the original inclined negatives fall into the plane of the central negative and supply extensions to that negative on the same scale.

The assumption thus far has been that the ground to be mapped is flat. For rolling and mountainous country the charts will be distorted or contain errors, whose amount will depend on the relief of the ground, the height at which the photographs were taken, and the angular range of the photographs. There is also the requirement of control, which must be supplied in every set of negatives in order to orient the charts and give them scales.

Without experience with a method so different in nature from the methods commonly used in surveying, it is not possible to draw the limits of its possible future field, but there are certain hindrances which are liable to delay, if not prevent, the general use of this type of photography. The most serious of these hindrances are the expense and hazards incurred. The airplane or the dirigible balloon would be required to reap the full benefits of this method, and the gain or loss in its use would depend upon the cost of operating the aerial vehicle. The farther the field of the surveys lies from facilities for transportation by water and rail and the rougher the country of that field, the less useful is the method at present. Its greatest usefulness will most probably be in military surveys and in topographic surveys of relatively flat regions where man-built structures are dense or where swamps and streams make surveying by older methods tedious and difficult.

FIELD INSTRUMENTS.

PHOTOGRAPHIC EQUIPMENT.

PANORAMIC CAMERA.

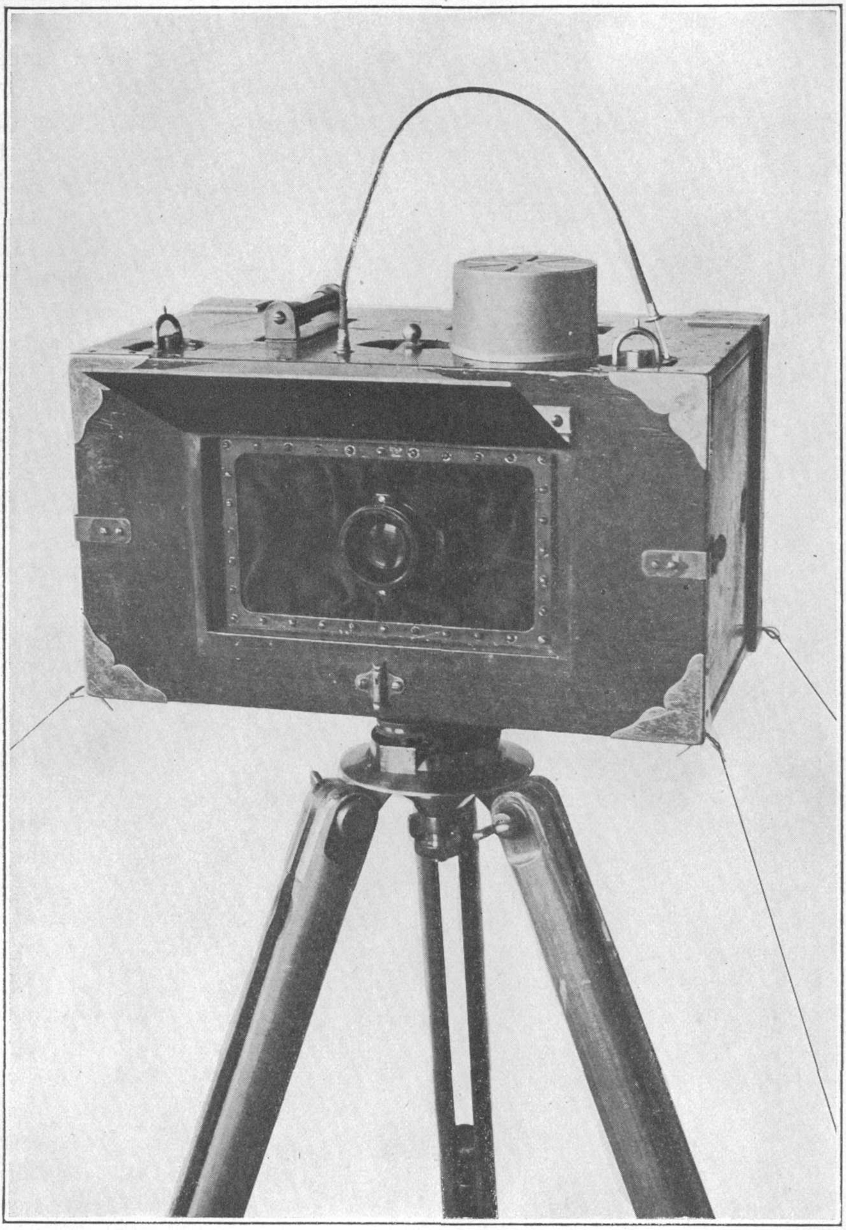
GENERAL FEATURES.

The panoramic camera set up for use is shown in Plate III. The camera box is made of aluminum and is inclosed in a protecting frame of mahogany that is lined with felt. The top of the aluminum box is the reference plane for leveling and the vertical axis carrying the lens is placed perpendicular to this plane. The circular film guides are adjusted so that when the film is in position for exposure all elements will be perpendicular to the level plane and hence parallel to the lens shaft. The horizontal scope of view is approximately 126°. A margin of 6° for each photograph allows ample range for setting the camera by open sight and a sufficient overlap near the limits of the photograph for identification. The vertical scope is about 18° above the horizon and 26° below it. The greater range is given to the foreground in order to photograph all except precipitous slopes. Two seats at right angles to each other are arranged on the top of the box to receive a detached level bubble which permits a rapid adjustment for level. This adjustment is the only one that is necessary in using the camera. The camera is connected with the tripod by three leveling screws of a common pattern. The slit in the lens funnel is about 0.6 inch wide, a width which allows as much light to reach the film as the required accuracy in image will permit.

The lens is revolved by a spring, and the rate of revolution is regulated by detachable fans connected by gearing with the lens shaft. The fans which project outside the box require protection from sudden blasts of wind, and this is provided in the form of a cylindrical cap. The camera box has an opening at the back for the insertion of film cartridges. Both reels have free right and left motion, and they are equipped with adjustable friction brakes to hold the film closely in contact with the guides. Contact bars are placed in the back of the camera to aid further in holding the film accurately in place. The door, which is hung at the top, when closed forms a light tight covering for the lens and can be inclined at any desired angle to shade the lens from the sun at the time of exposure. It is necessary to use the wind guys when the wind affects the level bubble. A fine and strong fish line gives good results. The guys are anchored before the camera is finally leveled.

Before using the camera a test is made to ascertain whether the proper relation exists between the lens shaft, film guides, and level plane by exposing upon a field containing several prominent objects in the same horizontal plane with the lens. These objects should be placed or selected so as to be far enough away from the camera to make the test effective. If the line passing through these several images is straight the proper relation exists, but if not the correction must be made before taking the camera to the field.

The camera has been constructed in two sizes, one employing a 5-inch cartridge and the other a 6-inch cartridge. The equivalent focal length of the lens is about 5.4 inches, and for topographic surveying the image is perfect through a range of 30° from the optical axis. The 6-inch film is better adapted for use in precipitous country, for its vertical range is about 8° greater than that of the 5-inch film. The disadvantage lies in the extra expense and inconvenience of procuring special films differing from the regular stock sizes, such as the 5 by 4 inch twelve-exposure commercial film.



THE PANORAMIC CAMERA.

By placing the lens in the 5-inch camera a little below the center line part of the advantage gained in the 6-inch camera can be had, and on account of this possible arrangement the 5-inch camera is preferred.

LIGHT BAND.

Figure 1 shows graphically the elements that should determine the width of the light slit in the funnel. The focal plane is represented by the line *rx*. The lines *el* and *ad* represent parallel planes perpendicular to the optical axis, through the light slit and the optical center of the lens, respectively. The focal length of the lens (*ou*) is 138 millimeters and the distance *oh* is 80 millimeters. The diameter of the aperture at F 32, represented by *bc*, is 4.3 millimeters, and at F 6.3 (*ad*) it is 22 millimeters.

The minimum width of slit that will permit maximum illumination at the center of the light zone (*u*) when the aperture F 6.3 is used is

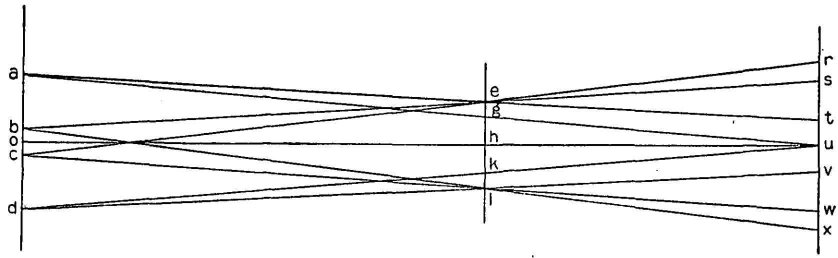


FIGURE 1.—Limits for light slit in panoramic camera.

shown by the lines *au* and *du*, crossing the plane of the funnel slit. This width (*gk*) is 8.6 millimeters. A source of error which must be considered is that caused by the use of a film in cylindrical form instead of a flat film. The maximum width of slit that can be used because of the cylindrical field is limited by the effect of the error in image ("softening") on both horizontal and vertical readings. Furthermore, the widest slit that the camera mechanism will conveniently allow is 15 millimeters. For a 15-millimeter slit the zone of full illumination will be 23 millimeters at the F 32 stop. The amount of this "softening," due to lack of focus, is shown for the edge of the zone in the following table:

TABLE 2.—*Amount of focus error due to light band.*

Stop.	Radius at focal plane (millimeter).	Effect on horizontal angles (minutes).	Effect on elevations at distance of 5 miles (feet).
6.3	0.04	1.0	8.0
11	.023	.57	4.3
32	.008	.20	1.5

We may therefore employ a light slit of any width between the limits 8.6 and 15 millimeters and maintain full aperture efficiency and introduce only negligible errors in image.

LENS SHAFT AND MOUNT.

In order to eliminate errors that would result from a failure to get the lens shaft accurately oriented with the film guides and the level plane, and from eccentricity in mounting the lens in the barrel, means for adjusting these positions might seem to be desirable. Experience in the construction of the cameras has shown, however, that the lens shaft can be placed with sufficient accuracy to make unnecessary, as well as undesirable, an adjusting mechanism which might prove a source of large and irregular errors, and the slight eccentricity that has resulted from the mounting of the lens can be obviated by turning the lens enough to throw the optical axis into the plane of the horizon.

LENS TEST.

Though there are doubtless other standard lenses that would adequately suit the purpose of the camera, the field work has not yet afforded an opportunity to make trials of more than one—the Zeiss Tessar series IIb. Tests of four of these lenses furnished reliable evidence of their uniformity of construction. The distortion is so slight as to be negligible. The table below gives the results of these tests, supplied by the Bureau of Standards.

TABLE 3.—*Results of tests of lenses.*

[Tests made by Bureau of Standards.]

Distance from lens axis (degrees).	Distance from lens axis in the focal plane (millimeters).	Distortion correction in millimeters for lens No.—			
		1	2	3	4
0	0	0.00	0.00	0.00	0.00
5	....	....	....	....	.00
10	24	.00	.00	.00	.00
15	37	− .02	.00	+ .02	− .03
20	50	− .06	.00	+ .04	− .05
25	64	− .11	− .06	+ .07	− .10
30	79	....	....	+ .02	− .00

Equivalent focal lengths: No. 1, 135.3 mm. No. 2, 138.5 mm. No. 3, 137.0 mm. No. 4, 136 mm.

A determination of the equivalent focal length of the lens must be made before the construction of the camera box is begun. The back focal length should also be ascertained. It is necessary for the circular film guides to be formed with a radius exactly equal to the equivalent focal length. The position of the lens in its collar can readily be fixed by simple measurement of the distance from the back lens surface to the film, this distance being equal to the determined back focal length. A test of image definition can then be made by exposing the lens in this position and at different points nearer to and more distant from the film. An examination of greatly enlarged lantern images from the resulting negatives will disclose any discrepancy in the position selected.

The degree of accuracy obtainable in turning horizontal angles from photographs taken with a panoramic camera will depend on the focal length of the lens and the refinement of the means of making measurements. The open sight employed in turning angles permits a setting on a point within 0.01 inch of its true position. At the circumference of a circular arc having a radius of 5.4 inches (the focal length of the lens employed) the error of 0.01 inch in pointing corresponds to an angular value of $6\frac{1}{2}'$.

INSTRUMENTS FOR DETERMINING DURATION OF EXPOSURES.

TYPES.

The many different styles of exposure meters and calculators in general use may be divided into three general types—(1) exposure meters, which are designed to measure the light intensity at the moment of exposure by means of sensitized substances; (2) exposure calculators, which are based on the computed intensities of the sun's light for given latitudes throughout the different seasons and for different hours of the day; and (3) the photometer type, which is designed to estimate the actinic value of the light reflected from the subject. The first type has only a moderate range of usefulness, and it is not adapted for landscape photography. The most troublesome feature of the second type is its unwieldiness. There are so many factors to be considered in arranging the scale that it seems impossible to design one for universal use. From the Equator to the polar regions the range of the intensity of the sun's light is too wide and differs too much from season to season and from hour to hour to make it possible to combine all the essential corrections in one compact design. It becomes necessary to employ different scales for different latitudes, and even in these scales there can be no provision for estimating the intensity of the light when the sun is very low and mists have risen to interfere with the light rays.

A simple and practical rule for timing exposures is given by F. H. Moffit. This rule requires the use, for a distant landscape of average brightness in fair weather, with F 16 stop, of the reciprocal of the sun's altitude in degrees to give the time in seconds or part of a second. Thus, if the sun is 20° high the time should be 1/20 second for F 16 stop in fair weather. Proper corrections should be made for cloudy weather and for different subjects and color screens.

Some of the statements made in reference to exposure may seem arbitrary to experienced photographers, and the writer realizes that the rules here given are by no means final. The purpose has been to indicate to the surveyor who is inexperienced in photography a procedure that will permit him to obtain satisfactory results.

CALCULATOR.

The table of exposure times (Table 4) and diagrams of altitude curves (fig. 2) have been arranged by J. B. Mertie, of the Geological Survey, and are based on the principle that the intensity of the sun's light varies directly as the sine of the sun's altitude, as presented by Alves.[1] Upon this foundation a beginning for the table was obtained by exposing to find the proper time and stop for distant landscape under maximum illumination, and the remaining quantities followed in arithmetical ratio.

TABLE 4.—*Time (in seconds) of photographic exposures in fair weather, according to the sun's altitude.*

[For use with plates and films of speed designated by Burroughs, Wellcome & Co. as 1/6; Watkins, 180; Wynne, F 90. Use "Near" for less than 2 miles; "Distant," to 15 miles; "Very distant," over 15 miles.]

Sun's altitude.	Stop: U. S. / F.	2.5 / 6.3	4 / 8	8 / 11	16 / 16	32 / 22	64 / 32	128 / 45	256 / 64
48°–90°	Very distant	1/640	1/400	1/200	1/100	1/50	1/25	1/12	1/6
	Distant	1/320	1/200	1/100	1/50	1/25	1/12	1/6	1/3
	Near	1/160	1/100	1/50	1/25	1/12	1/6	1/3	2/3
30°–48°	Very distant	1/480	1/300	1/150	1/75	1/40	1/20	1/10	1/5
	Distant	1/240	1/150	1/75	1/40	1/20	1/10	1/5	2/5
	Near	1/120	1/75	1/40	1/20	1/10	1/5	2/5	4/5
22°–30°	Very distant	1/320	1/200	1/100	1/50	1/25	1/12	1/6	1/3
	Distant	1/160	1/100	1/50	1/25	1/12	1/6	1/3	2/3
	Near	1/80	1/50	1/25	1/12	1/6	1/3	2/3	1 1/3
15°–22°	Very distant	1/240	1/150	1/75	1/40	1/20	1/10	1/5	2/5
	Distant	1/120	1/75	1/40	1/20	1/10	1/5	2/5	4/5
	Near	1/60	1/40	1/20	1/10	1/5	2/5	4/5	1 3/5
11°–15°	Very distant	1/160	1/100	1/50	1/25	1/12	1/6	1/3	2/3
	Distant	1/80	1/50	1/25	1/12	1/6	1/3	2/3	1 1/3
	Near	1/40	1/25	1/12	1/6	1/3	2/3	1 1/3	2 2/3
7°–11°	Very distant	1/120	1/75	1/40	1/20	1/10	1/5	2/5	4/5
	Distant	1/60	1/40	1/20	1/10	1/5	2/5	4/5	1 3/5
	Near	1/30	1/20	1/10	1/5	2/5	4/5	1 3/5	3
5°–7°	Very distant	1/80	1/50	1/25	1/12	1/6	1/3	2/3	1 1/3
	Distant	1/40	1/25	1/12	1/6	1/3	2/3	1 1/3	2 2/3
	Near	1/20	1/12	1/6	1/3	2/3	1 1/3	2 2/3	5 1/3
3°–5°	Very distant	1/60	1/40	1/20	1/10	1/5	2/5	4/5	1 3/5
	Distant	1/30	1/20	1/10	1/5	2/5	4/5	1 3/5	3
	Near	1/15	1/10	1/5	2/5	4/5	1 3/5	3	6

[1] Alves, G. M., Outdoor exposures: Photominiature, vol. 5, No. 54, September, 1903.

Table 4 supplies any desired stop and time for the sun's altitude between 3° and 90°, when direct readings can be made for altitude. For simplicity in using the table it has been divided into zones which are broad toward the zenith and narrow near the horizon. A division of this kind is permissible, for the reason that the average quantities of time can be employed for a considerable change in the sun's altitude without introducing errors in results.

When the sun is not visible its altitude has to be determined in another way. Figure 2 is arranged for use in connection with the table when the sun is obscured. The diagrams are drawn for lati-

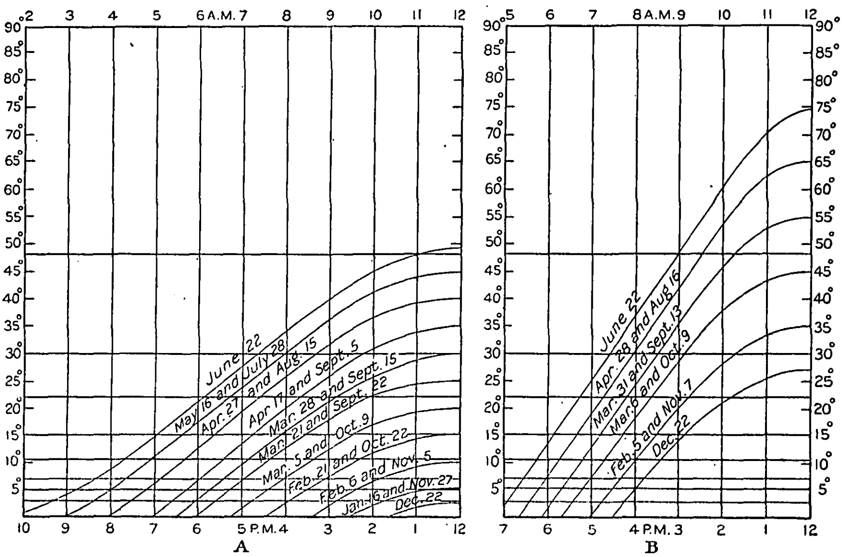


FIGURE 2.—Curves of sun's altitude. A, Latitude 39° N.; B, latitude 64° N.

tude 39° N. and 64° N. and they are appropriate for use within zones of 4° or 5° of latitude. For use in other latitude zones it is necessary to construct other series of curves. The curves were obtained from the formula

$$\sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t \quad \text{..........} (1)$$

in which h = true altitude of sun, ϕ = latitude, δ = declination, t = hour angle.

It will be seen that the curves have an equal spacing at midday. This result was obtained by determining the dates at which the sun's altitude would have certain noon values. That is, the different values of the sun's declination, which would give certain fixed noon elevations, were calculated. In formula (1) the term cosine t becomes unity when $t=0$ (that is, at noon). The formula then can be converted into the form

$$\cos \delta = \sin h \cos \phi \pm \sin \phi \cos h \quad \text{..............} (2)$$

and in that form it is best suited for calculating with the minimum of labor the declination values above mentioned. When these declination values are known formula (1) can again be utilized in calculating the sun's altitude for the curves at the different hour angles.

PHOTOMETER.

The photometer type of exposure meter operates directly upon the subject, and theoretically it should supply the desired lighting factor more quickly and more accurately than any of the other devices, but it requires practice to get its "run" and to make the correction for individual vision. Compared with the calculators it has the advantage of possessing practically unlimited range and of measuring the light coming from the subject instead of calculating a general lighting condition. The practice of using a photometer and checking it with a calculator has given satisfactory results.

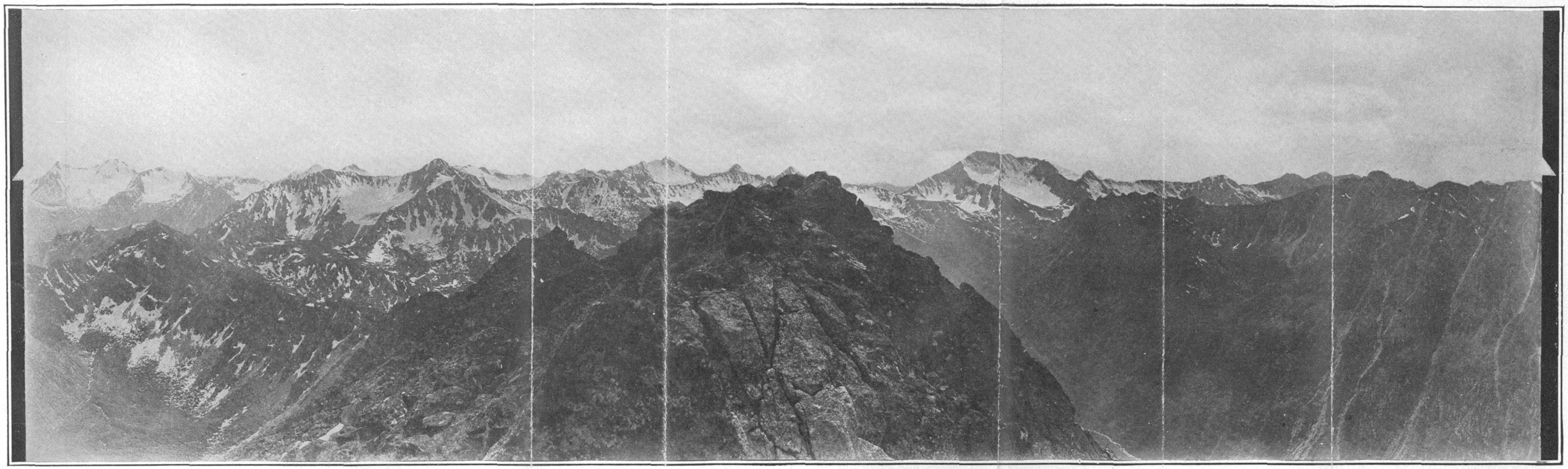
COLOR FILTERS.

A suitable color filter is a great aid in long-range landscape photography. The best color filter for photographic use is one that absorbs the rays of short wave length and allows the greatest portion of the remainder of the spectrum to pass through the lens. The light coming from distant objects, owing to its high percentage of the shorter wave lengths, acts with very much greater intensity than that from the nearer areas. The purpose of the filter is so to neutralize this stronger actinic light that the rays from all portions of the landscape may act sufficiently in a given time to produce fair images and to eliminate haze. The chart of curves shown in figure 3 is drawn from data furnished by the Bureau of Standards for different types of filters. Curves J, G, and L1 indicate efficient filters; E and P are of lower value; and L2 is almost worthless for topographic work.

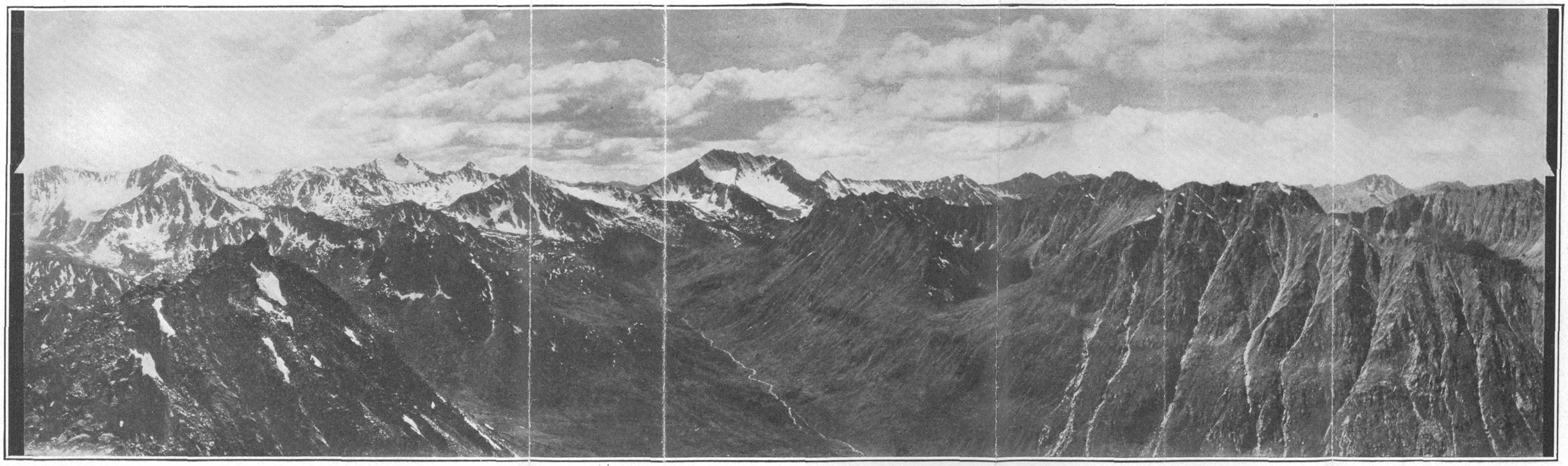
The value of a proper filter is shown by the two photographs reproduced in Plate IV. The view shown in Plate IV, *A*, was taken without a filter early in the afternoon in June. Half an hour later the photograph shown in Plate IV, *B*, was taken, a filter of type G being used. This view faces approximately in the same direction as the preceding one, from the near knoll which is shown in Plate IV, *A*. The two photographs were taken from positions only 200 feet apart.

FILMS.

The films used should be of standard quality and sensitive to yellow and green light rays. Films are commonly labeled with a date after which they are not warranted to be free from deterioration. Experience with sealed films in Alaska has shown that they remain practically unaffected for several months beyond the date of the expiration of the guaranty. As this date is about one year from



A.



B.

PHOTOGRAPHS ILLUSTRATING VALUE OF COLOR FILTER.

the time the films were made it is safe to use them in a cool climate within 18 months from that time. It is doubtful whether this range of time would be greater than 12 months in a warm climate.

The number of film cartridges which should be taken for the field work will depend on the character of the survey and the area to be covered. A few extra cartridges should be included, in order that the supply may certainly be adequate. In reconnaissance surveys, which are made on a scale of 1:180,000, the area surveyed will very often be determined by the weather and the length of the season. In these surveys the probable number of unsuitable days is deducted from the number of days in the season, and an estimate is made on the basis of using three rolls of four exposures in a working day for each camera. This estimate provides for two stations a day for each camera. By area the estimate should be at the rate of three rolls for 40 square miles.

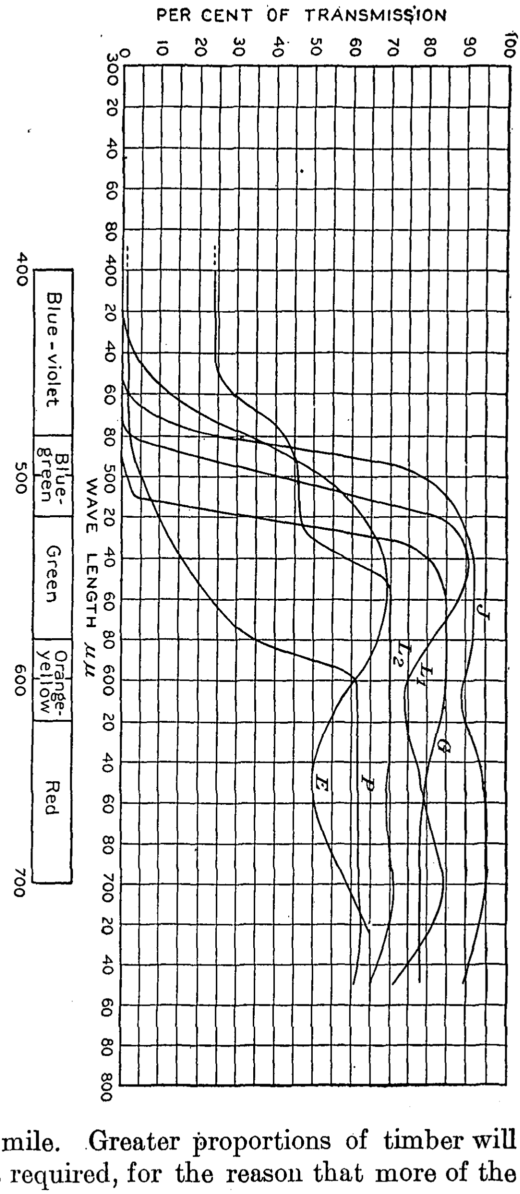


FIGURE 3.—Curves showing transmission of light through color filters of different types.

For surveys on a scale of 1 mile to the inch in country having little timber the number of rolls of film required will be approximately one to the square mile. Greater proportions of timber will lower the number of rolls required, for the reason that more of the area will be surveyed by traverses.

DEVELOPING OUTFIT.

TANK.

A developing outfit is indispensable in the field. By its use at times when regular field operations are rendered impossible, enough films can be developed to furnish thoroughly reliable tests of the exposures that have been made. Not only does the development eliminate the uncertainty as to the quality of the negatives being produced, but it greatly lessens the danger of injury to the films from moisture and light.

The form of developing outfit which, in the opinion of the writer, best meets the requirements is the developing tank, and the wooden changing box is discarded for a black sateen bag. This bag is really a "muff" of double cloth about 2½ feet long and 3 feet in circumference, which is supplied with elastic bands to draw the openings about the wrists when being used. The remaining parts consist of a spool and an apron. The complete kit includes changing-bag, metal tank, spool, and apron. The outfit takes little more space than the cylindrical tank, and the changing bag can be operated, after a little practice, with as much ease as the changing devices of other types. The bag affords far greater security against light during the work of changing, for it permits the use of the sense of touch, whereas the others must be manipulated "blindly." The apron is started on the spool before inserting it in the bag and the film is attached inside the bag and the winding completed there. Thus the film can be felt continually, whereas in the use of the wooden changing box no knowledge of the operation can be had until the lid is removed and the film, if uncovered, has been injured by light.

DEVELOPER.

The developer used should be that recommended by the manufacturers of the film, and it should be fresh, in order to insure no chemical change, or else it should be prepared according to standard formulas with pure chemicals by careful weighing. For field use, the prepared developers are much more convenient, but they are more expensive. The minimum quantity of developer taken for a survey should be sufficient to develop a few films every two or three weeks. With only a slight addition of weight, sufficient developer to develop all the films may be taken. Because of the saving in time it is convenient to use the developer in double strength. If this is desired, double the quantity should be available. The developer should be kept in moisture-proof packages.

TRAY FOR FIXING BATH.

The most convenient tray for the fixing bath is one made of paraffined canvas, about 16 inches long, 6 inches wide, and 4 inches deep. Such a tray may be folded into a small space for packing, and it will remain practically water-tight for several years. It should have loops at the top corners for the insertion of sticks, which serve to hold the walls upright.

FIXER.

Like the developer, the fixer should be fresh, pure, and packed in moisture-proof cases. That prepared and recommended by the producers of the film is likewise to be preferred. The hypo solution should be used with a hardener. The quantity to be taken should be determined at the rate of 1 pound of fixer to each eight rolls of film that are to be developed.

THERMOMETERS.

Long stirring thermometers with a flat disk at one end are the most convenient in form for tank use. Extra ones should be included in the equipment, to use in case of breakage. Thermometers of this type are sold by most dealers in photographic supplies.

DRYING CLIPS.

Drying clips of the spring and jaw type aid greatly in handling the films after development. A substitute for these can be readily made of sticks by splitting, notching, and tying them with thread. A clip or split stick should be fastened on each end of the film while it is drying.

PLANE TABLES.

FORMS.

The plane tables used in surveys in Alaska are of two patterns. For the more important stations and control a board 18 by 24 inches, set upon a strong tripod equipped with the Johnson head, is employed. No traverse lines except those of important watercourses, roads, etc., are executed for the small-scale reconnaissance maps, so the larger plane table suffices for the entire work. For larger-scale maps, such as those on a scale of an inch to the mile, a small board from 6 to 15 inches square supplements the larger table. The tripod head for this table is a smaller one, of the Johnson type. It is light and simple in mechanism. The Johnson head and both types of plane tables are fully described in the maker's catalogue, and therefore need no further mention here.

SHEETS.

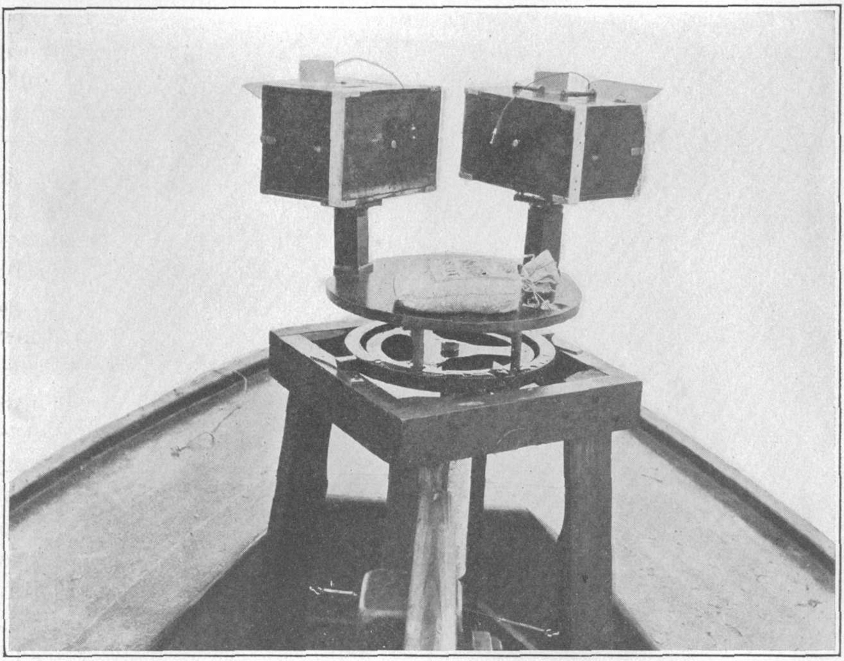
The triangulation scheme of control for the photographs may be drawn upon either double mounted paper or white opaque celluloid. The writer has found the celluloid preferable to the paper. Its one great advantage over paper is its freedom from injury by water. It holds pencil lines fairly well and is not more subject to contraction and expansion than paper. It must be guarded against fire, but so must paper.

Perhaps the most valuable recently developed auxiliary to plane-table work is the thin-sheeted frosted celluloid, which is rapidly taking the place of linen for making the locations of stations. It has the very great advantage of holding securely the original lines drawn from stations and thus furnishes permanent reference sheets for control. It frequently happens in extensive triangulation schemes that the positions of certain mountains, which may be used as stations, can not be accurately determined at the time they are being occupied. The transparent celluloid eliminates this difficulty, for by its use the determination of the true position of any station may be deferred until checks have been obtained from other stations more favorably situated. Indeed, it is possible to use these sheets on returning from the field to plot the entire triangulation scheme on a large sheet and thus to carry a check over the entire work of a season.

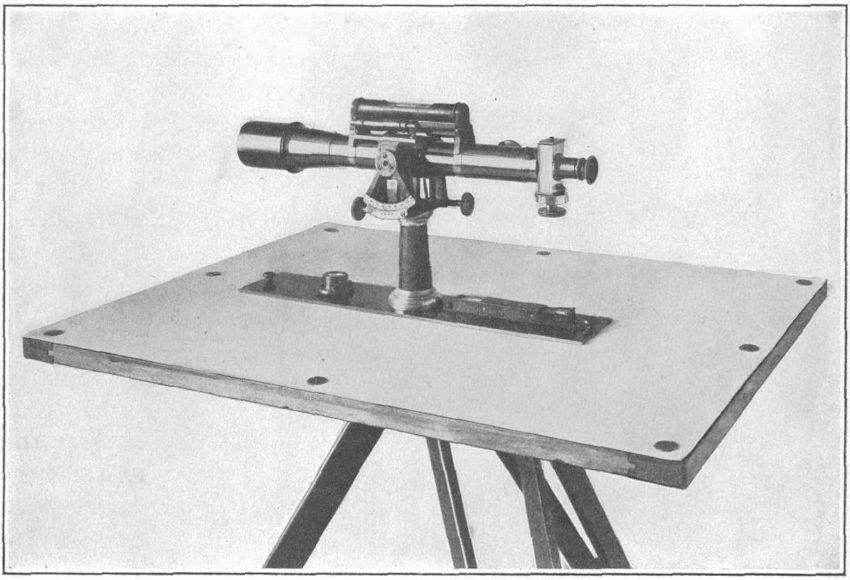
TELESCOPIC ALIDADE AND ATTACHMENTS.

The most necessary features in the telescopic alidade are rigid joints, objective efficiency, and lightness. The ruler should be about 15 inches long and the standard long enough to handle with ease. The circular arm should be graduated to read 30° at level in order to eliminate the necessity of positive and negative signs in the notes. Plate V, *B*, shows an instrument of recent design which properly meets the requirements. The auxiliary level bubble reduces the number of angular readings almost one-half, for when it has been adjusted for level position a single angular note upon a point completes the record.

An important attachment that seems not yet to have come into general use is the micrometer, which in certain uses may take the place of the stadia wires to considerable advantage. In form it is similar to that in use on refined terrestrial and astronomical instruments. Its advantage over stadia instruments lies in the fact that it permits a greater distance to be measured at a single reading, the limit of distance being determined solely by the effective range of the telescope. In operation the micrometer may be described as differing from stadia instruments by employing a fixed base and a movable wire instead of a graduated rod and fixed wires. Within certain limits the base may be of any desired length, as for a thousand



A. PANORAMIC CAMERAS SET UP ON GIMBAL-RING STAND ABOARD LAUNCH.



B. TELESCOPIC MICROMETER ALIDADE AND PLANE TABLE.

feet, between 5 and 10 feet; for a mile, between 25 and 50 feet; for 10 miles, 200 to 500 feet. This base may be marked by divisions on a regular stadia rod, by the distance between flags or cross bars attached to a standing tree, or by the distance between two trees or

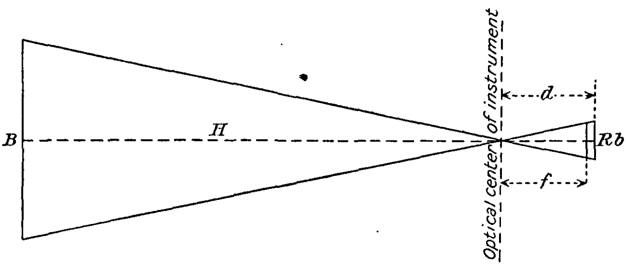


FIGURE 4.—Diagram showing mechanical principle of micrometer attachment for telescopic alidade.

rock cairns. The accuracy attainable with the micrometer for individual readings is from 1 in 100 to 1 in 500, and traverses can be executed with much greater accuracy due to compensating errors.

The formula for micrometer use can be deduced in a manner similar to that for stadia. In figure 4, let

B = base at right angles to line of sight on which readings are to be made.

H = distance of base from the optical center of the instrument.

d = perpendicular distance of plane of micrometer wire from the optical center of instrument (the wire moves in a plane perpendicular to the optical axis).

b = distance wire is moved by one revolution of micrometer.

R = number of revolutions of micrometer to cause wire to move the apparent length of base.

f = principal focal distance.

Then, from the similar triangles, we have

$$Rb : d = B : H, \text{ or } H = \frac{Bd}{Rb} \qquad (1)$$

In formula (1) d varies with H, but from the relation

$$\frac{1}{f} = \frac{1}{H} + \frac{1}{d}$$

we obtain a value

$$d = \frac{fH}{H - f}$$

which may be substituted in formula (1), with the result that we obtain a new formula:

$$H = \frac{Bf}{Rb} + f \qquad (2)$$

in which all the values necessary for a solution for H can be readily determined.

As f is negligible, in comparison with distances usually measured, we may write

$$H=\frac{B}{R}C$$

in which C represents the micrometer constant.

C can be determined by tests on a known base over a carefully measured course, using the formula in the form

$$C=\frac{HR}{B}$$

The direction or bearing of the base must be known, and if it is other than at right angles to the line of sight its effective value practically becomes

$$B'=B \sin a \quad \text{(3)}$$

a being the angle formed between the line of sight and the line of the base. The error introduced in obtaining formula (3) on the assumption of a right triangle is so slight, because of the small angle subtended by the base at the instrument, that it need not be considered in the calculation.

If the base stands at an elevation above or below that of the instrument the formula requires a further correction for difference in elevation.

The effective base then becomes

$$B''=B \sin a \cos V$$

where V is the vertical angle to the base. The general formula then takes the form

$$H=\frac{B \sin a \cos V}{R}C$$

The micrometer may also be used for stadia readings because the micrometer attachment customarily carries three fixed wires, to facilitate readings, besides the movable wire. It is only necessary to determine the point, as may be noted on the graduated drum, at which the fixed wire should stand to give the desired stadia interval between it and one of the fixed wires.

TRANSIT.

A light mountain transit is employed in surveys in Alaska to carry forward the triangulation. The transit further serves for observations of azimuth and latitude. A connecting attachment which receives the leveling screws makes its use possible on the plane-table tripod. The transit has a 4½-inch horizontal circle and an 8-inch telescope and can be read to 30″ of arc, so that the degree of accuracy attainable with it is about 1 in 5,000.

CHAINS.

A 100-foot steel tape is used to measure base lines. Through timber, where stadia traverses are impracticable, distances are measured with a linen tape or cord. This line is usually from 300 to 528 feet long, the length being made to conform with the scale graduations. Braided fish line of about one-tenth inch diameter is excellent material for the "chain." As this mode of obtaining measurements is usually employed over rough and obstructed courses, it becomes necessary to "tie in" such traverses at intervals not greater than 2 or 3 miles, and the tie points also serve as barometer checks.

ANEROID BAROMETER.

The aneroid barometer renders valuable service but must be used with caution. At least two daily checks are necessary besides the initial setting to obtain results reliable within liberal limits of error. The aneroid is doing its normal work if it registers the difference in elevation within 10 per cent. Furthermore, there are a great number of daily and atmospheric irregularities which, if they could be measured, would make the work of compensation too great to be profitable. The 2½-inch pocket barometer is in common use. The user should test his aneroid thoroughly to learn its peculiarities before forming the habit of using magnifying glasses and verniers for readings.

FIELD WORK.

SCALE OF SURVEYS.

The panoramic camera has been employed in surveys on field scales of 1:48,000 and 1:180,000. About 500 square miles have been mapped with it on the larger scale and about 22,000 square miles on the smaller scale. It has therefore been thought best to confine the descriptions largely to the work on the smaller scale and to add, as occasions arise, such notes as may be necessary to explain the differences of practice for the more detailed surveys.

HORIZONTAL CONTROL.

ACCURACY.

In general map control may be divided into two classes—(1) precise control, which places the map accurately in position on the earth's surface and at the same time connects all parts of the map together in a properly related system; and (2) a less precise control, which, though it supplies a practically correct and accurately oriented web of points and distances, does not attempt to determine those positions on the earth's surface with exactitude. Precise control is usually obtained independently of topographic surveys. It is relatively expensive but is necessary where great divisions of the earth are to be mapped or where smaller map units are gradually extended and joined together. Control of the second class is commonly carried along simultaneously with the topographic survey.

The topographic maps of areas in Alaska published by the United States Geological Survey have been primarily intended to supply geologic and other useful information to the American public. The facts that they were indispensable as a base for assembling and clearly presenting that information and that they have high intrinsic value solely as topographic maps require no emphasis, yet it was because of the demand for geologic information that funds became available for the topographic surveys. It will therefore be understood that they were incidental to work of a broader scope. This dependence is neither peculiar to surveys in Alaska nor is it an unusual condition in topographic surveying. Contoured maps are expensive to make. The impetus for carrying them through is almost invariably gained from some convincing need which entails the use of a base map.

It should be kept in mind that systematic surveys in a frontier country will be expensive, that so far as possible immediate demands for useful and reliable data must be met, and that the work should be done with all possible celerity. So, however desirable it might have been to commence a system of triangulation of the first order at the beginning of systematic surveys and to continue it to a measurable extent each year, this could not have been done with the small funds available without crippling the work for which the survey was primarily undertaken. Furthermore, in order that the greatest amount of information should be quickly gathered and that areas of special economic importance should first be mapped it was necessary to carry on detached surveys in widely separated regions, and it has not been possible to determine those regions long enough in advance to establish zones for a triangulation system that would supply usable results within a reasonable time.

From the foregoing remarks it is evident why the less precise type of control has been employed. The simplest methods were used in obtaining this control, and the time spent in the work was only as much as was thought necessary to procure sufficient data. The results obtained have on the whole been entirely satisfactory so long as the surveys, when joined together, have not embraced very extensive areas. As was expected, in recent years, where in some areas greater distances have been spanned, inherent discrepancies have developed, owing to the lack of more refined instrumental triangulation and geodetic adjustment, and these discrepancies had to be adjusted by arbitrary means.

As future surveys will join together still greater stretches of detached and semidetached areas, the need for better control will press apace. During the last several years, however, excellent systems of geodetic control have been supplied along much of the southern coast of Alaska by the United States Coast and Geodetic Survey, along the international boundary by the International Boundary Commission, and in certain regions by the General Land Office.

Extensions from these systems can now be made, with much greater facility than formerly, to cover regions where precise control will soon be urgently needed. With the exception of certain surveys that could be readily controlled by direct connection with one or the other of the two systems mentioned above, topographic surveys in Alaska have been accomplished with the aid of control of the less precise character.

METHOD OF EXPANSION.

The procedure here described is followed in reconnaissance surveys. For larger-scale maps of smaller areas the main difference lies in the length of sights and the greater number of targets built ahead of observation work.

Ground is chosen to obtain a base as long as possible which shall have suitable points disposed to form a quadrilateral. From necessity the base is usually short, half a mile sufficing if natural conditions are favorable for expansion. The ground is staked and measured along the slope with a 100-foot steel tape. Levels are then carried over its length in order that the horizontal distances between stakes may be obtained. Targets are built at the ends of the base line and at every station in the initial quadrilateral. Beyond these stations sights are projected ahead at prominent and suitable mountain peaks. The aim is to obtain a checked distance between two elevated stations several miles apart before dispensing with targets placed ahead of observation. At the outset distances between stations must be selected to conform with the length of base in order to avoid angles which are too acute, and once this has been accomplished the triangulation net may be expanded and the distances between stations increased to 30 or 40 miles.

The ends of the base line and all stations of the initial quadrilateral are occupied with the transit, and the lengths of the sides of the triangles are computed, plane angles being used. Points representing the ends of the base line are plotted upon the plane-table sheet on the field scale to be used.

From these stations lines are also drawn upon the plane-table sheet to serve as checks on the computations and also to assist in establishing a rigid orientation. All other visible future stations are likewise sighted with the alidade. Two main difficulties confront the engineer in this work. First, he must keep in mind the several scattered peaks which he has selected as triangulation points and be able to identify them from different locations, and, second, he must exercise judgment as to the suitability of those points for future occupancy. The first difficulty is minified by the use of the plane table.

The second difficulty may be reduced by including other peaks near those of first choice for use as substitutes or alternatives, provided this is done cautiously, so as not to increase the number to the point of confusion.

In spite of the most careful work errors are liable to creep into the control scheme. In order to detect these errors and to determine their amount, an additional base should be laid out for every 50 or 100 miles surveyed.

LATITUDE.

Observations for latitude are made either by measuring the altitude of the sun at noon or the meridan altitude of a known star, and the transit serves for this work. All observations are made with the telescope direct and inverted. Declinations are taken from the Nautical Almanac. The formula for use in computing the latitude is

$$\varphi = 90° - (h - r - d)$$

in which $h =$ altitude of sun's center or star, $r =$ refraction, $d =$ declination at time of observation.

The method gives only approximate results, yet by repeating the observations results can be obtained which are correct within 1,000 or 2,000 feet. If a series of observations is made throughout the field work a mean can be obtained, which should be used for the map. The results are not reliable enough to check the horizontal control scheme.

AZIMUTH.

Observations for azimuth are also made with the transit upon either the sun or a circumpolar star. Observations upon some star, as Polaris, at elongation give the most reliable results, but because of the long hours of daylight in high latitudes during the summer the stars are not often available. For stellar observations at elongation the formula is

$$\sin \mathrm{A} = \sec \varphi \cos \delta$$

in which $\mathrm{A} =$ angle between star and true north, $\varphi =$ latitude of place, $\delta =$ declination of star; and for convenience it is necessary to determine the local mean time of elongation.

For solar observations it is necessary to know the approximate time. A consistent routine should be followed in morning and afternoon observations in order to eliminate doubt as to which limbs of the sun are being observed. Observations are made primarily to obtain the altitude of the sun for use in the formula

$$\tan \tfrac{1}{2}\mathrm{A} = \frac{\sin (\mathrm{S} - \mathrm{H}) \sin (\mathrm{S} - \varphi)}{\cos \mathrm{S} \cos (\mathrm{S} - \mathrm{P})}$$

in which S = half the sum of P, φ, and H, H = altitude of sun corrected for refraction, φ = latitude, P = sun's polar distance, A = azimuth reckoned from the north.

If solar observations alone are used for orientation they should be made at points whose distances from one another are represented on the map by intervals not greater than 10 or 12 inches.

In determining azimuth the engineer should take care to have the distance between the station and the mark great enough to eliminate errors that might arise from eccentricity of the instrument and should carefully connect the readings with the map. The station selected for an observation of azimuth should either be sighted from another station that has been accurately located or its position should be exactly fixed in the triangulation scheme, and by either method due regard should be given to orientation.

LONGITUDE.

The lunar method for determining longitude is the only one available to the surveyor equipped with the means employed in surveys of the type under consideration, and this method gives results so incommensurate with the time and labor necessary for the observations that it is not commonly used. Therefore observations for longitude are generally made only in regions that have telegraphic communication with some established position. When a position is once established in a region it usually serves for all surveys which can be tied to it.

The Geological Survey has made no telegraphic longitude determinations in Alaska but has utilized several longitude stations determined by the United States Coast and Geodetic Survey, the General Land Office, and the International Boundary Commission.

VERTICAL CONTROL.

METHOD.

In reconnaissance surveys vertical control as well as horizontal control presents difficulties. Where a topographic map of a region remote from any previous hypsometric communication with the sea is to be made the factors for determining the method of vertical control are the expense, time, and degree of accuracy desired. If a possible error as great as 10 per cent is allowable the aneroid barometer will furnish the simplest and easiest beginning. For most purposes a topographic map whose contours all indicate the country to be 10 per cent higher or lower than it really is would be as serviceable as one built upon a correct initial elevation. With present-day facilities in map printing by photolithography the later adjustment to the correct datum would not be a serious difficulty. At some expense of time and funds a set of mercurial barometers may reduce the probable error in datum to 5 per cent. From methods whose cost is nominal and whose probable error is great the step is made abruptly into methods that entail great expense. Two of these methods are available, namely, vertical angulation and spirit leveling; the latter is the most precise method in general use. Unfortunately it is impracticable for initial surveys, such as those made in Alaska, because of the absence of highways or other possible routes for extension. Vertical angulation then remains as the only practicable and dependable method for these surveys.

In the earlier surveys in Alaska, where no connection with sea-level or some previously determined points could be readily obtained, the datum for elevations was determined by mercurial barometers. Some of these determinations served for connected surveys that were carried through several seasons and embraced several thousand square miles of territory. The maps resulting from these surveys were therefore consistent with the initial degree of accuracy, for vertical angulation, which was used to extend the vertical control, introduced very small cumulative errors.

Through the work of the United States Coast and Geodetic Survey, the International Boundary Commission, the Alaskan Engineering Commission, and the General Land Office the precise altitude of a number of stations in Alaska is now known, and many of the later maps of areas in Alaska have been based on these altitudes.

DEGREE OF ACCURACY ATTAINED.

TABLE 5.—*Accuracy of elevations determined with the telescopic alidade.*

Distance between points (miles).	Average number of readings.	Mean variation between computed elevation differences (feet).
3- 5	4	1½
5-10	4	3½
10-15	5	6
15-30	7	21

The average cumulative error in vertical angulation in surveys in Alaska has been estimated at not more than 25 feet in 100 miles. In a recent survey the error in 250 miles is but 60 feet, and as this error was distributed over about 100 stations the average error per station is less than 1 foot.

All the main sources of error in vertical angulation can be eliminated or fairly well determined except those caused by refraction of light. The errors chargeable to other causes may be reduced to almost negligible quantities by careful and consistent manipulation of the instruments. As errors due to refraction may be greatly reduced by employing averages of many angles, readings should be made upon all visible stations and control points from the greatest possible number of stations.

STATION WORK.

USE OF PLANE TABLE AND TELESCOPIC ALIDADE.

When the distance between two points and the true or assumed elevation of one or both of them have been determined the work of the plane table is mainly that of expanding the horizontal and vertical control in order that the photographs may accurately and readily supply all the information they contain. A detailed explanation of the station work with the plane table need not be given here. There are many points, however, in the use of the alidade which in order to obtain the best results require constant watchfulness, and, moreover, these points the inexperienced topographer is liable to neglect by failure to realize their importance. Every possible check upon the work should be obtained as it progresses. Next to the task of keeping track of the almost numberless lines on the sheet the hardest is to locate the stations with uniform accuracy. The frosted celluloid is here of very great value, for by its use the adjustment of the position of a station may be postponed until the weather is more favorable or until additional control has been procured. The number of lines which must be drawn upon the plane-table sheet from stations is very much reduced by the use of the photographic method. It is a simple matter to retain in mind or to describe two or three dozen objects sighted. It is not necessary, therefore, to locate the station on the map before the lines are drawn, but they may be kept on the transparent celluloid until the topographer is ready to transfer them to the map. In this manner stations which at the time they are occupied can not be definitely located on the map are merely held for additional observations. Plane-table work should be done with all possible skill, for a failure to use every means of refinement available reduces by so much the chance of keeping the errors in the negligible class.

SELECTION OF STATIONS.

The most difficult feature of the field work lies in the selection of stations. The necessary number of stations and no more should be chosen for the camera, in order that progress in the field work may be as rapid as possible. If the dependable reach of the photographs is known the task is to find the favorably situated peaks from which the greatest proportion of the surrounding topographic features can be seen. Experience has shown that if all the stations could be located on commanding peaks all the data necessary in the photographs could be obtained by selecting peaks from 8 to 10 miles apart. Unfortunately the most prominent peaks are not so regularly placed, and many of them can not be ascended without special equipment for mountain climbing and an unwarrantable expenditure of time. As the topographer is thus forced to take less favorable positions, he must keep track of those parts of the country which the camera has not photographed and must obtain the additional views at other stations. This feature will not only require continual watchfulness but there will be a corresponding reduction in the rate of progress on the map owing to the reduced efficiency in the stations. Ordinarily three inferior stations will be required to supply the data that can be obtained at one first-class summit. Where it is reasonable to assume that a more favorable peak can be climbed, the desirability of occupying it should be considered in the light of the time and energy necessary to occupy the three less favorable stations.

In order to estimate the influence which the relative elevation and isolation of the station have upon its value for the work a number of photographs taken from different elevations have been examined to determine the amount of information they supplied for constructing contours. The specimens were selected from reconnaissance surveys, and estimates were made for percentages of a unit of area whose radius was 5 miles. The results are shown in the following table:

TABLE 6.—*Relative value of stations.*

Station No.	Relative elevation of station.	Average distance of higher portions of area (miles).	Percentage of area higher than station.	Percentage of area shown in photographs.	Percentage of crests visible.
1	Highest point		0	50	95
2	.....do		0	60	100
3	.....do		0	75	98
4	At mean of relief	4	40	60	70
5	.....do	3	20	40	30
6	At three-fourths of relief	2	10	42	50

The result of the examination is decidedly in favor of the highest peaks and most isolated points as against a greater number of points of smaller visual range. Under ideal conditions where stations a few hundred feet higher than any other points in the circle could be chosen the rate of daily progress would be about 200 square miles. The difference between this figure and the progress that has actually been made suggests that the selection of stations deserves all the attention the topographer can give to it. Difficulties met in traveling have a marked influence upon the rate of progress of topographic surveys, however, so that the disparity between possible and actual results can not be entirely eliminated by selection of more favorable stations.

In the examination whose results are given in Table 6, station 1 was situated at the edge of an intricate mountain mass, so that it embraced a wide valley on one side and many ridges and spurs on the other. It was isolated with respect to nearly one-half the area. The area shown in the photographs is small, but as most of the crests are visible the station should be rated as well selected. Station 2 was surrounded by less complex topographic forms, so that though the ratios indicate more efficient photographs than those obtained at station 1, the actual number of points supplied by them was considerably less. Station 3 was well isolated and surrounded by country of simple topography. The high value of the photographs taken at station 4 is due to the isolation of the station. The photographs taken from stations 5 and 6 have only between one-third and one-half the value of those taken at more favorable locations.

USE OF CAMERA.

MANIPULATION.

The manipulation of the camera at the stations is simple. At most stations it is necessary to shift the camera to one or two near-by positions in order best to photograph the country. When the camera is moved to near-by points the directions and distances from the station to the substations are noted. As a rough guide to the photographs the general direction of the view must be known. Some known point mentioned as "near center," or "20° from left edge" adequately indicates the relation of the negative to the map. The camera is equipped with guide lines on top which include a scope of 120°. A mental note is made of distant objects in range with each of these lines for the camera's position during the first exposure. For the second exposure the camera is turned to embrace the field where the first left off. For the third exposure, a test sight should also be made as a check to see whether the field of the third view joins that of the first. A compass may be used to turn off the angles between exposures, but it should be checked by the open-sight process.

The wind guys should always be used when the wind is 5 or 6 miles an hour or more. Mountain tops are at all times subject to puffs of wind. The shortest time of revolution of the lens is several seconds and as the camera must be kept as stable as possible throughout the exposure, all precautions to that end should be taken.

Films should be put in and taken from the camera at the stations, for if a roll is left unsealed long it will absorb enough moisture to injure the emulsion. This precaution is especially necessary if the exposed films are to be held several weeks for development or if they are to be resealed in the water-tight cans. The exposed films should be repacked in the cans to protect them, and this can not be done with safety unless the films are kept dry.

DETERMINATIONS OF DURATION OF EXPOSURE.

The most interesting part of the field work is to be found in the search for the proper duration of exposure. Different conditions of the weather, which cause unequal lighting, and a great range of subject in both kind and distance present exceedingly difficult obstacles to the attainment of uniform efficiency in negatives. Smoke is a serious impediment to topographic surveying. Its presence in quantities may check phototopographic work entirely, and it always curtails the effective range of the camera. Its effect is perhaps even more serious on phototopographic work than on the ordinary telescopic plane-table work. In general, when the atmosphere is smoky the camera can not be relied upon for distances greater than one-third the range of the unaided eye. In other words, if the atmosphere is smoky and topographic forms stand out unmistakably to the natural vision at a distance of 10 miles from the station the camera will not likely reach more than 3 or 4 miles. In many regions a more or less smoky atmosphere is common, and the less frequent clearer days should be utilized to obtain a fair number of longer-range negatives. With present-day facilities it is very difficult to give to a single negative the proper exposure to obtain clear images both of details along near and dark slopes and of peaks 15 to 30 miles away. On the brilliant days duplicates should invariably be taken, with a light equivalent for the distant country about one-fourth that for the nearer. Films are so easily transported and the panoramic camera requires so little time to operate that whenever doubt is felt as to the result duplication should be the rule. One of the most advantageous features of the panoramic camera is that it permits an elimination of uncertainty in exposure because it can be operated rapidly and photographs covering the whole range of aperture may be taken in a very few minutes.

Attention should be directed to the great difference in the amount of light reflected from bare areas and from heavily wooded country. Dense timber absorbs much more light, so that the exposure for timbered areas should be about eight times as long as that for the higher levels. In passing from bare mountains to timbered valleys the photographer is likely to err in not making sufficient allowance for the increased absorption. Furthermore, the atmosphere in valleys is less clear and more disturbed than that at the tops of the mountains. This condition gives rise to much interference of the light rays entering the lens; details are lost by the increased haze, and inferior negatives result. In general, the higher the position of the camera, the better is the atmosphere for photography. Exposures should not be made from the floor of a valley or plain when these positions can be avoided. Even a slight knoll will raise the lens above much of the unfavorable atmosphere, and the higher the knoll the better will be the results. This rule holds true upward to the highest peaks. The photographer should keep in mind these general rules in order that he may be able to judge fairly well by the eye what the range of his camera will be when he occupies stations in different types of country and under different atmospheric conditions.

In determining the most favorable weather for photographic surveying it must be borne in mind that the lens is to be directed toward every point of the compass, so that a condition which might be best for a view in one direction will most likely be poorly suitable for the landscape in the opposite direction. A typical condition is that where a slanting sun casts shadows that accentuate slopes and gulches. The surveyor can neither choose the time for exposure nor move his camera to catch the best lighting. Except within very narrow limits, wherever the sunshade permits, he must take photographs at all hours of the day, regardless of the position of the sun. That condition which is nearest uniform over the country to be photographed is in general the most favorable.

The following schedule for classifying conditions of lighting has been found very practical:

	Value.
Fair; no clouds or a few detached clouds; sun high	1
Fair; in the direction of the sun when the sun is low	2
Many detached clouds (requires two exposures)	1–4
Cloudy; landscape completely shadowed by thin clouds	2
Cloudy; landscape completely shadowed by thick clouds	4
Stormy; rain and mist over portions of landscape	4–8

The first of these conditions is, until middle afternoon, the most favorable for landscape photography. By late afternoon, because of the greater radiation from the earth, the haze becomes too great for the best work at long range, and very late in the afternoon the sun will destroy images in its direction. Frequently in the higher latitudes an excellent condition for photography exists immediately after sundown, when the shadows have disappeared and the light has become more uniformly diffused. The presunrise glow offers the same advantages. The exposures at these times should be about the same as for the lighting just before sunset or after sunrise.

The next most favorable condition is that when a high stratum of clouds completely overcasts the country. If the atmosphere is then free of smoke the camera's range is practically as great as during fair weather. If the clouds are gray there may be some difficulty in distinguishing very distant snow-capped peaks.

Detached clouds cause local difficulties by casting shadows that appear like hillocks on the photographs. These shadows can usually be detected by comparison with companion views obtained on other days. The difficulty may be further lessened by taking duplicate exposures after sufficient time has elapsed to allow the clouds to shift their position. If detached clouds are numerous, exposures should be made both for the shadows and for the sunlit areas. Exposures made under this condition give negatives of irregular range, yet little difficulty is experienced in their use for a range of 5 or 6 miles or less. Beyond that distance some portions will be clear, but others will be too uncertain to furnish accurate information.

During stormy weather the camera work is hampered to a serious degree. Rain and mist even in very slight quantities form impenetrable screens to photography. The only recourse is to duplicate the exposures by watching for chances between showers. Allowance should be made for a greatly reduced range.

The following table showing records of exposures is inserted as a guide in the use of calculators or meters:

TABLE 7.—*Records of exposures in latitude 62° N.*

Date.	Elevation (feet).	Hour.	Weather.	Subject.	Direction.	Stop.	Time (seconds).	Remarks.
June 20	6,000	11 a. m..	Fair.....	Dark mountains with much snow.	Southwest.	F 8	1/5	Screen with factor 32.
20	6,000	11 a. m..	..do.....	.....do...........	North.....	F 11	1/5	Do.
July 10	5,700	6 p. m...	...do.....	.....do...........	East......	F 6.3	1/6	Do.
Aug. 15	5,700	3 p. m...	...do.....	Dark mountains.	North.....	F 6.3	1/5	Do.
18	6,200	2 p. m...	...do.....	Dark mountains with much snow.	South.....	F 8	1/5	Do.
Sept. 13	5,400	4 p. m...	...do.....	Dark mountains.	East......	F 6.3	1/2	Do.
15	1,000	10 a. m..	Densely cloudy.	Dark valley slopes	....	F 6.3	1	Do.
22	At sea level.	9 a. m...	Fair.....	Partly timbered dark slopes.	Northwest	F 6.3	1/7	Do.
Oct. 5	...do.....	2 p. m...	Densely cloudy.	Mountain tops powdered with snow.	South.....	F 6.3	1/2	Do.
5	...do.....	2 p. m...	...do.....	Dark timbered slopes.	...do.......	F 6.3	2	Do.
1	3,000	5 p. m...	...do.....	Timbered slopes and valley.	...do	F 6.3	1	No screen.
1	3,000	5 p. m...	...do.....	Snow - covered mountain tops.	...do.......	F 8	1/5	Do.

AUXILIARY CAMERAS.

Surveys with the panoramic camera are greatly facilitated by the employment of one or two auxiliary cameras, especially if a route must be rapidly traversed and as great a scope of country mapped as possible, which is a common condition in reconnaissance surveys. Panoramic photographs have a greater value here than those of all other types in that they show readily and accurately the position from which they are taken. As a check telescopic readings are made upon as many of these subsidiary camera stations as can be obtained. The practice as pursued in Alaska has been to employ two cameras in the topographic party. The photographer then makes daily trips on one side of the course traveled and the engineer and assistant work on the other side. The two cameras should commonly occupy stations from 5 to 10 miles apart in order to cover the maximum area, though they remain near enough together to close up the stretches between. The width of country which can thus be embraced in the map is nearly double that which the engineer alone could cover. A third camera would considerably increase the daily area, though not quite in the same ratio, except in regions of unusually favorable topography.

The photographer is equipped with a camera and all the necessary detached parts, a tripod, a 12-inch plane-table board, a 10-inch open-sight alidade, a compass, an aneroid barometer, and a notebook. He travels alone and carries a pack which weighs about 30 pounds. Besides taking the usual number of photographs at his stations he takes half a dozen or more sights at other stations and prominent peaks, on frosted celluloid with the open-sight alidade on the small board. The barometric elevation is also recorded, and when he doubts that the photographs will show the shape of the mountain occupied he sketches a few contours close about it. Lastly, he should indicate briefly those portions of the area within a radius of 10 miles which the photographs cover. The sights taken at his stations, though not essential in establishing the positions of the stations on the map, have immediate value in indicating where the topographer should look for those stations and in the selection of future stations. The sketches of the country photographed from the stations help the topographer in choosing stations for succeeding days. The degree of success which the photographer attains with his work depends on his aptitude as a mountaineer, topographic sense, hardiness, and ability to retain a correct mental picture of the country he sees. Experience in topographic surveying tends to develop all these qualities, and therefore such training, though not essential, is helpful to the photographer. Likewise, familiarity with cameras aids to a considerable degree, yet the manipulation of the panoramic camera can be readily acquired by all who have a proper appreciation of the accuracy demanded in surveying instruments.

By alternating from side to side the topographer can keep track of the photographer's stations and the scope of his photographs and thus determine the progress of the work. Consultations over the progress sketch will then clear up the doubtful spaces.

The following records of a photographer's work on four consecutive days indicate in another way the nature of his task. The records are typical.

July 25.—On this day camp was moved 8 miles. Left morning camp at 6.30 a. m.; arrived at evening camp at 5.45 p. m.; distance traveled 14 miles. Altitude climbed during the day, 3,500 feet. Number of stations occupied, 2. Time spent on stations, 3 hours Number of photographs taken, 12. Sights taken to 15 points; slight sketches.

July 26.—Time between camps, 13 hours. Distance traveled, 11 miles. Altitude climbed, 2,700 feet. One station occupied. Time of occupation, 5 hours (delayed for weather to improve). Four photographs taken. Thirteen sights and sketch. Camp moved 6 miles.

July 27.—Camp not moved. Left camp at 4 o'clock a. m. and returned after 6 p. m. Distance traveled, 10 miles. Climbed over 6,000 feet and occupied 4 stations. Sixteen exposures but no sights. Time on stations, 3 hours and 40 minutes.

July 28.—Camp moved 9 miles. Time between camps, 10 hours. Distance traveled, 15 miles. Altitude climbed, 4,000 feet. One station and 2 substations occupied. Eight exposures. Time on stations, 2½ hours (delayed by wind). Eight sights and sketch.

DEVELOPMENT OF FILMS IN THE FIELD.

As soon as possible after field operations have been started a few films should be developed to ascertain the results that are being obtained in the negatives. A fair-sized tent should be available for the work of development, and in high latitudes this tent should be heated, in order that the development may be carried on satisfactorily during stormy weather, when regular work at stations is interrupted. The writer has used the camp's cook tent, size 10 by 12 feet, which was satisfactory for developing a small number of films at a time, but in order to develop a large number of films a tent should be provided for that purpose. Whether the extra tent is to be taken should depend on the means of transportation and the length of time which would elapse before the exposed films could be got to headquarters for development. Fresh films can be kept several months after exposure without noticeable deterioration, provided they have been kept dry.

The strength of the developing solution and its temperature should be accurately known when the film is developed in order that the development may be properly timed. The temperature of the solution should preferably be near 65° F. and never above 70°. After development the film is rinsed in cold water eight or ten times before removing it from the tank. All water used for solutions, rinsing, and bathing should be clear and free from matter in suspension.

Until the film has been passed through the fixing bath it will be affected by light. However, the effect of subdued daylight upon the film during the change from the developing tank to the fixing bath is so slight, when the operation is done quickly, that it may be safely accomplished outside a dark room. Negatives which have thus been changed in a white tent on cloudy days have not been noticeably affected. While in the fixing bath the films should be shaded or covered until the fixing solution has begun to act. They may then be drawn through the bath by raising and lowering while being held at the ends. This process will insure uniform action of the fixer.

It is highly important for the films to be thoroughly washed after fixing. This can be readily and effectively done by stretching them horizontally in pool of a stream where there is little current. In putting the films in the pool and removing them care should be taken not to stir up the sediment in the bottom of the pool or in the stream above it. The films should remain in the water half an hour. If they are washed in basins the water should be changed four or five times and the films allowed to remain immersed for an hour or more.

The films are hung up to dry by clips and anchored to the floor from the lower end. The temperature of the tent should not be allowed to go above 80° F. while the films are drying. Noncurling films will twist and curl while they are drying but will flatten out when completely dry.

When dry the developed films are labeled according to roll and exposure number and then cut. They should be packed flat. In order that intelligent judgment may be passed upon the resulting negatives, some skill must be attained in appraising their quality. The negatives are examined for density, definition, and clearness in details. If possible, a sample negative embracing a broad landscape should be kept for comparison. This should be one from which the clearest possible prints have been obtained. Notes are made for guidance in making future exposures.

TRAVERSES.

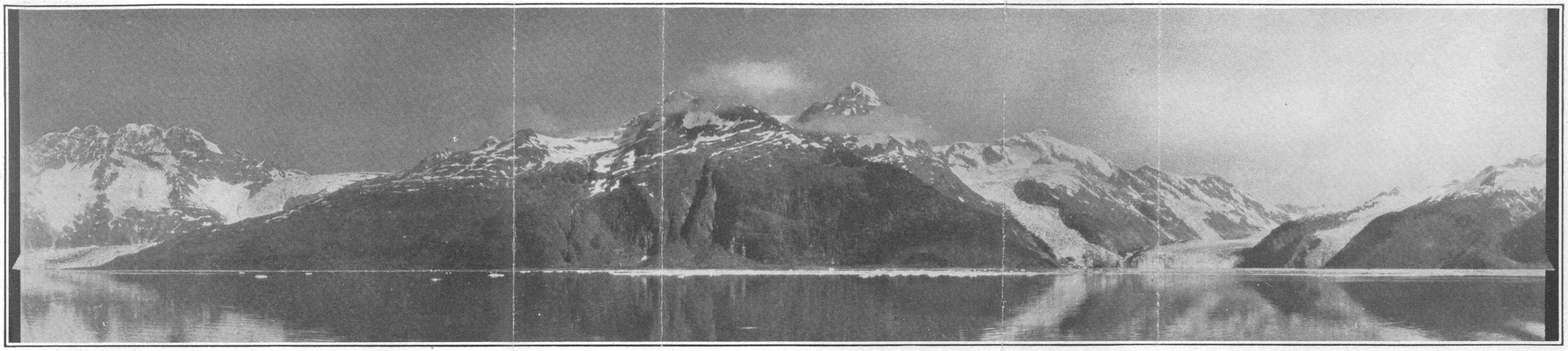
Roads, railroads, and trails have not been built over any great extent of Alaska, and hence in the reconnaissance surveys the time necessary to make traverses of these features is very slight. The few traverses necessary can be executed without instruments in addition to the regular equipment. In the more detailed surveys, however, roads, trails, and many of the stream courses require traverses of some character in order that they may be placed upon the map with accuracy. The camera can seldom photograph more than portions here and there of such features, although localities where trails zigzag up a slope afford unmistakable subjects for its work. The camera is relied upon to locate and furnish the elevations of a sufficient number of points to control the traverses.

The method of executing the traverses depends on the character of the feature to be traversed, the relief, and the degree of accuracy desired. Under favorable conditions, such as are found in traversing a railroad or a good road, the best results can be obtained by stadia or micrometer, the elevations being carried along by vertical angles. In a rough country over trails or poor roads and along small streams another method is usually employed, which is more practicable, permits greater speed, and, if properly controlled, gives results of a refinement commensurate with the ruggedness of the country. Distances are obtained by a line (cord or linen tape) and the aneroid supplies the elevations. The work of the magnetic needle and tape in these traverses is commonly much more satisfactory than that of the aneroid. This instrument is liable to eccentric errors, which necessitate a continuous watchfulness in its use. The smaller tripod and board here supplement the larger instruments. For brush work a board about 7 inches square, or no larger than is necessary to contain the work of one day, is advantageous.

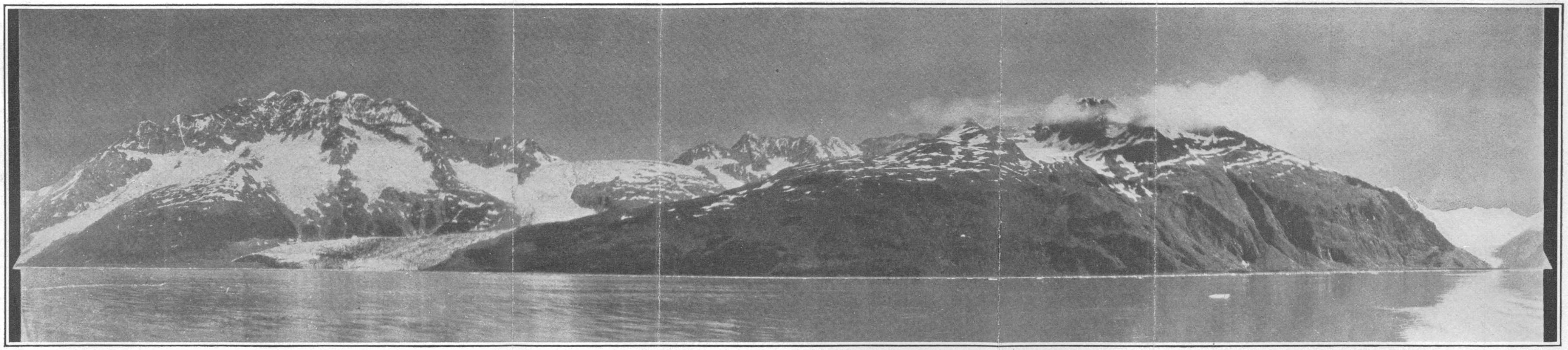
The extent of traverses is shown by the red lines on the Port Valdez map (Pl. I, in pocket).

USE OF PANORAMIC CAMERAS ABOARD SHIP.

The field season of 1916 afforded an opportunity to use the panoramic cameras aboard a launch in the sheltered fiords of Prince William Sound, Alaska. The mountains there rise rather abruptly from the water's edge, and their tops reach elevations ranging from 2,000 to 10,000 feet. The conditions were, therefore, unusually favorable for this work. A 40-foot gasoline launch was used for the cruises and two cameras were mounted on a stand with gimbal rings (Pl. V, *A*, p. 32). The stand was made of wood and stood about 3 feet high. The gimbal rings were made of cast brass and the bearings were wedge-shaped. A brass tube 2 feet long was suspended from the center of the inner ring to support a stabilizing weight. In order to reduce the sensitiveness of the gimbals it was found desirable to attach four stiff coil springs to the lower end of the tube and stretch them to the legs of the stand. Three short brass posts formed a support for a circular top plate which could be rotated in any desired direction. The circular plate was made of 1-inch pine boards, and a slotted brass ring plate was screwed to its under side to receive the heads of the posts. At the rim of the circular plate and spaced 120° apart were fastened two upright wooden posts having brass plates on top similar to tripod heads. To these plates were screwed triangular adapters, and the leveling screws of the cameras rested in the adapters as when mounted on tripods. A bag of shot about equal to the weight of one camera was placed on top of the circular plate to counterbalance the weight of the cameras. The cameras were adjusted in position so that when exposures were made a few degrees of the horizon were included in both negatives. The cameras were loaded and made ready for exposure before mounting. After they were mounted in the adjusted positions the engine was shut off, and they were leveled as carefully as the oscillations of the boat permitted. Exposures were then made at the moment when the movement of the boat seemed least. At the time of exposure all men aboard remained still and in selected positions, and the boat was kept on a given course. The maximum speed of the boat was 6 knots, and at the time of exposure this was usually reduced to about 2 or 3 knots.



A.



B.

PHOTOGRAPHS TAKEN ABOARD LAUNCH FOR USE IN TOPOGRAPHIC MAPPING OF COUNTRY ADJACENT TO SHORE.

The scale of 1:90,000 was used in the field for plotting the control stations and adjusting the traverses of the survey, but in the office compilation the map was drawn on the scale of 1:180,000, with 200-foot contours. The survey covered about 2,000 square miles of territory and included 562 miles of stadia, micrometer, and tape traverses. The launch was run about 220 miles, and 220 pairs of photographs were taken during the cruises. The time spent in running was 58 hours. Furthermore, in order to expand the triangulation system from the points supplied by the United States Coast and Geodetic Survey, 42 plane-table stations and, in addition, 62 camera stations on land were occupied. These stations supplied a sufficient number of secondary points to establish the positions of the boat at the moments of exposure. These positions were determined by the use of transparent celluloid sheets, as described under the heading "Station work" (p. 41). The negatives resulting from the exposures aboard the launch were on the whole very satisfactory, but could have been improved by the use of a larger boat, which would not have been so greatly affected by swells.

The photographs reproduced in Plates VI and VII were taken from the moving launch and are part of a series that covers a certain landscape. As the horizon line (in these views the shore line) is slightly curved, measurements for altitude were made from the shore line immediately under the points sought instead of from a horizon indicated at the edges of the photographs. In general these measurements are reliable when the definition of the image is good.

There are three sources of error incidental to the use of the panoramic cameras aboard ship, which are thus classified:

(1) Errors due to the forward movement of the boat at the time of exposure. The time required for exposures is about 5 seconds. The speed of the boat should therefore be reduced according to the scale employed for the map, so that the amount of displacement of the boat during exposure will not affect the graphic plotting of positions. If the scale is a mile to the inch, 25 feet may be assumed as the limit for this error. For this scale, therefore, the speed of the boat should not be allowed to go much beyond 3 miles an hour.

(2) Errors due to the ship swinging off course. To obtain accuracy in graphic plotting by the use of photographs on the scale mentioned it will be necessary to keep the course of the vessel within 5′ of arc in order to use points that are as far as 10 miles from the camera. For less distances the limit may be increased in proportion. Except when the beam wind is blowing, little difficulty will be experienced in fulfilling this requirement.

(3) Errors due to the oscillations of the boat. These errors are the most serious, and their amount will depend on the altitudes of

points and their distances from the cameras. As shown in figure 5, where a = half the angle of oscillation, x = the amount of displacement of the image of the point due to oscillation, v = the vertical distance of the point above the horizon, f = the focal length of the photograph, d = the map distance from the camera to the point, and e = the allowable error at the distance d, we shall have

$$x = v \tan a$$

and from the similar triangles the proportion

$$f : v \tan a = d : e$$

whence

$$\tan a = \frac{fe}{vd} \qquad (1)$$

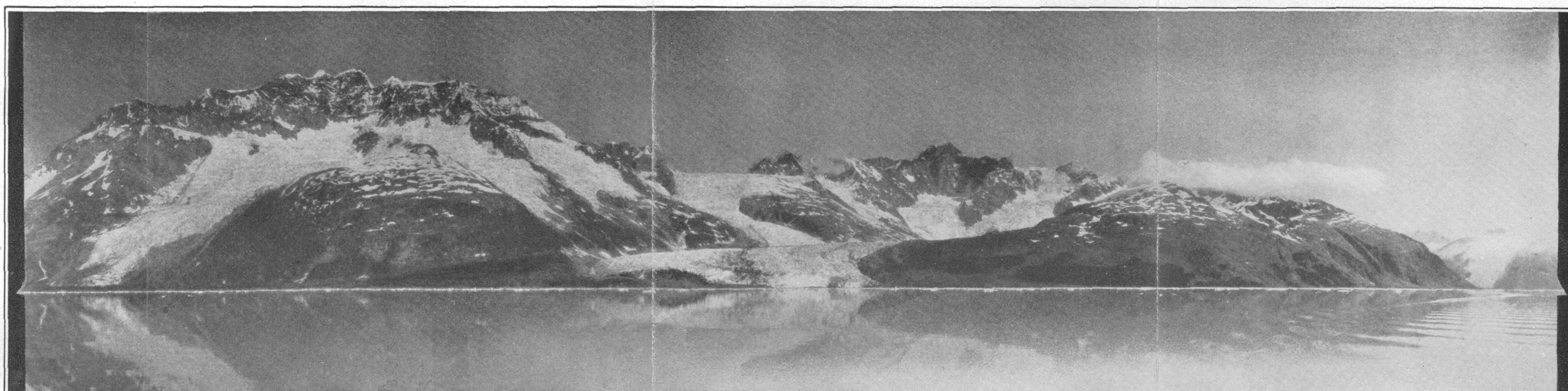
As an extreme example, a point 10,000 feet high, which appears in one of the views shown in Plate VII, will serve to determine the angular value allowable for oscillation of the boat when the scale is a mile to the inch. The image of this point, which is the highest in the area photographed from the boat, is 1.42 inches above the horizon. The photographs used have an average focal length of 5.3 inches. Therefore, if v is 1.42 inches d will be approximately 7.25 inches (the point is 7.25 miles from the camera). The limit of error that would be allowable in the radial line from the camera to the point is 0.005 inch. Applying these values to equation (1), we have

$$\tan a = \frac{5.3 \times 0.005}{1.42 \times 7.25} \text{ and } a = 9' \text{ (approximately).}$$

Therefore the maximum angle which is allowable for oscillation of the boat, when the scale is to be a mile to the inch, may be taken as approximately 18′ of arc. The level bubbles used on the cameras should be graduated far enough each side of the center to indicate when this limit is reached.

The photographs obtained from a boat in the manner described have certain advantages and limitations. By the use of the cameras aboard a boat it is possible to obtain photographs from positions which otherwise could not be utilized. Along much of a bold coast line, such as is typical in certain parts of Alaska, these photographs will be adequate, with the necessary control and traverses, to complete the topographic survey of a considerable strip of land adjacent to the shore. Often, however, in order to obtain all the information necessary to complete the survey, it will be necessary to supplement the marine photographs with others taken from summits. However, the number of stations that must be made on land will be few, and they can be definitely determined at the time of the cruises in order

A.



B.

PHOTOGRAPHS TAKEN ABOARD LAUNCH FOR USE IN TOPOGRAPHIC MAPPING OF COUNTRY ADJACENT TO SHORE.

to be most useful. By utilizing to the fullest possible extent the small number of fair days in those regions of the coast where misty and rainy weather prevails the method promises to be particularly valuable. In the field work of 1916 about 40 per cent of the weather was unsuitable for either station work or photography, but the delay on account of weather was negligible, for the station and photographic work was kept well ahead of the traverses, and these were run in almost all kinds of weather. It is probable that in similar surveys the method will allow the field work to progress unhampered during seasons when unfavorable weather runs as high as 60 per cent.

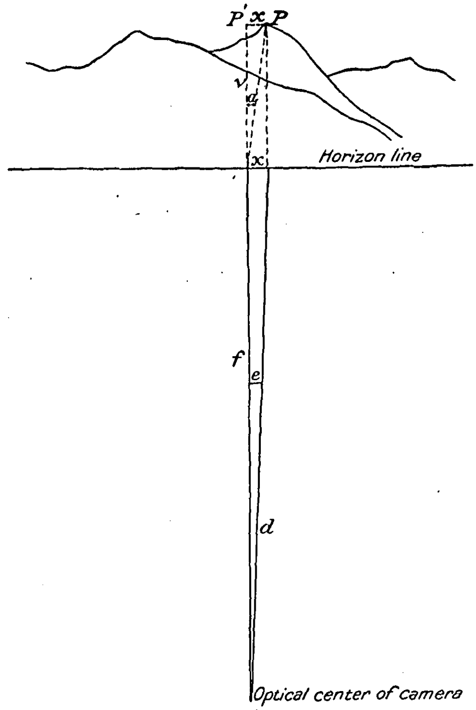


FIGURE 5.—Limit of oscillation of boat carrying panoramic cameras during exposure of the films.

The range of the photographs taken aboard ship is not so great as that of photographs taken inland, for the reason that the oscillation of the boat will prevent sharp definition in images of very distant points. However, if the defects due to the ship's motion, as stated above, are reduced as suggested, there should be little difficulty in using points 12 to 15 miles away.

OFFICE INSTRUMENTS.

PANORAMIC PHOTO-ALIDADE.

If the straight line AB in figure 6 represents the rectified arc RR′ of a circle which subtends the angle X, then any part of AB, as AP, will, if measured along the arc, subtend an angle B, which may be thus expressed:

$$B=\frac{AP}{AB}X$$

If, therefore, the point P in traveling from A to B can be made to rotate a radial arm about O through the angle x, the arm will indicate the direction from O to any point on AB at which P may stand. Now, AB may be considered as representing the horizon line of a photograph obtained with a panoramic camera and ROR′ a horizontal section of the camera containing the optical axis. Then, if the photographs were all of the length AB, a simple mechanism which maintained the relation indicated would supply the direction of any point of a photograph with reference to some other point of the photograph. As a matter of fact, although photographic paper prints made from the same negative run closely to a common size, there is a slight variation. Furthermore, such a mechanism should be suitable in both damp and dry weather, not only for prints made from numerous negatives obtained in a single camera but for those of several cameras equipped with lenses of slightly different focal length.

To meet these conditions the device must be adjustable. If, therefore, in figure 6, the photograph has a length AB′ greater than

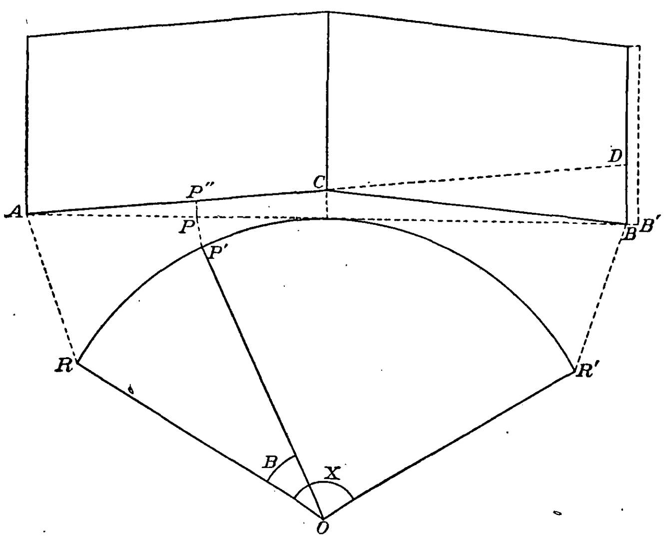
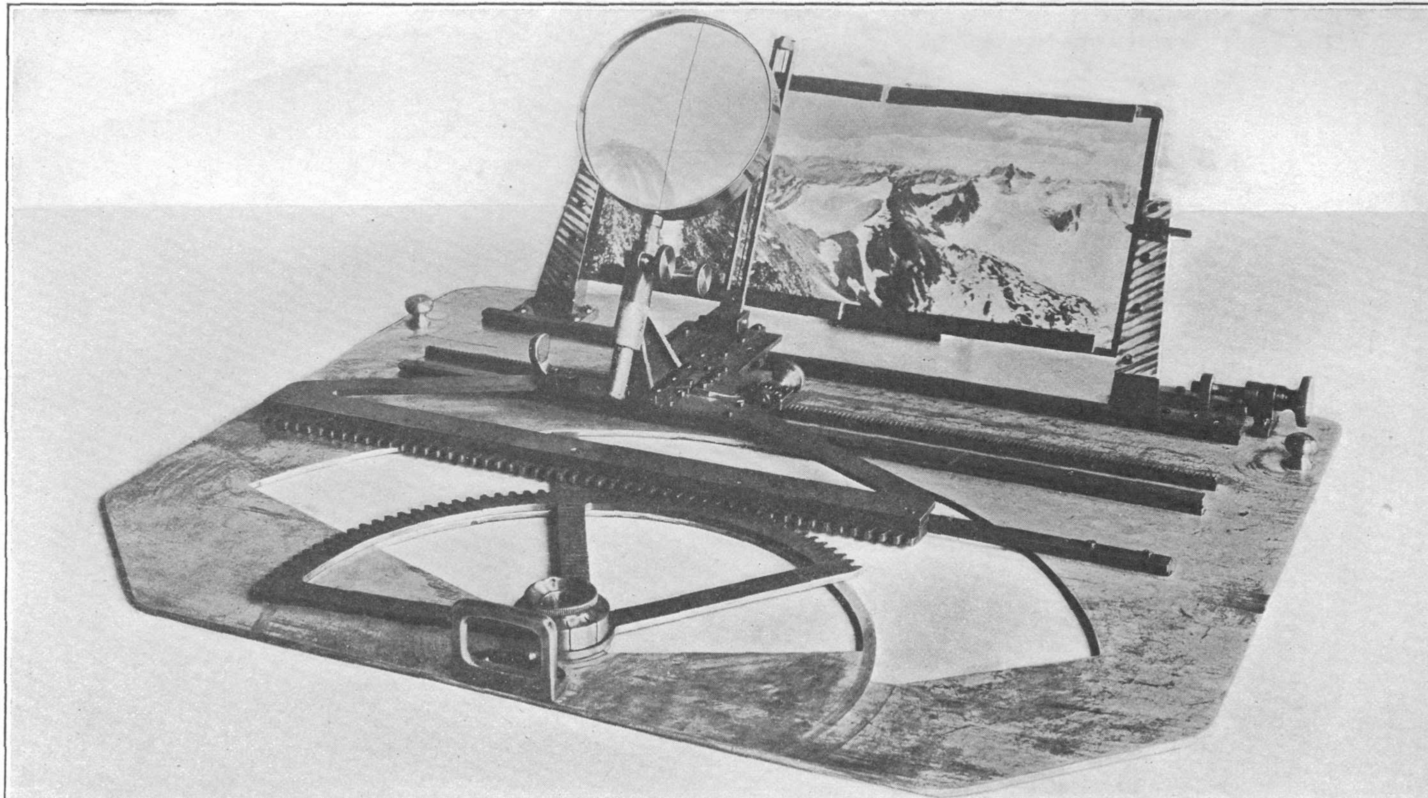


FIGURE 6.—Principles of the panoramic photo-alidade.

AB, the instrument may be "broken" at the middle, so that in hinging on the axis passing through that point the end B′ can be made to fall at B, and the triangle ACB thus formed will be an isosceles triangle. The effective length of the photograph will now equal the arc RR′, and if, as the point P moves along AB, perpendiculars to AB are drawn from P to intercept the broken line ACB, as PP″, the radial arm OP′ will indicate the direction of the point P″ from O. This relation may be shown as follows:

AC is prolonged to meet at D the perpendicular to AB erected at B. Then CD = CB and the two similar triangles AP″P and ADB give the relation

$$AP : AP'' = AB : AD \ (AD = AC + CB)$$



PANORAMIC PHOTO-ALIDADE.

Plate VIII shows the instrument that was devised on the principles explained above to obtain upon the map sheet directions of points contained in panoramic photographs. In order to impart the rotary motion to the radial arm, the circle to which the arm is fastened has teeth which engage with a movable straight-line rack. The rack is moved distances equal to the spaces between points on the photographs, and the arm attached to the gear wheel is rotated through the angles which those spaces represent. The photographs are contact prints, not enlargements, but they vary a little in length and width. Furthermore, the lenses differ slightly in equivalent focal length. In order to take care of this range in sizes of prints, the gear wheel is cut with a radius a fraction of an inch less than the focal length of the shortest prints, and the frame, which hinges at the middle, can be "broken" by means of the screw at the extreme right of the instrument, so as to cause the ends of the photograph to rest at a distance apart which will give the camera's fixed angular scope (approximately 126°). The line of sight is at right angles with the line of the rack and the horizon line, so the two last-mentioned lines are parallel. The gear wheel revolves around a point which represents both the optical center of the lens and the camera station. A centering device is arranged so that this point can be placed over the position of the station on the map. Furthermore, in order that the photograph may stand in a position convenient for sighting, the frame which holds it is inclined at an angle of 30° to the vertical.

ROTARY SCALE.

The instrument that has been constructed to expedite the measurement of distances of points above or below the horizon line on the photographs is shown in Plate IX. It consists of a movable traveler which carries a taut wire stretched at right angles to the direction of movement. At one end of the traveler is placed a rotary dial, which is geared to a rack attached to the traveler. Movements of the traveler are registered on the dial. The dial is graduated to hundredths of an inch and can be read approximately to five-hundredths of an inch. A base plate is provided in order that the frame which carries the mechanism may be clamped to it so as to hold the photograph in place. The dial is revolved until it registers zero; then the photograph is inserted and the wire placed along the horizon line. The clamp is thrown on and readings are noted. The factors obtained by use of this instrument are employed along with the corresponding map distances to obtain differences of elevation.

ELEVATION COMPUTER.

Figure 7 shows the device employed to determine differences in elevation between points on the map. The principle of this device is that the series of triangles formed in the camera are similar to the corresponding series existing in space at the station. In the camera the focal length of the lens is homologous to the horizontal distance from the station to the point, and the distance that the image of the point lies from the horizon line is homologous to the difference in elevation between the station and the point. Whence comes the formula

$$\text{Difference in elevation} = \frac{VD}{F}$$

in which V is the quantity obtained from the photograph, D the map distance, and F the focus for the photograph. The apparatus, therefore, has two horizontal scales, which are laid on a single line

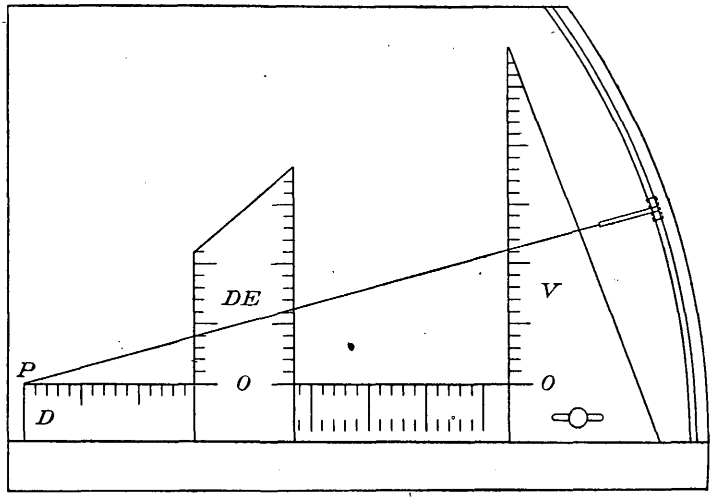
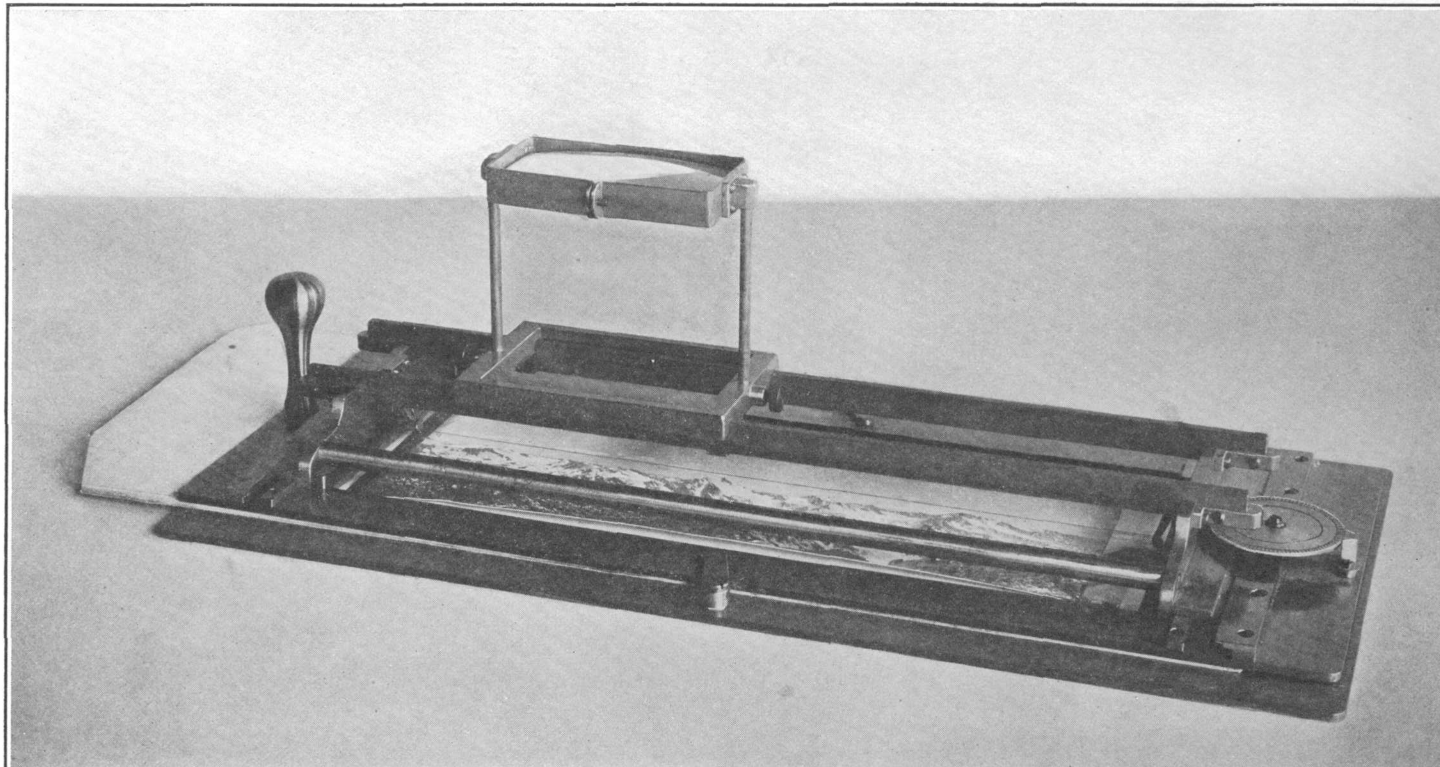


FIGURE 7.—Elevation computer.

in the plane of the horizon, and two vertical scales, which are laid at right angles to this line. The pivot point P represents the station and the optical center of the photograph. The vertical scale marked V represents the photograph, and the other vertical scale represents the point whose elevation is sought. The distance from the pivot point to the scale marked V is taken as equal to the focal length of the photograph, or some multiple of it, and the scale V is graduated to correspond with this relation. The scale D is assumed as a convenient quantity, and the scale DE is made to correspond with it. The vertical scales read zero at the horizon line. The thread is set at the quantity V on the scale V, the scale DE is brought to the point on the scale D which reads the distance as scaled from the map; and then the difference in elevation is read



ROTARY SCALE.

from the scale DE. If the focal distance and the scale V are doubled and the two remaining scales are 1:48,000, the differences in elevation can be read to 10 or 15 feet, and the proportions will require a board about 14 by 18 inches.

LOGARITHMIC PLOTTER.

A logarithmic plotter, which is to be constructed, has been designed in order to obtain an instrument which will furnish the elevation as well as the location of any point common to two panoramic photographs, which can be set up together in proper relation to each other and to the map. The instrument involves the use of four logarithmic spirals, which are arranged in pairs, and each pair of spirals will serve to register upon graduated drums the difference of elevation between the stations and the point; a traveling pencil will indicate the position of the point. The work which will thus be done is the solution of the equation

$$\text{Difference in elevation} = \frac{VD}{F}$$

as explained under the heading "Elevation computer" (p. 56). It is furthermore expected that, to a slight extent, contours can be traced directly with the instrument and that outlines of bodies of water and courses of streams can be obtained very rapidly.

OFFICE WORK.

PREPARATION OF MAP SHEETS.

The map is compiled either on the field sheets or on fresh sheets. If considerable sketching has been done in the field it will be more satisfactory to complete the map on the field sheets unless local errors in the plotting of the stations are found to exist in the scheme of horizontal control. It will not be necessary to replot the control points if the error is merely one of scale, for the maps are published on a reduced scale, and any consistent error can be taken into account in the reduction process. If opaque celluloid has been used in the field the compilation is usually made on fresh sheets of double-mounted calendered paper. It is desirable, though not necessary, to have the map on a single sheet. A size greater than 24 by 36 inches is inconvenient to handle, so the office sheets used are not larger than those dimensions. The triangulation points are plotted and all the necessary elevations computed before the work on the photographs is commenced.

The map projection, which consists of the latitude and longitude lines, may be drawn on the sheets either before or after the map has been compiled, but it is more satisfactory to have it done in advance of the compilation, chiefly because of the aid which the projection lines give in the plotting of control points and because of the contraction or expansion likely to take place while the map is being drawn, which would necessitate a computation of projection values for an irrational scale.

PREPARATION OF THE PHOTOGRAPHS.

Contact prints are made from the negatives on sheets large enough to allow sufficient margin at the edges for them to be trimmed to the size necessary for use in the photo-alidade. The trimming is done with a sharp knife on a glass plate. A second glass plate is employed for the double purpose of regulating the size of the photographs when trimmed and of supplying straight edges for cutting. It is of the dimensions desired for the photographs and has smooth, parallel edges. It also carries marks which serve as guide lines in placing it over the untrimmed photograph. The photographs are trimmed and then labeled with their proper station numbers. A group is selected for immediate work, and these photographs are compared to identify and mark the control points and numerous other points common to two or more of them. The amount of marking necessary will depend on the scale of the map and the character of the topography. The photographs are then ready for use in the photo-alidade and the rotary scale.

The film must be in uniformly close contact with the paper in printing and the timing must be as nearly correct as possible. The printing should therefore be done by one who is skillful in judging the capacity of the negatives. Several photographs should be tested for dimensions to make sure that the contraction has been uniformly distributed, and warped prints should be discarded. Under uniform atmospheric conditions photographs from a single camera measure closely to an average size, so that if the contour interval is not small a common focal length may be used for the set without introducing errors large enough to interfere with the proper placing of contours.

For convenience in work and consistency in dimensions "printing out" papers which are unglazed or only slightly glazed have been found most satisfactory. The paper should be fairly heavy and of a kind that can be dried without "squeegeeing." An examination of many photographs gave a maximum variation between length and width of 0.5 per cent and an average of 0.1 per cent. The changes in print sizes may therefore be considered as uniform, and the decrease in width will be practically proportional to the decrease in length.

USE OF THE PHOTO-ALIDADE.

The requirements necessary for the use of the photographs are (1) that the camera station and the direction to at least one point in a photograph must be previously ascertained, or (2) that if the position of the camera is unknown, four or five known points must be included in a set of photographs taken at one station. The photo-alidade, therefore, in the second contingency, serves to locate the position of the station. For the location of the station from the photographs the known points should be distributed around the horizon, though a location can be satisfactorily obtained from one photograph if the position of the camera is favorable with respect to the known points. The locations are made on sheets of transparent celluloid, so that the method is merely an adaptation of the well-known tracing-paper method.

When the position of the station has been determined, a photograph is adjusted in the frame of the photo-alidade, as shown in Plate VIII, and a known point is sighted. The instrument is then centered over the station and the edge of the revolving arm is brought into line with the direction of the point sighted. The photograph will now be in orientation on the map, and the marked points are sighted in order that lines may be drawn in their directions. The lines are labeled to correspond with the marks on the photographs. Companion photographs from other stations supply the cross lines for intersection, just as in the plane-table method.

The accuracy of the position of a station when determined from the photographs is quite sufficient for all local work, for it is of about the same degree as that obtained with an open-sight alidade in the field, but positions of stations should not be relied upon for extension of control. The points in the photographs sighted for the location of stations should be well defined. One of them should be far enough away to establish a satisfactory orientation. The photographs used for obtaining the position of a station should be taken from the same spot.

Plate X shows a traverse of a shore line which was mapped from the accompanying photograph. The position and elevation of the camera above the bay were determined in the field. The photograph was set up in the photo-alidade, so that the directions to numerous points could be drawn. At the same time a duplicate photograph was used in the rotary scale (Pl. IX, p. 56) to supply the vertical factors of the points as they were sighted in the photo-alidade. The elevation computer (fig. 7) then supplied the distances, which were plotted as the sights were taken. In this use of the photograph the reverse of the process of obtaining differences of elevation was employed—that is, the vertical factors as obtained from the photograph and the difference in elevation being known, the rotary scale was manipulated with respect to these two known quantities to supply the distances.

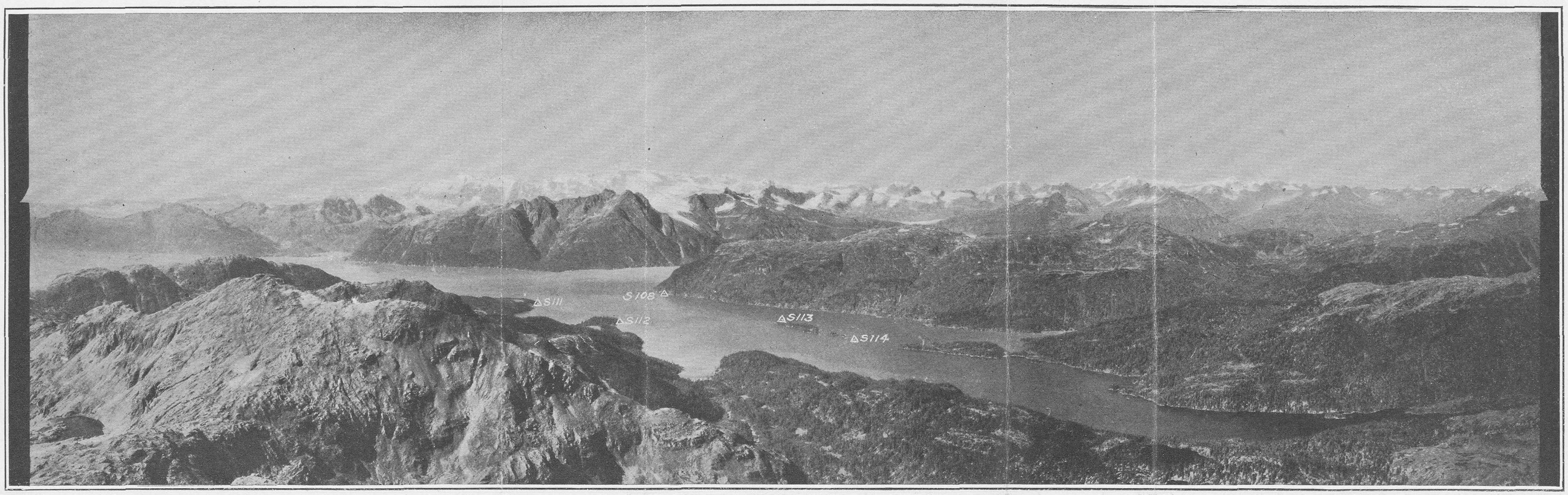
In Plate X the photograph is placed near the traverse rather than in the photo-alidade in order to show better its relation to the shore line as mapped. Certain points are labeled on both the photograph and map in order that the connection may be easily followed. If the difference of elevation between the station and the point sought is as great as 600 feet to the mile, corresponding to an angle of depression of about 6°, this method supplies distances sufficiently accurate for the scale of 1:48,000.

The triangles indicate stations for control that were occupied with the plane table, and the tangent lines represent sights that were taken from them. These lines supply a measure of the accuracy of the traverse of the shore line. As a further test the shore line as traversed by the United States Coast and Geodetic Survey on a scale of 1:40,000 is shown in Plate X, reduced to the scale of 1:48,000, beside the line obtained from the photograph.

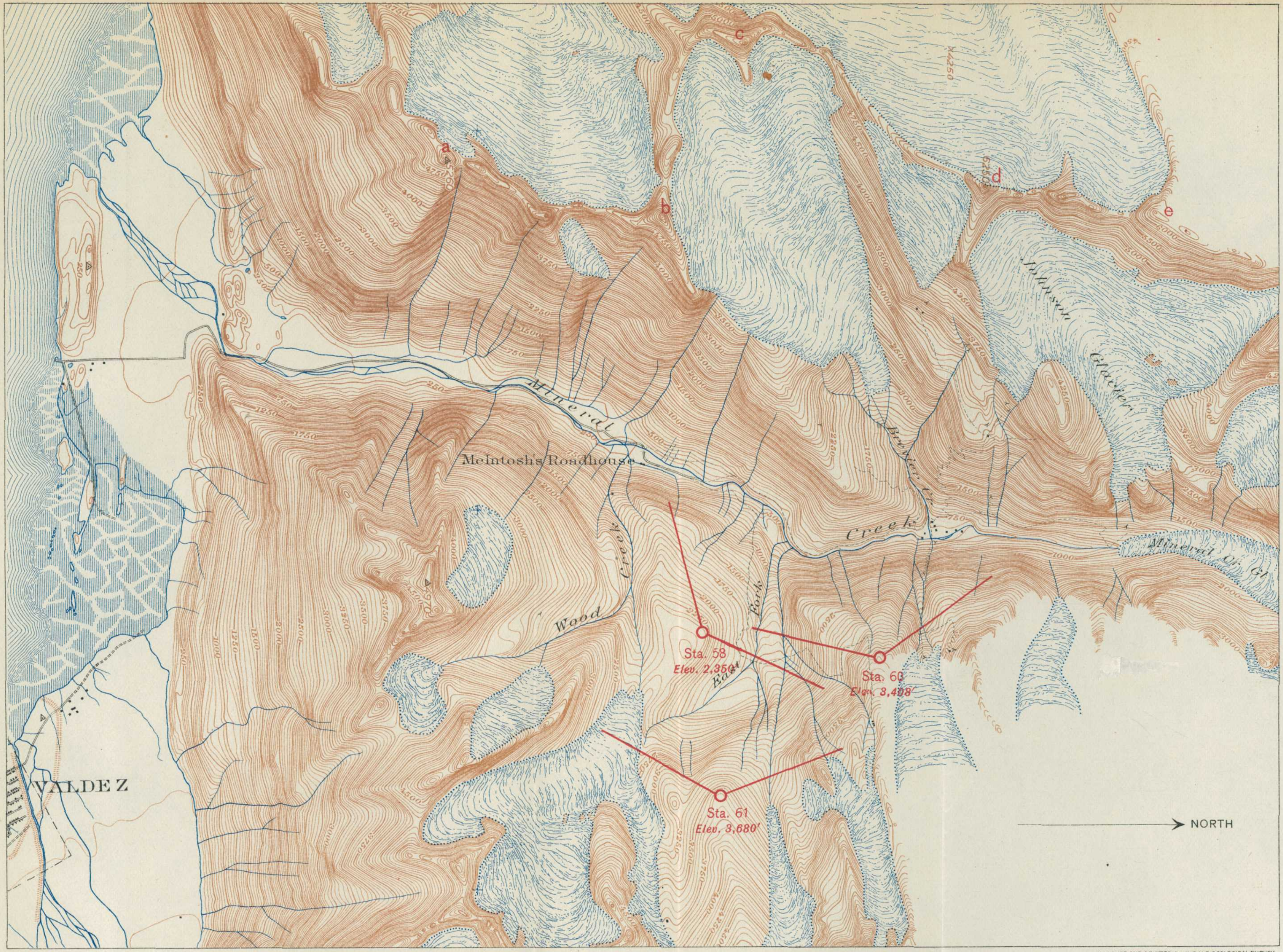
DETERMINATION OF ELEVATIONS.

Table 8 is a sample of the form in which the notes for determining elevations are kept. The focal length of the photograph is given in the first column and the station number in the second. The third column indicates the points upon which readings are to be made. Readings from the rotary scale are entered in the fourth column and the distances taken from the map in the fifth column. From these quantities the differences of elevation, which require correction for curvature and refraction, are obtained by means of the elevation computer.

The results shown in the table indicate the degree of accuracy obtainable from the photographs. The variations of the sets of elevations are due principally to the fact that the measurements are made without the aid of precise micrometers.



MAP SHOWING PARTS OF SHORE LINE OF JACK BAY, ALASKA, AND PHOTOGRAPH FROM WHICH IT WAS DRAWN, WITH TRAVERSE OF THE SAME AREA BY THE UNITED STATES COAST AND GEODETIC SURVEY.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

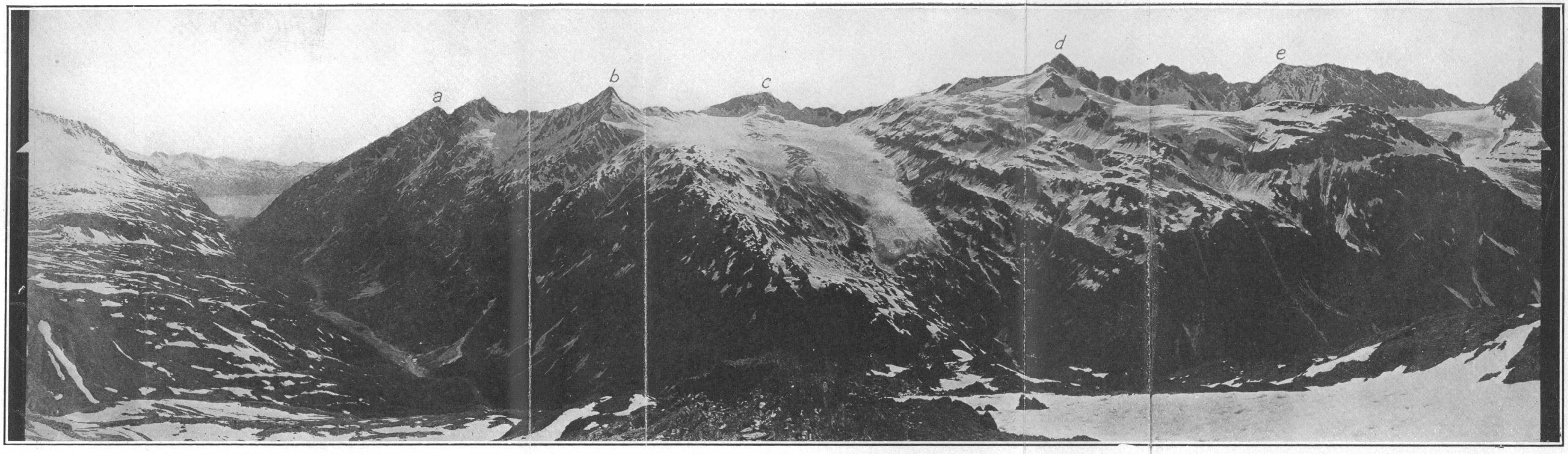
MAP OF PART OF PORT VALDEZ DISTRICT, ALASKA
ILLUSTRATING USE OF PHOTOGRAPHS

Red lines indicate horizontal scope of photographs

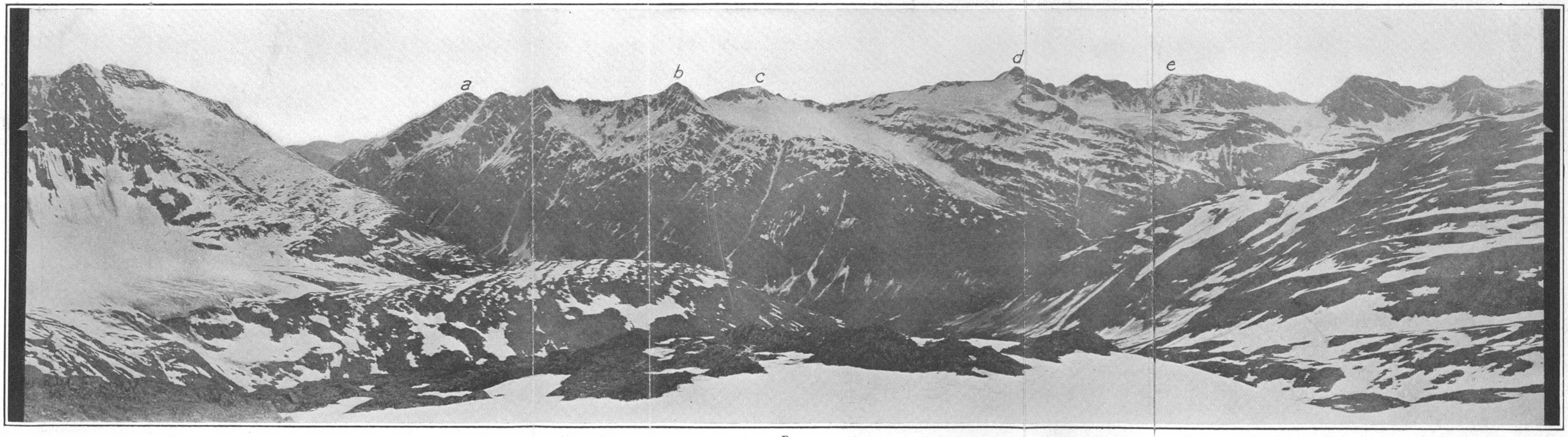
Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 50 feet.



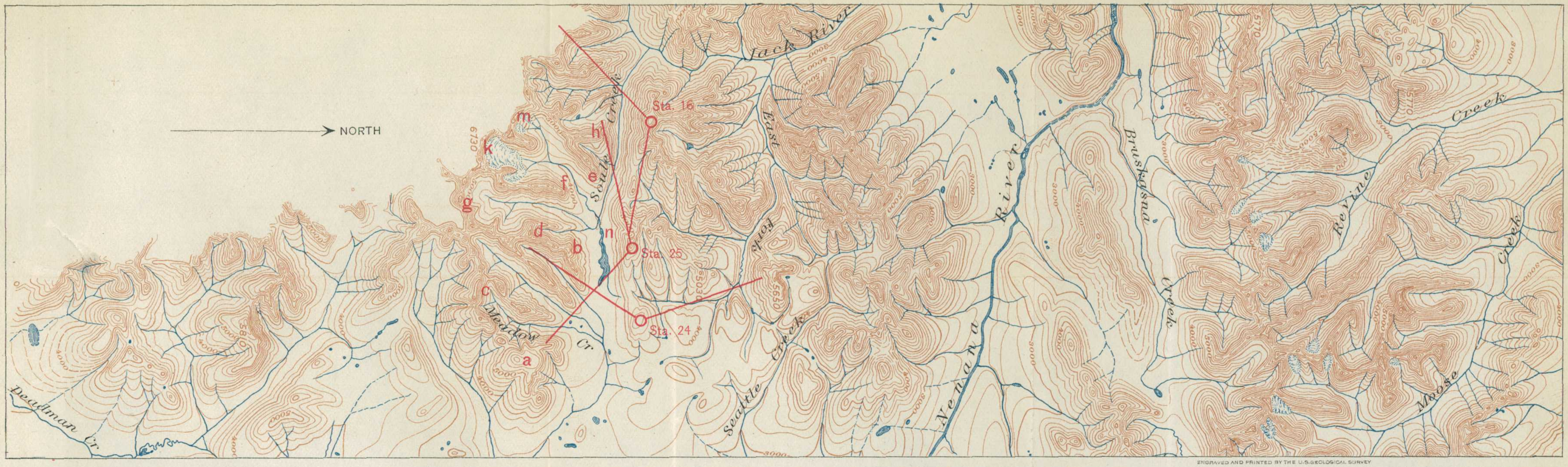
A.



B.

COMPANION PHOTOGRAPHS TAKEN FROM STATIONS 60 AND 61, COVERING PORTION OF PORT VALDEZ DISTRICT, ALASKA.

See Plates I and XI.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

A. MAP OF PART OF BROAD PASS REGION, ALASKA

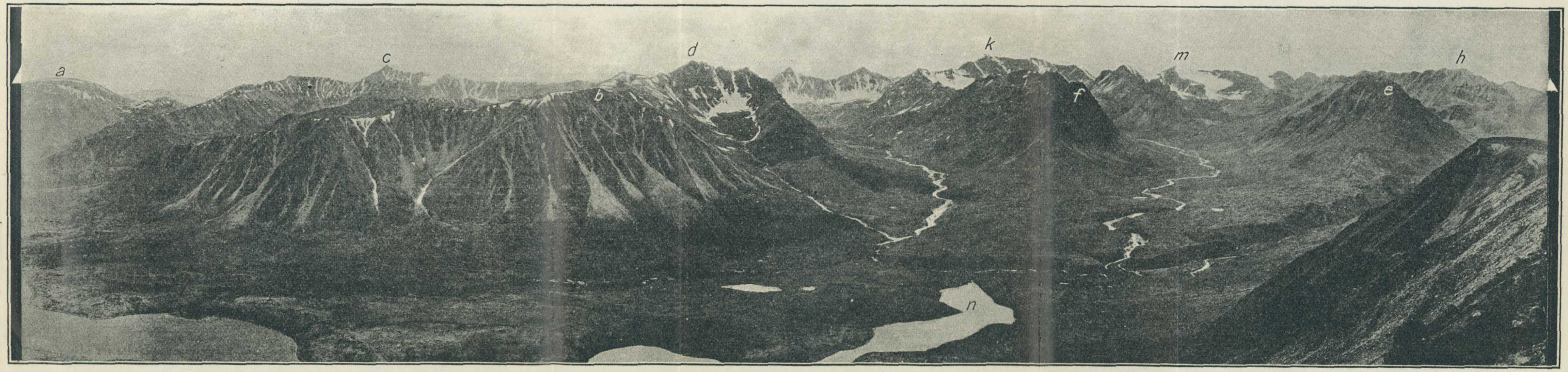
Red lines indicate horizontal scope of photographs

Scale $\frac{1}{250,000}$

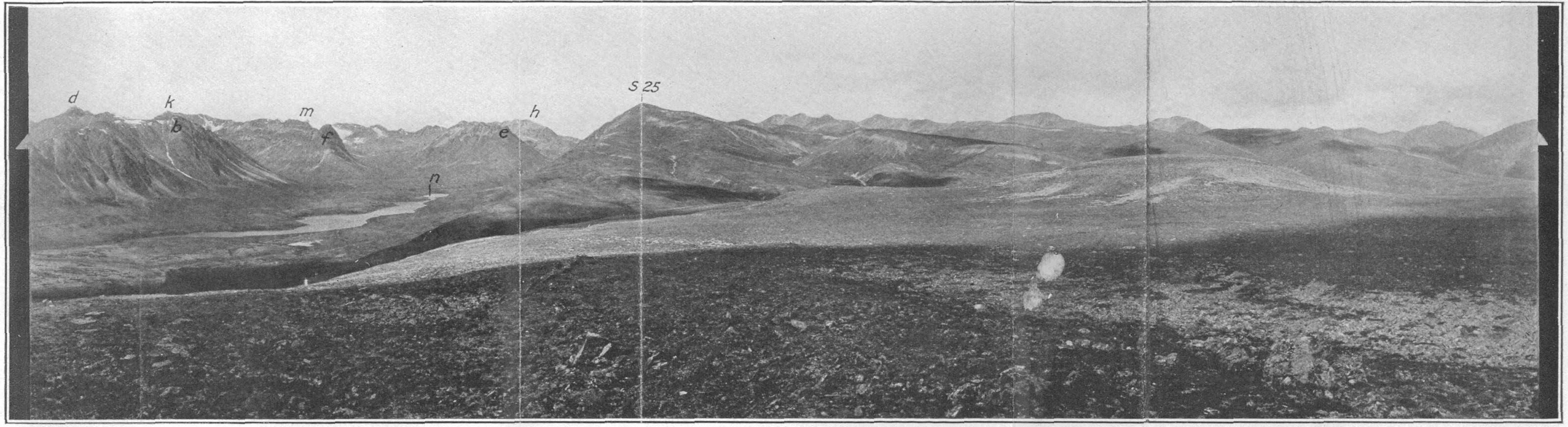
5 0 5 10 15 Miles

5 0 5 10 15 20 Kilometers

Contour interval 200 feet.

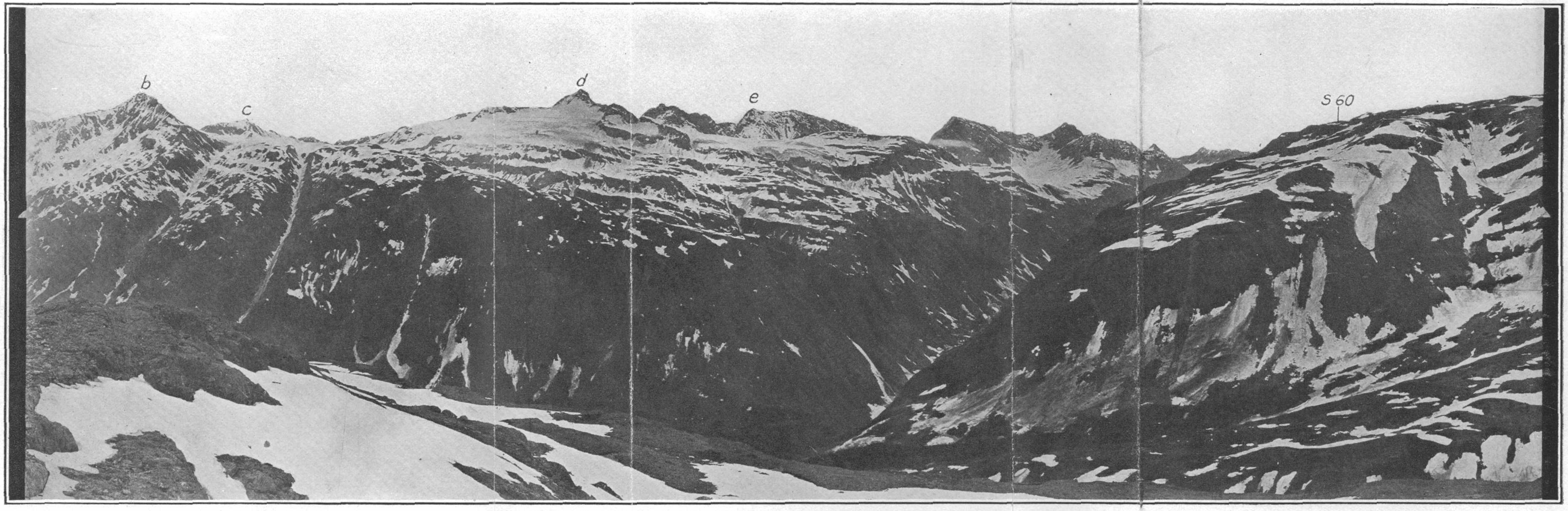


B. PHOTOGRAPH TAKEN FROM STATION 25



A. PHOTOGRAPH TAKEN FROM STATION 24, BROAD PASS REGION, ALASKA.
See Plates II and XIV.

B. PHOTOGRAPH TAKEN FROM STATION 16, BROAD PASS REGION, ALASKA.
See Plates II and XIV.



PHOTOGRAPH TAKEN FROM STATION 58, PORT VALDEZ DISTRICT, ALASKA.

See Plates I and XI.

TABLE 8.—*Notes on elevations obtained from photographs.*

Focal length of photograph.	Station from which photograph was taken.	Label of point read upon.	Vertical factor, measured from horizon line of photograph to image of point read upon.	Distance of point from station.	Apparent difference of elevation.	Correction for curvature and refraction (+).	Corrected difference of elevation.	Elevation of station as corrected.	Mean elevation.
Inches.			*Inch.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
5.32	9	4-7	0.170	4.11	690	14	704	3,995	4,006
5.32	8		.420	3.85	1,600	13	1,613	4,013	
5.32	12		.290	4.99	1,430	19	1,449	4,010	
5.32	9	4-8	.120	3.77	450	13	463	3,754	3,768
5.32	8		.390	3.50	1,350	12	1,362	3,762	
5.32	12		.270	4.50	1,210	16	1,226	3,787	
5.32	9	4-9	.125	3.34	410	11	421	3,712	3,735
5.32	8		.440	3.05	1,330	10	1,340	3,740	
5.32	12		.300	3.96	1,180	13	1,193	3,754	
5.32	9	4-10	.185	5.51	1,010	22	1,032	4,323	4,338
5.32	8		.375	5.21	1,940	20	1,960	4,360	
5.32	12		.315	5.60	1,750	22	1,772	4,333	
5.32	34	Sta. 35	.110	5.55	600	22	622	6,432	[a]6,313
5.32	32		−.75	14.20	−1,055	120	−935	6,245	
5.32	38		.190	10.10	1,800	63	1,863	6,235	
5.32	39		.155	16.06	2,465	152	2,617	6,350	
5.32	23		.30	15.90	470	150	620	6,304	
5.33	52	Sta. 65	.050	9.15	450	52	502	3,909	[b]3,902
5.33	52	Sta. 55	.260	6.30	1,620	27	1,647	3,896	
5.33	52	Sta. 70	.085	11.70	990	83	1,073	3,866	
5.33	52	Sta. 50	.035	8.95	310	50	360	3,880	
5.33	52	Sta. 17	.300	5.60	1,660	22	1,682	3,924	
5.33	52	Wick.	.135	13.46	1,800	109	1,909	3,921	
5.33	52	Sta. 48	.120	11.55	1,370	81	1,451	3,909	

[a] Elevation of station 35 as determined by telescopic alidade, 6,320 feet.
[b] Elevation of station 52 as determined by telescopic alidade, 3,906 feet.

The application of the method is illustrated by the map shown in Plate XI and the photograph shown in Plate XII, labeled "Sta. 60." If the distance, D, from station 60 to any point, as that marked *d*, is scaled and the vertical factor, V, obtained by measuring the height of the point above the horizon line (indicated by the horizontal lines of the notches), a calculation may be made to determine the elevation of the peak by using the formula

$$\text{Difference in elevation} = \frac{VD}{F}$$

The elevation of station 60 is 3,408 feet, V measures 0.80 inch, D scales 3.57 miles, and F is 5.32 inches, whence

$$\text{Difference in elevation} = \frac{\frac{0.80}{12} \times 3.57 \times 5280}{\frac{5.32}{12}} = 2{,}830$$

Calculation of elevation of point sighted.

	Feet.
Difference in elevation obtained from photograph	2, 830
Correction for curvature and refraction	12
True difference of elevation	2, 842
Elevation of station 60	3, 408
Elevation of peak "*d*"	6, 250

ADJUSTMENT OF TRAVERSES.

Traverses may be adjusted to the map either in the field or in the office if they are on the same scale as the map, but if they are on a different scale it will be more satisfactory to adjust them in the office. In surveys on the larger scale the traverses are run on the scale of the map, but in reconnaissance surveys it is more convenient to run the traverses on a scale greater than the scale of the map. For instance, if the station work is done on the scale of 1 : 180,000, the scale of 1 : 90,000 is used for the traverses. It is then necessary to reduce the traverses to the scale of the map, and this is ordinarily done by photography or the pantograph, photography being used if the traverses are extensive. Distances between known points common to both map and traverse sheets, rather than the nominal scales, are used to determine the amount of reduction. In the "celluloid transfer," now largely in use, carbon images of the traverse lines are printed on thin, transparent celluloid in such a way that they may be transferred rapidly to the map by burnishing. This is done by photography and has great value because of its accuracy and rapidity. Lines thus transferred to the map appear much like pencil lines and are inked with the rest of the map.

CONSTRUCTION OF CONTOURS.

All the topographic mapping that has so far been done by the United States Geological Survey with the aid of the panoramic camera has followed the usual course, in which the topographer at the end of the field season takes up in the office the compilation and drafting of the finished map. The practice of allowing the topographer to carry his work through the proof reading has been found desirable in plane-table surveys. It is not likely that another draftsman could compile a map from photographs with as good results as the man who did the field work. At any rate, training in topographic expression will be imperative in the office work. Therefore, although in a measure the method simplifies and reduces the field work, it requires considerable topographic skill to extract the data from the photographs and to sketch accurately the forms on the map. Sketching contours from photographs differs very little from sketching in the field. The best opportunity for contrasting sketching from photographs with field sketching is afforded by the degree of dependence which must be put upon the eye in placing contours along slopes. In field sketching, where a station is occupied once, or rarely more than once, the eye must be relied upon to a far greater degree in placing minor features than in sketching when photographs may be examined in any matter of detail whatever.

In compiling data from photographs it has been found best to concentrate upon a small area and to complete that area before taking up another. The elevation notes are kept conveniently at hand to supply the elevations, and the photographs are examined again and again in order that the forms may be correctly represented. Drainage should be drawn before the contouring is commenced. No rules for the drawing of the contours will be given here, for it is largely a matter of skill in draftsmanship that can be acquired only by practice.

In order to illustrate the use of the photographs in sketching contours a portion of the Port Valdez map (Pl. XI) and photographs (Pls. XII and XIII), used in sketching areas on the map, have been given to show the relations of the photographs to the map. A portion of the Broad Pass map (Pl. XIV) and also a series of views (Pl. XV) are given for the same purpose. The positions of the stations, the angular scope of the photographs, and a few prominent peaks are marked on the maps, and the corresponding points are labeled on the photographs.

THE APPLICATION OF PHOTOGRAMMETRY TO AERIAL SURVEYS.

INTRODUCTION.

The purpose of these suggestions is to indicate methods for the employment of aerial photographs in making military reconnaissances. The object to be accomplished is to determine the values of horizontal and vertical distances over a terrane of moderate extent.

The survey of a district by methods of aerial photography, as in the older methods, involves the measurement of a base and of horizontal and vertical angles and the determination of certain station positions in order that other distances and elevations may be determined. The procedure of aerial photography consists of (1) the measurement of a base, (2) the exposure of the negatives (corresponding to instrumental observations of other methods), (3) the establishment of the positions of the photographic (aerial) stations, and (4) the work of intersection and determination of elevations from the photographic negatives.

In the discussions that follow five cases are considered. Four of these fall under the general head of district reconnaissances and one under the head of rapid route reconnaissance. Under case 1 is pointed out the method by which an aerial reconnaissance of considerable precision may be made, and under case 2 a method that should permit the determination of comparatively long distances with a fair degree of accuracy. Case 3 suggests a possible working method for the employment of photographs obtained with a minimum photographic equipment. Case 4 treats of a method which, though of only relative accuracy, yet, on account of its facility of application, may prove of considerable value. The suggestions for rapid route reconnaissances are probably already well known to aviators who have had experience in taking photographs of the ground beneath them during flight in airplanes. Photographs taken with the optical axis of the camera directed down from positions over relatively flat country should supply maps of great reliability, provided proper means are employed to determine the variation of the optical axis from the vertical line.

GENERAL CONDITIONS.

At the outset it is well to discuss briefly the degree of precision that can be expected from photographic negatives exposed for the purpose of making measurements. Recent tests have proved that the anastigmatic lens will produce a sensibly true perspective and that a camera can be constructed with its parts assembled in as nearly mathematically correct relation to one another as the parts of a telescopic instrument employing a similar lens, provided the same degree of care is given. The question is therefore resolved into this: What error will be introduced in the calculation of an angle from ordinates measured on a photographic negative? It is evident that this error will depend on the error arising in measuring the ordinate, the focal length of the lens employed, and the error in determining the angle of inclination of the negative.

In photogrammetry the reference planes are properly the horizontal plane passing through the optical center of the lens and the vertical plane containing the optical axis. The angle of inclination is the angle that the optical axis makes with the horizontal plane, so that if a is the angle between two points to be measured in a horizontal plane, b the angle of inclination, f the focal length of the lens, and x the horizontal ordinate measured on the negative we shall have

$$\tan a = \frac{x}{f \cos b}$$

whence

$$da = \frac{f \cos b}{f^2 \cos^2 b + x^2}\, dx$$

Without going into the differentials of this equation with respect to each of the quantities appearing, it will suffice to state that they indicate certain conditions to be avoided as well as the conditions that are conducive to accuracy. The conclusions may be stated thus:

1. The error brought to a through the measurement of x decreases as x increases—that is, the greater the angle the less the relative error.

2. In general the longer the focal distance of the negative the less the error in a. For negatives inclined near to a horizontal position x may approach a value equal to $f \cos b$. This condition renders the determination uncertain. The condition corresponds to that when both x and $f \cos b$ are small.

3. The maximum error due to the influence of the inclination may be expected when $\cos b = \frac{x}{f}$.

Negatives obtained from aircraft are subject to still other errors, which are due to the displacement of the vehicle during the time of exposure and to the angular motion of the camera.

If we assume that the speed of the machine will not exceed 100 miles an hour (147 feet a second) during exposure and that a displacement of 1 foot is allowable, the greatest time of exposure should not exceed 1/150 second. For a stop of F 6.3 in bright weather this time may be reduced to 1/600 second, which is sufficient to assure rigorous precision.

The allowable angular movement of the camera may be determined from the requirements to give sharp definition in image. Simple means of making measurements from negatives impose a limit to definition of image of 0.1 millimeter. For a lens of 12-inch (305-millimeter) focus a movement of 0.1 millimeter in image during the interval of 1/150 second corresponds to an angular movement of about 1′. For work of precision it is therefore necessary to assure a practical elimination of angular movement. The value of 1′ of arc affords a measure of the accuracy to be expected from photographic measurements when the necessary precautions are taken in doing the field work. It corresponds to about 1.5 feet in a mile, or 15 feet in 10 miles.

Finally, there is to be considered the error which has its source in the means of establishing the position from which the photograph was taken and of connecting this position with known positions on the ground. It is plain that if the degree of precision indicated by the foregoing statements is not to be lost, means for accurately establishing the camera's position must be adopted, The obvious method of observing the camera's position from three or more stations on the ground will not suffice to determine this position unless the observations are made photographically, an electric current being used to assure a simultaneous exposure of four cameras. This requirement, which is at present impracticable of accomplishment, eliminates the possibility of using this method. A method that affords a practical and comparatively simple means of locating the camera's position is that of photographing a measured base at the instant of obtaining the photograph of the region to be surveyed. In this manner the error introduced will be no greater than that inherent in photogrammetry or that arising from the measurement of the base.

Systems of triangulation made up of stations suitably disposed eliminate the necessity of laying out a base. This condition may for the present, however, be excluded from consideration, for in those regions where a triangulation net has been established maps will most probably have already been prepared.

THE BASE.

The form of the base will vary according to the requirements of the survey or the time available to lay it out. The form which is most suitable is illustrated by figure 8. At each end of a carefully measured base line, AD, an equilateral triangle is measured on ground as nearly level as can be found. The length of AD will depend on the distance to be covered by the survey and it should be long enough to make intersections in the field of the survey at angles not less than 30°. The stations A, B, C, E, etc., are marked by white disks of a size suitable for the distance from which they are to be photographed.

The stations are also connected by a line of levels. As a check upon intersections a third triangle may be measured near the middle of AD. This will be used when photographs from three positions are required for the survey.

The aviator flies above the triangles at a height sufficient to permit good views of the region to be reconnoitered. Exposure upon a triangle is made at the same instant of exposure upon the district under investigation. The negatives thus obtained may be those of

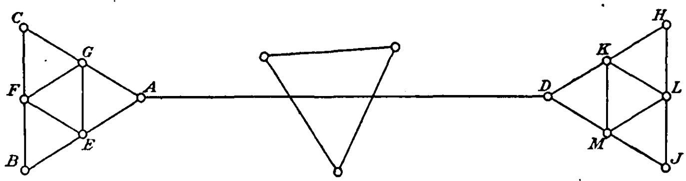


FIGURE 8.—Form of triangular base for determining positions of aerial photographic stations.

a single camera or of a combination of two cameras. The different arrangements of cameras will be discussed under the cases to be considered. The image of the triangle serves to supply the position and elevation of the "station."

When the distance to be covered by the reconnaissance is not great, and for special arrangements of the cameras, the whole system of the base may be reduced to a single triangular figure. This use will be mentioned under the several cases.

SPECIAL LEVELING DEVICES.

JARDINET TUBE.

In order that the angle of inclination of negatives taken in an approximately vertical position may be known, it is necessary that the position of the horizon line be determined. This may be obtained from the equilateral figure mentioned or by means of the Jardinet tube, a contrivance designed for the purpose. The Jardinet tube seems to be well adapted to balloon use, but on account of the complication of centrifugal forces there is doubt as to its applicability to use in airplanes. Figure 9 shows the arrangement of this device. It consists of a system of parallel closed tubes joined by other tubes, in which is contained a quantity of mercury. Two branches of the main tubes have enlarged sections, so that the center of the total surface of the mercury, which remains at a constant distance from the plane of the bottom, will be shifted to a point near the plane of the enlarged tubes. In this way the distance between the two principal planes AB and CD may be divided by the center point of the surface into parts having a ratio such as 1 to 10 or 1 to 12, the ratio being ascertained by a calculation.

The tube should be calculated and constructed to conform with the focal length of the lens to be employed. The tubes of uniform section are placed in contact with the plate and the enlarged sections occupy positions such that the center of the surface blends with the

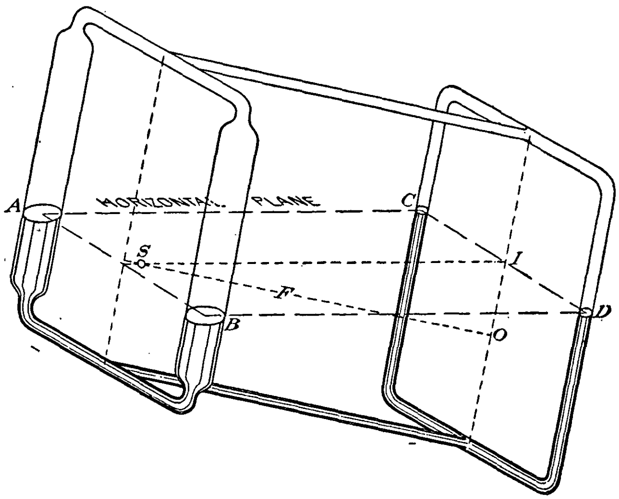


FIGURE 9.—Jardinet tube. (From Saconney's Métrophotographie.)

optical center of the lens. The shadowgraphs of the mercury surfaces supply the horizon line. Cameras that are intended for exposure in a vertical position may be equipped with the Jardinet tube.

UNIVERSAL LEVEL.

For horizontal negatives (obtained with the optical axis of the lens directed down) the universal level bubble may be adopted to supply the angle of inclination. In this device, too, as in all forms of gravity levels, centrifugal forces will be likely to introduce errors. It will be necessary that the spherical sector of the level subtend an angle wide enough to embrace the range of oscillation of the camera—as much as 6° or 8°. The level should be mounted on the side of the camera near the back and its image will be registered photographically upon the plate at the time of exposure. For this it will be necessary to employ a small lens and two prisms as shown in figure 10. The surface of the level should be checkered by lines which will be photographed at the time of the bubble. The position of the bubble with reference to the checkered pattern indicates the angle of inclination. It is necessary to employ a focal-plane shutter.

FILMS, PLATES, AND COLOR SCREENS.

On account of the necessity of making instantaneous exposures with moving cameras the flat field camera seems at present to be the only type suitable for aerial photography intended for metric use.

By reason of their liability to buckling roll films should be used only in cameras of the smaller sizes, and even in those film negatives can not be relied upon for precise measurements. It will probably be safe to use films only for rapid route reconnaissances, in which precision in measurements is not of the first importance.

The plates to be used should be the most rapid panchromatic plates availa ble. They should be so selected that the negative may register details ranging through a great variety of colors and distances, and that the use of color screens may not seriously impair their rapidity. In fact, the plates and color screens should be selected together in order to obtain the best results. Such a combination as the Wratten panchromatic plate and the K_3 color screen is one of the most efficient obtainable. The color screen should be such as will equalize the actinic power of the colors of the spectrum.

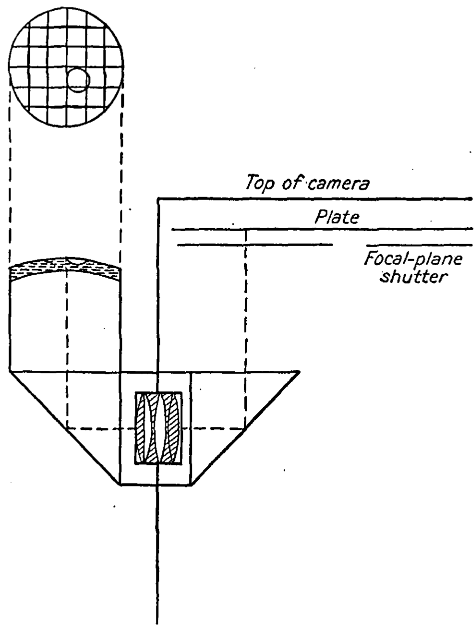


FIGURE 10.—Arrangement of universal level on camera. (After Capt. Ulyanine.)

DISTRICT RECONNAISSANCES FROM AIRPLANES.

CASE 1. PRECISE SURVEY.

GENERAL CONDITIONS.

The purpose in the case to be first considered is to determine with precision, from the known positions of certain points, the positions of points lying in an inaccessible district. The procedure consists in establishing the positions of aerial stations from which the points to be determined may be photographed and then located. The most precise method of accomplishing this from aircraft is that in which two joined cameras are employed, one of which establishes the position of the cameras and the other supplies the negatives covering the district to be reconnoitered. The most satisfactory arrangement of the cameras will be that in which one is pointed down and the other horizontally, the two optical axes being set exactly at right angles. This arrangement requires a base with two or more triangular figures above which the photographs will be taken. The length of the base will depend on the distances to be measured; the size of the triangles will depend on the height at which the photographs are to be taken. The focal length of the principal camera will likewise depend on the distance to be covered and the limit to the size of objects to be located. In the discussion that follows it is assumed that the maximum distances to be measured will not exceed the range of heavy field artillery—6 or 7 miles. For greater distances the reconnaissance may be made either by increasing the focal length of the principal camera or by changing the arrangement of the cameras, as described under case 2.

PHOTOGRAPHIC EQUIPMENT.

At 7 miles the scale of the photographic image will be $\frac{f \text{ (in inches)}}{12\times5280\times7}$. Therefore, if the lens has a focal length of 12 inches, the scale will be approximately 1:37,000; for a focal length of 24 inches, about 1:18,500. The scale of 1:37,000 will permit the identification of objects as small as 30 feet in greatest dimension; that of 1:18,500, objects as small as 15 feet. These figures give a measure of the accuracy of the method, provided the base is laid out with care.

The principal camera should conform with the figures just given according to the requirements of the work it is to do. The lens should be an anastigmat, free of distortion through an angle of 30° from the optical axis, and it should work with a wide aperture. The camera should be constructed of aluminum upon a rigid frame and should be equipped with centering marks and a focal-plane shutter permitting an exposure as rapid as 1/600 second. It may be desirable to include the Jardinet tube, though this device is not necessary in the procedure under discussion.

If the lens of 12-inch focus is used, plates measuring 10 by 14 inches will give a field of about 45° by 60°. A plate of the same size in a camera of 24-inch focus will give a field one-half as large. The lens should be so placed as to shift the optical center of the negative to a point about halfway between the middle and lower edge of the negative. The size of the plate will probably be limited by the facilities for handling the camera in the machine. Exposure will be made by a release that actuates the shutter of the principal camera simultaneously with that of the auxiliary camera.

The auxiliary camera will be of 6-inch focus and give a 6 by 6 inch negative whose field embraces an angle of nearly 60°. It will be equipped with an anastigmatic lens, focal-plane shutter permitting an exposure at 1/600 second, centering marks, and release joined with that of the principal camera, and it will be fastened to the principal camera so that the optical axis of one camera will lie in the principal plane of the other and the two optical axes form an angle of 90°.

The two cameras, which thus form a single photographic instrument, may require a special aimer to permit pointings in the two directions. This aimer (fig. 11) consists of two frames delimiting the fields of the cameras, a mirror, and an eyepiece, and may be attached to the instrument. The frame corresponding to the field of the principal camera should have cross wires indicating the horizon line and a center line perpendicular to the horizon line. Exposures will be made with these wires resting as closely as possible upon the apparent horizon and the center of the district to be photographed,

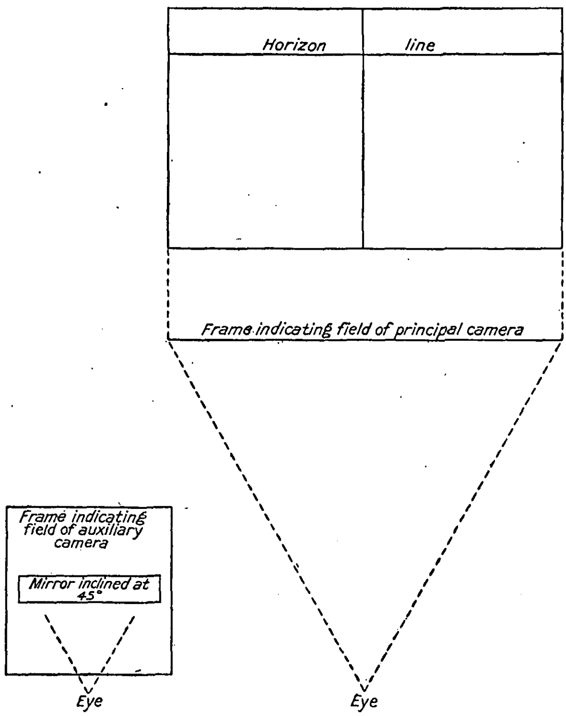


FIGURE 11.—Arrangement of camera aimer.

respectively. The instrument may be suspended by a strap (elastic if the vibrations of the motor require it), and it should have a handle for making pointings.

CONTROL.

The negatives will be controlled by means of equilateral triangular figures tied together by a measured base. The targets forming such a triangular figure should lie sensibly in the same plane, for the reason that by imposing this condition the work of locating the photographic station will be greatly simplified and reduced. The size of a triangle should be such that its photographic image will cover more than half the negative. The length of each side of the triangles should therefore be approximately two-thirds the elevation of the cameras above the ground.

The position of the photographic station and its elevation with respect to the base may be determined from the image of the figure (auxiliary negative). This image also supplies the orientation of the principal camera with respect to the base. The angle of inclination is likewise supplied by the image of the equilateral figure. This may

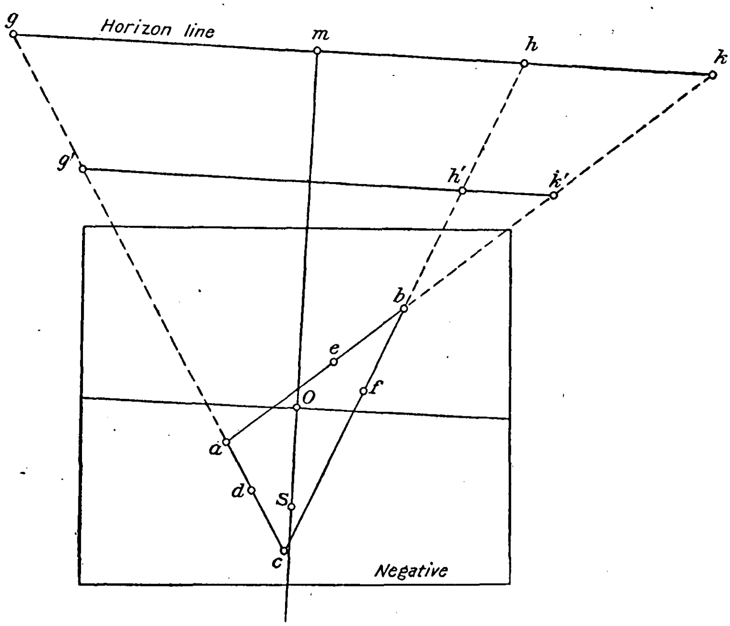


FIGURE 12.—Determination of horizon line and station point of negative.

be taken directly from the principal negative if the camera has been equipped with the Jardinet tube.

If *a*, *b*, *c*, *d*, *e*, *f*, figure 12, represent the images of targets (auxiliary negative) forming four equal equilateral triangles, the horizon line may be found as follows:

Prolong *ac*, *ab*, and *cb*. From the relation existing between harmonical conjugates of perspectives the horizon line may be found by taking a distance

$$ag = \frac{ac \times ad}{dc - ad}$$

$$bk = \frac{ab \times eb}{ae - eb}$$

and

$$bh = \frac{bc \times bf}{cf - bf}$$

Then the line *ghk* represents the horizon line.

From the optical center of the negative draw the line O*m* perpendicular to the horizon line. The angle of inclination *b* follows from the relation $\tan b = \frac{f}{Om}$, *f* being the focal length for the negative.

When the auxiliary negative is only slightly inclined from a horizontal position the horizon line will fall at a great distance outside the limits of the negative. The distance O*m* may then be found by taking distances as *cg′* and *ch′* proportional to *cg*, *ch* to supply a line *g′h′k′* parallel to the horizon line. The direction of O*m* will result, and a calculation can be made to determine its length.

The position of S (the point of the negative which indicates the projection of the photographic station upon the ground plane) is established from the relation

$$oS = \frac{f^2}{Om}$$

In order to locate upon a drawing the position of the photographic station with respect to the plotted positions of the targets proceed as follows:

Having determined on the negative (fig. 12) the position of S by the method just explained, from *s* on a tracing of the negative or a positive

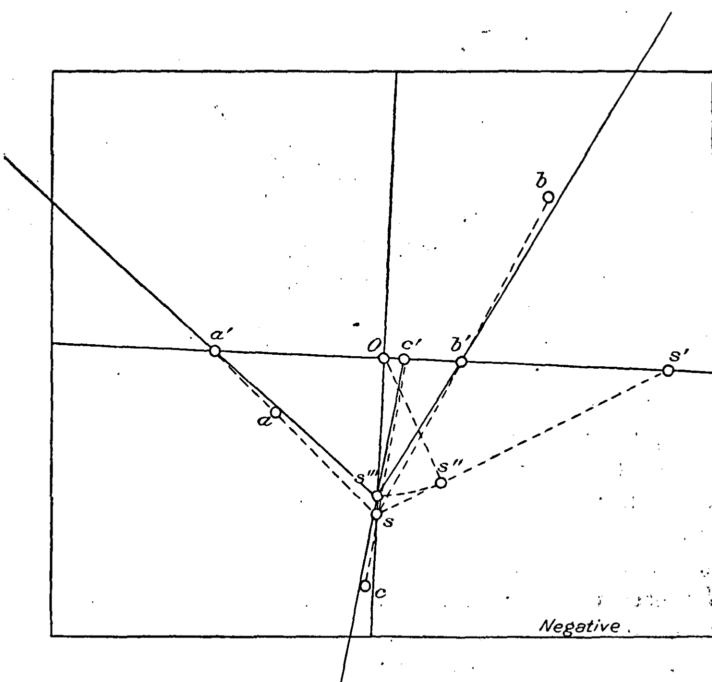


FIGURE 13.—Determination of station position.

print (fig. 13) draw lines through each of the points *a*, *b*, *c*, to meet the horizontal line through O at *a′*, *b′*, *c′*, respectively. Lay off a distance Os' equal to the focal length of the negative. Connect s with s', and let fall upon ss' a perpendicular Os'' from O. Take Os''' equal to Os'' and then draw from s''' lines through the three points a', b', c'. These lines supply the horizontal angles formed at the photographic station by lines to the targets.

ORIENTATION.

The orientation of the principal negative results from the orientation of the auxiliary negative. In relying upon this method of orientation there will be conditions under which the angles at the point s''' (fig. 13) will necessarily have to be determined by lines of relatively short lengths, which render the orientation unreliable. In order to assure a precise orientation it will be desirable to determine by intersection from the base the position of one or more points lying in the field embraced by the vertical negatives.

THE SURVEY.

Such a photographic survey from aircraft as the one under discussion may be considered as consisting of four different steps—(1) laying out the base, (2) obtaining the photographic negatives, (3) establishing the photographic station and orienting the negatives, and (4) locating points. In order that the time required for accomplishing the work of the different steps may be reduced to a minimum the procedure should follow the course of first laying out the triangular figures and then obtaining the negatives, the work of joining the triangular figures by the base being performed while the negatives are being prepared for use and the positions of the negatives established with reference to the triangular figures. The plotting of positions of points may then be commenced as soon as the complete base has been surveyed and plotted.

The time required for the first three steps, which bring the survey to a state of preparation to commence the plotting of points, should be no more than that necessary to prepare and plot the base. Negatives can be developed in a few minutes, and measurements may be made from them immediately thereafter. The calculations for establishing the position of the photographic station require less than a dozen measurements, and the calculations themselves should require no more than an hour to complete.

The base should be laid out by chain and transit so as to assure a degree of precision no less than that possible in measurements from the negatives to be used. A precision of 1 in 5,000 or even 1 in 10,000 may be attained without greatly curtailing the speed of the work.

The triangular figures may be laid out rapidly by employing two steel tapes and building up the figure from several adjoining triangles having a length of side equal to the common length of the two tapes.

The procedure outlined in this case should be sufficient to locate the positions of prominent points over an area 3 or 4 miles wide lying at a distance of 3 to 7 miles from the base. In relatively flat country the information thus supplied might be sufficient for the purposes of control and regulation of artillery fire. In hilly country it would probably be necessary to supplement the data thus obtained by photographs taken from positions over the district of the survey with camera directed down, the supplementary photographs being controlled in position and scale by points located from the principal negatives.

CASE 2. PRECISE SURVEY.

GENERAL CONDITIONS.

The procedure in case 2 differs from that of case 1 in that two separate cameras instead of a composite instrument may be employed to give similar results. This method permits a wider latitude in the movements of the aerial vehicle, for stations may be made anywhere within certain generous limits of the base, but the difficulties of manipulating the cameras are increased, and special means of orienting the principal negatives will almost always be required. The gain over the procedure of case 1 comes from an increase in range.

The particular positions of the photographic stations that eliminate the necessity of control other than that supplied by the negatives are those from which the two negatives, auxiliary and principal, embrace common ground and in which the principal negative may be oriented by directions plotted from the auxiliary negative (fig. 14, *A* and *B*). For such use it would be convenient to have the two cameras joined in a manner that permitted them to be easily detached. As this arrangement may be considered a particular application of the general method, the discussion will be devoted to the procedure of broader scope.

PHOTOGRAPHIC EQUIPMENT.

The two cameras should be similar in design and size to the principal camera described for case 1. They should be of not less than 12-inch focus and employ plates as large as the limitations of airplanes permit. Both should be equipped with the Jardinet tube. The remaining details should conform with those mentioned for the principal camera of case 1.

CONTROL.

The system of control will consist of a number of triangulation stations (fig. 15), so disposed as to present a minimum number of three targets to the field of the auxiliary camera, from whatever position the exposures may be obtained. It will furthermore be necessary to have at least one additional object of known position in the district to be reconnoitered, to serve for the orientation of the principal negatives. The breadth of the field covered by targets should be approximately as great as the distance from the photographic station to the nearest targets, and the farthest targets should

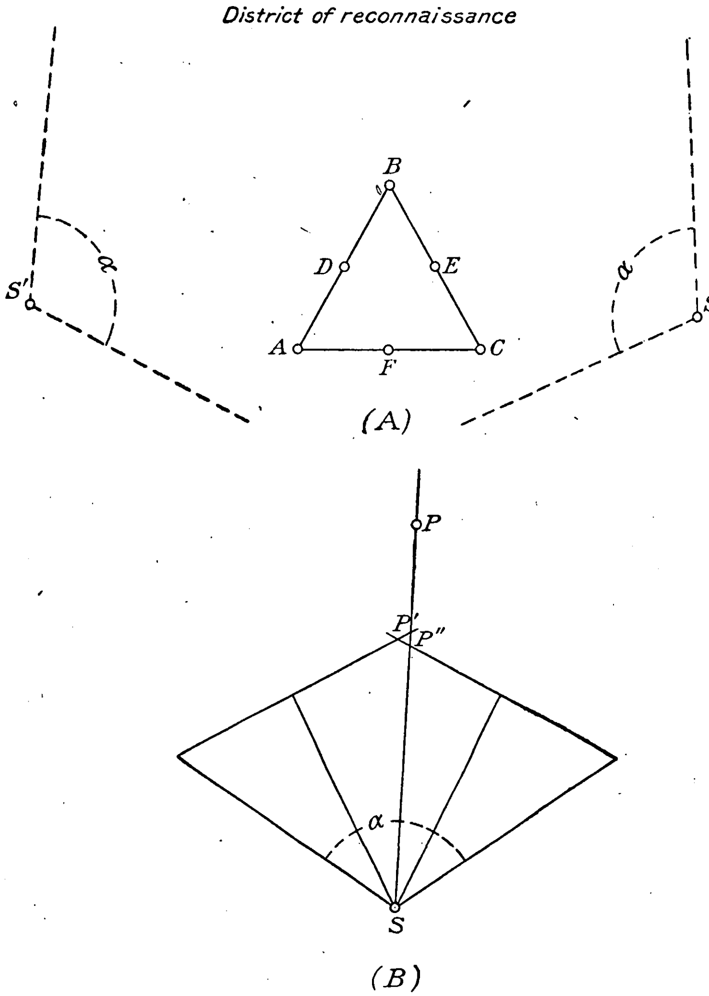


FIGURE 14.—Arrangement of two joined cameras, with plates approximately vertical.

be so placed as to stand a few miles from the nearest. The elevations of the targets must be known in order to determine the positions and elevations of the photographic stations. The targets should be of uniform design, whitened to contrast with their surroundings, and large enough to be plainly visible at the distance from which they will be photographed. Their size in feet should be about five times the distance in miles. Advantage may be taken of buildings or other existing objects conveniently situated which may serve as targets.

OBTAINING THE PHOTOGRAPHIC NEGATIVES.

Figure 15 shows the positions of the photographic stations relative to the targets and the district to be reconnoitered that yield the greatest range. The distance between the aerial stations should be kept great enough to form a suitable base for intersection within the area of investigation.

The cameras will be exposed with the plates approximately vertical. Though it might be possible for a single operator to expose with assurance of aim the two cameras in opposite directions at the same time, it would require a skill that could not be attained except by considerable training. It is therefore probable that the manipulation of the cameras would require two operators. The exposures will be controlled by a single release.

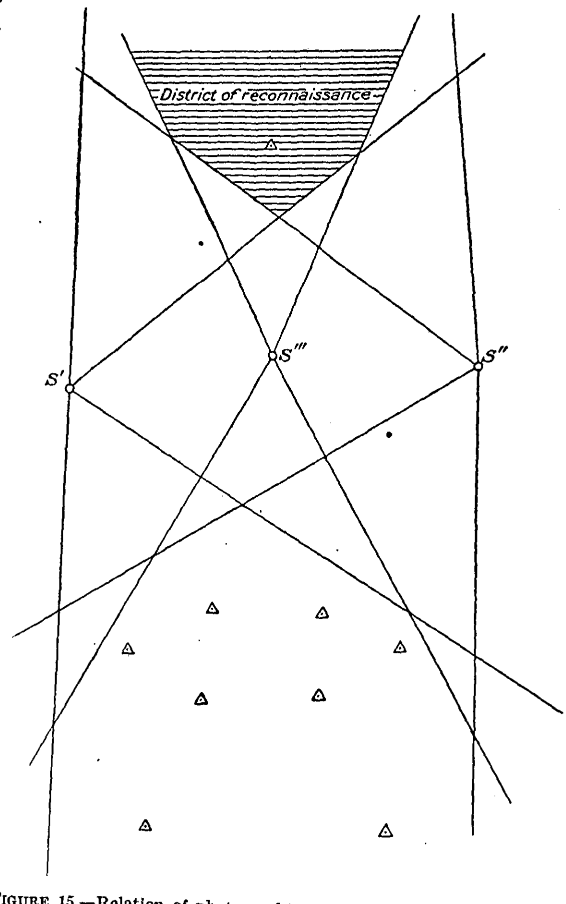


FIGURE 15.—Relation of photographic stations to targets and district of reconnaissance; two separate cameras.

ESTABLISHMENT OF THE POSITIONS OF THE PHOTOGRAPHIC STATIONS.

The positions of the photographic stations are determined from the known differences of elevation of three or more targets whose images appear in the auxiliary negatives. The accurate location of the aerial station requires a precise determination of the angle of inclination of the negative. The method consists of a series of successive approximations gradually approaching the correct solution, in which the approximate angle of inclination is at first employed to determine the approximate distances from the photographic station to the targets, and then a new calculation is made to determine the angle of inclination. This process is repeated until it becomes evident that the error is reduced to a negligible quantity.

If in figure 16 S represents the photographic station, O the optical center of the negative, HI the horizon line, b the angle of inclination

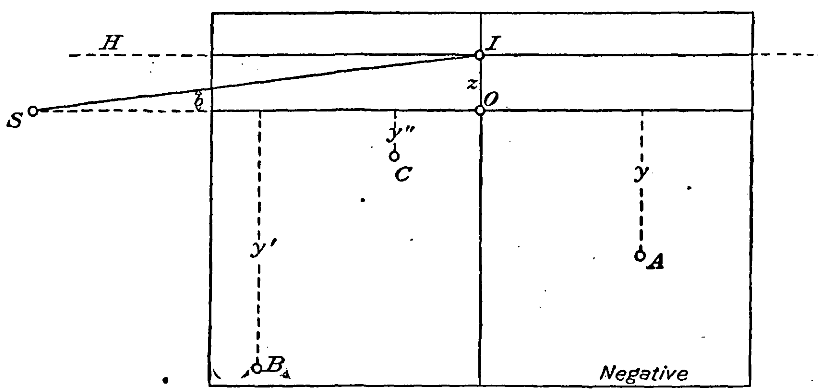


FIGURE 16.—Relation of angle of inclination of negative to elementary distances.

of the negative, SO $=f$ the focal distance, z the distance OI, and y the ordinate of any point A, we shall have $\tan b=\frac{z}{f}$.

Then if H (fig. 17) represents the elevation of the station above the known point A, and D the distance S′A′ (projection of S′A into the principal plane), the formula for determining the elevation will be

$$H=D\times\frac{z+y}{f-y\tan b}$$

If now a second point B, differing in elevation from A by an amount E, appears in the negative, we shall have for the elevation of the photographic station above B

$$H'=D'\times\frac{z+y'}{f-y'\tan b}$$

and as $E=H-H'$ we shall have

$$E=D\times\frac{z+y}{f-y\tan b}-D'\times\frac{z+y'}{f-y'\tan b}.$$

Substituting $\frac{z}{f}$ for $\tan b$ and developing the equation with respect to z we get the result

$$z^2[Eyy'+f(Dy'-D'y)]-z[Ef(y+y')+(D-D')\ (f^2-yy')]f+f^3\ [Ef-Dy+D'y']=0$$

which is the equation of inclination to be employed.

After having thus determined precise values for D, D′, and D″ (applying to a third point) and for z, the horizontal angles between the points may be turned off on a sheet of frosted celluloid and the station located on the map.

The angle of inclination of the principal negative must now be determined from knowledge of the difference in elevation between the photographic station and some known point included in the negative. After the angle of inclination is determined the negative

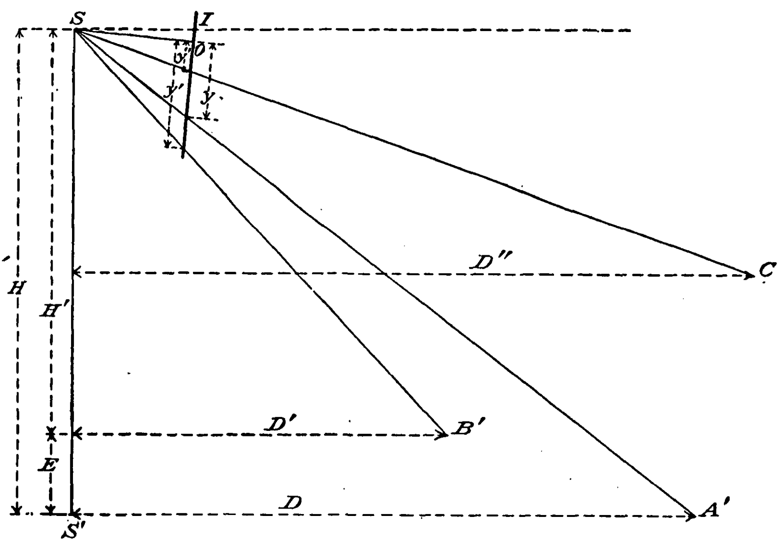


FIGURE 17.—Determination of the angle of inclination of an aerial negative from images of targets differing in elevation.

may be oriented on the map and lines drawn for intersection upon objects whose images are common to two or more negatives. Elevations may be determined by use of the formula given above.

CASE 3. MINIMUM PHOTOGRAPHIC EQUIPMENT.

GENERAL CONDITIONS.

In case 3 the minimum photographic equipment is required. A single camera may be exposed in a horizontal position (optical axis approximately horizontal) to obtain two or more negatives which shall embrace the targets of a prepared base and the region to be reconnoitered. The negatives serve in the double capacity of establishing the station positions and of supplying the information necessary for the survey. The field of usefulness of this method is narrow.

PHOTOGRAPHIC EQUIPMENT.

The lens should be capable of embracing a wide field, and its focal length should be great enough to furnish images of objects 20 feet in greatest diameter as distant as 5 miles. A rapid lens of 12-inch focus will therefore be chosen, and it will be mounted in an aluminum box large enough to give a negative 10 by 14 inches. The lens will be so mounted as to cause the optical axis to strike the plate at a point about 3 inches from its bottom edge. The exposure will be made by means of a focal-plane shutter permitting an exposure at 1/600 second. The camera will carry an open-sight frame to outline its field of view, and the frame will have cross wires for aiming. The horizontal field of the camera will embrace 60° and the vertical field points on the ground as near as 1½ times the height of the camera. The camera may be suspended by a strap and aimed by hand. Exposures will be made with the horizontal wire of the aimer cutting the apparent horizon.

CONTROL.

The control may be obtained from one or more triangular figures as indicated in figure 8 (p. 67). If a single triangular figure is used, it will be necessary to maneuver the airplane carefully in order to be certain that the negative embraces the district of reconnaissance and the base. The triangle should therefore be laid out with appropriate length of side. The positions for exposure will be to each side and back of the figure. A third exposure may be made from a position behind the figure and in line with it and the district of reconnaissance. If two triangular figures joined by a base are used, the positions will be behind the figures and in line with the district to be surveyed.

DETERMINATION OF THE CAMERA'S POSITION.

The distance of the camera from the base and its elevation at the time of exposure will be determined by use of the perspective properties of the regular triangular figure formed by the targets. Such a determination requires at least six targets, sensibly in the same plane, forming really four joining equilateral triangles. The solution is similar to that given under case 1. For some positions of the camera the horizon line may be more rapidly determined by the procedure given below.

If *a*, *b*, *c*, *d*, *e*, *f*, in figure 18, represent the images of the targets found in the negative, the parallel lines *ab* and *fe*, *cb* and *fd*, *ca* and *ed* will meet on the horizon line, which may therefore be determined by prolonging the lines mentioned. The horizon line, which supplies the angle of inclination, *b*, of the negative having been determined, there remain to be found the distance between two points of the negative, forming a line parallel to the horizon line and the corresponding distance upon the ground. The line *fg*, parallel to the horizon line, may be drawn on the negative and measured. The actual distance FG, corresponding to *fg*, can be found from a drawing of the triangular base to a convenient scale by applying the principle of harmonic relations.

The line *cgeb* is laid upon the drawing of the base (fig. 19) so that each of the points mentioned except *g* falls upon its corresponding

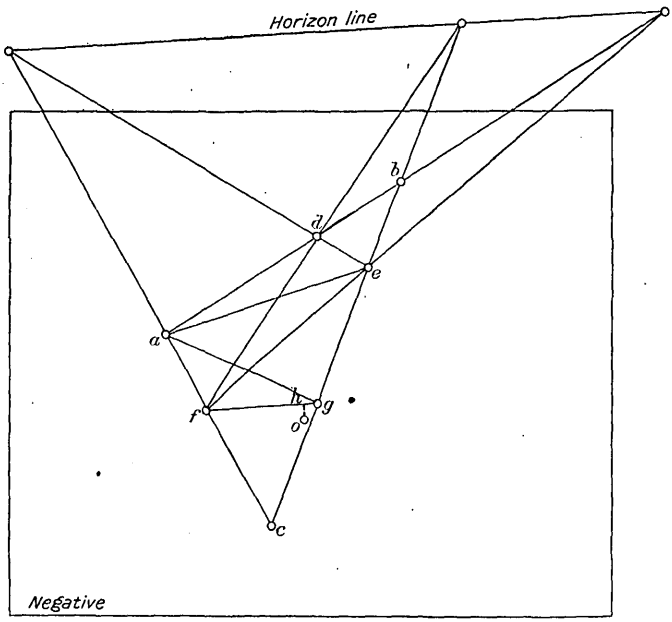


FIGURE 18.—Determination of negative line to locate position of aerial station. (From Saconney's Métrophotographie.)

line from A. The position of *g* then determines the direction of the line AG to give the point G.

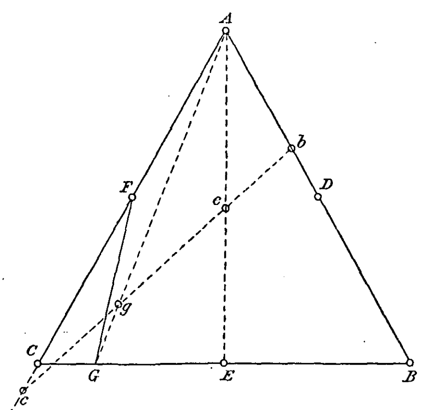


FIGURE 19.—Valuation of the line found in fignre 18. (After Saconney.)

The perpendicular line from the photographic station to the line FG strikes that line at some point H, represented on the negative (figs. 18 and 20) by *h*. If, then, O is the center of the negative and

u the angle, subtended by the ordinate oh, we shall have (fig. 20) the formula for slant distance:

$$D_s = \frac{FG}{fg} \times \frac{f}{\cos u}$$

f being the camera's focal length, whence the horizontal distance is

$$Dh = \frac{FG}{fg} \times \frac{f \cos (u \pm b)}{\cos u}$$

and the difference of elevation

$$E = \frac{FG}{fg} \times \frac{f \sin (u \pm b)}{\cos u}$$

The sign of b depends on whether b is to be measured above or below the principal line SO.

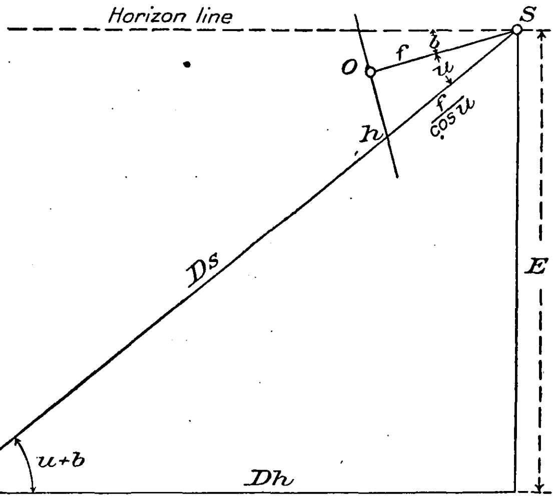


FIGURE 20.—Determination of elevation of aerial station.

CASE 4. A SINGLE CAMERA WITH A JARDINET TUBE.

GENERAL CONDITIONS.

The purpose in case 4 is to obtain the relative positions of several points in an isolated district (the survey to be made approximately to a given scale), independently of the positions of points in known territory, from photographs of the district obtained with the optical axis of the camera approximately vertical. The reconnaissance is based on the difference of elevation of the aerial stations as noted by barometer at the instants of exposure. This procedure differs from that of case 3 in that the negatives supply the horizon lines, and the relative positions of the photographic stations are determined from two points lying in a known plane (horizontal or vertical) so situated that they may be included in two or more negatives embracing the district. It is therefore necessary that the relative elevations of the aerial stations be known.

PHOTOGRAPHIC EQUIPMENT.

The camera and attachments will be similar to those described for case 3, with the addition of the Jardinet tube.

CONTROL.

It will be assumed that the barometric elevations have been noted and that the planes of the negatives were approximately vertical. The horizon line supplies the angle of inclination (*b*) of the negative.

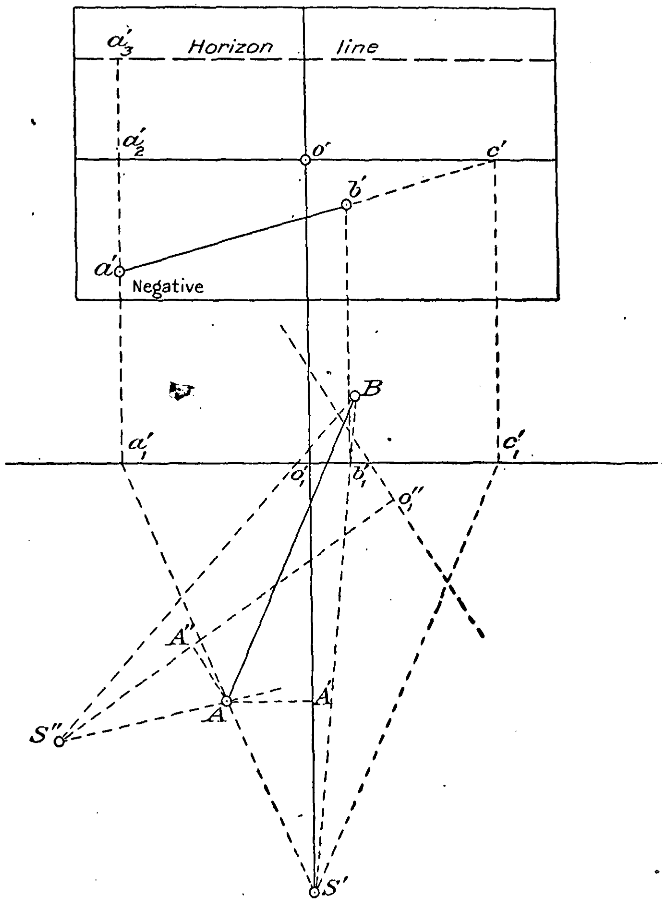


FIGURE 21.—Relative positions of photographic stations. (From Saconney's Métrophotographie.)

Two points, A and B, lying in the same horizontal plane (shore line or stream course) are found that are common to each of the negatives. The line (on the negative) connecting the images of these two points is prolonged to strike the horizon line at some point *c′*. The line from the optical center of the lens to the point *c′* is parallel to the line AB on the ground.

Lay out on a drawing (fig. 21) a line to represent the distance between A and B. From what is now known, namely, that $S'o'_1=f$

cos b', that AB is parallel to $S'c_1'$, and that A and B fall upon the respective lines $S'a_1'$ and $S'b_1'$, the negative may be oriented with respect to AB, and by following a similar course for the second negative on a transparent sheet the relative positions of the two photographic stations S′ and S″ are ascertained.

In order to determine the scale of the drawing it is necessary to apply the barometric difference in elevation of the two stations in the formula

$$\text{Difference in elevation} = S\left(\frac{S'A' \times a'a'_3}{f - a'a'_2 \tan b'} - \frac{S''A'' \times a''a''_3}{f - a''a''_2 \tan b''}\right)$$

with reference to some point, as A, of the line AB. In the formula S represents the scale of the drawing, f the focal length of the camera, b' and b'' the angles of inclination of the respective negatives, and the remaining factors such as are indicated by figure 22 or implied for the second negative. By solving this equation for S the scale of the drawing is determined. A change to any desired scale may then be made before continuing with the work of intersections.

If a third negative is to be used, it may be oriented upon the drawing in a manner similar to that explained for the second negative.

The elevation of any located point relative to the photographic stations can be determined with a degree of accuracy commensurate with the precision obtained in establishing the difference of elevation of the photographic stations. The formula for this use is

$$\text{Difference in elevation} = \frac{DV}{f - y \tan b}$$

in which D is the projection of the distance from the station to the point upon the line of the optical axis (on the drawing), V the vertical distance (on the negative) of the point below the horizon line, f the focal length of the camera, y the ordinate of the point (vertical distance on the negative from the point to the horizontal axis passing through the optical center of the negative), and b the angle of inclination of the negative.

RAPID ROUTE RECONNAISSANCE FROM AIRPLANES (CASE 5).

ENERAL CONDITIONS.

In case 5 the camera is employed in a vertical position to obtain overlapping photographs of the country passed over in flight.

The photographic equipment necessary will depend on the altitude at which the flight is to be made and the scale desired for the resulting map. The scale of the photograph is given by the relation $\frac{f}{H}$, f being the focal length of the lens and H the height of the camera above ground. Hence, for a lens of 6-inch focus the scale at an elevation of 5,000 feet will be 1:10,000; at 10,000 feet, 1:20,000. Furthermore there is to be considered the limit to the size of discernible objects. It may be assumed that objects whose images are less than 0.01 inch can not be easily identified on the photograph. Hence, on the scale of 1:10,000 objects less than 8 or 10 feet in greatest diameter will not show clearly, and for a scale of 1:20,000 this limit will be about 20 feet.

In this use it is essential that the lens have a wide angular range (60° to 70°), and the manipulation of the camera will be greatly simplified if film cartridges can be employed. A camera equipped with such a wide-angle lens of 6-inch focus would approach the limit of size suitable for the employment of roll film. From the foregoing considerations it would seem that a lens of about 6-inch focus would be the most suitable for the purpose.

PHOTOGRAPHIC EQUIPMENT.

The photographic equipment might therefore consist of a rapid and wide-angle lens of 150-millimeter focus mounted in an aluminum box, having a focal-plane shutter to work as rapidly as 1/600 second. The universal level may be attached to indicate approximately the deviation of the negative from the horizontal position. Marks to register shadowgraphs in the form of saw teeth will indicate the optical center of the negative. The camera could be so constructed as to permit exposures at definite intervals either automatically or by release and to accommodate a film cartridge capable of many exposures. An open-sight frame to indicate the field of the camera could be mounted on the camera or placed in a convenient position for sighting. It would be of particular value in timing the exposures while crossing hilly or mountainous country and as a rough check upon the rate of the flight.

A color screen of low factor may be used when its use would not require an exposure time greater than 1/50 second.

CONTROL.

The control of photographs obtained in flight over comparatively flat country may be obtained with a sufficient degree of accuracy by barometer readings at the instants of exposure, checked at the outset by a photograph of a measured base. Where practicable, a second base included in one of the photographs of the series may be used.

In passing from flat country, such as a valley with a large stream, to hilly country the control must be maintained by other means. This may be accomplished approximately by estimating the distance between the photographic stations from the rate of flight, the photographs being reduced in proportion to their elevation above the ground. This procedure is subject to large and irregular errors.

A method which provides a basis for calculation of the scale of photographs of rough country is to obtain the photographs from positions differing considerably in elevation. The differences of elevation of the aerial stations should be as much as several hundred feet, and the photographs should overlap one another by as much as one-half their width. From the differences in elevation of the camera at the times of two successive exposures, as given by the barometric readings, the scale of each photograph may be determined with a degree of precision commensurate with the general degree of precision of this method of making reconnaissances.

Photographs of hilly country may be oriented by points almost directly under the camera's positions. The scale may be established as follows: Draw the line *ab* (fig. 22) representing a distance between two points, A, B, which are so chosen that they lie as nearly as possible directly below the positions of the camera at the instants of

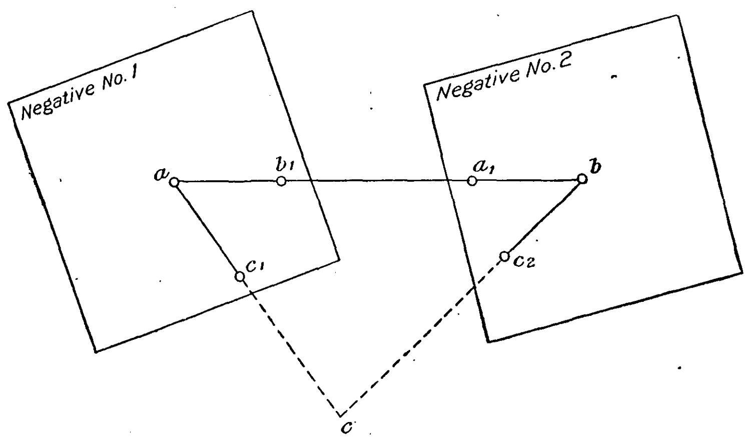


FIGURE 22.—Determination of scale of photographs; negatives approximately horizontal.

exposure of the respective negatives. Prolong ac_1 to meet bc_2 prolonged at c, the relative position of any third point, C. If then f represents the focal length of the camera, E the barometric difference of elevation of the camera at the two positions, and $\frac{1}{S}$ the scale of the drawing, we have

$$E = f\left(\frac{ac}{ac_1} - \frac{bc}{bc_2}\right) S$$

from which S may be determined, and then the actual distance between A and B as represented by *ab* scaled.

The maximum inclination allowable in the method just given is about 5°. If the angle of inclination exceeds 5° it will be necessary to employ the method described for case 1 (fig. 13). For rapid reconnaissances, therefore, it is essential that the angle of inclination of the negative be kept below 5°.

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