Photogrammetric Mapping of the Brooks Range *

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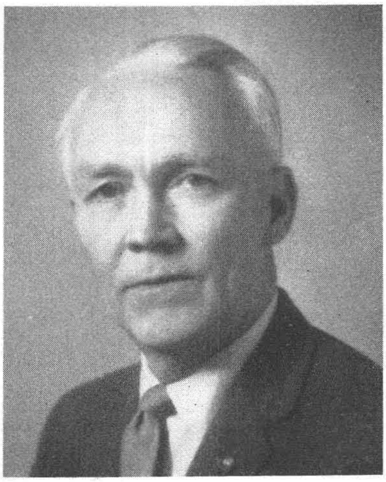
ABSTRACT: *This paper briefly reviews the background requirements for 1:250,000 scale maps in the Brooks Range area of Alaska; the problems that were faced in the initial planning of the job, and a detailed description of the photogrammetric operations in the Denver Office of the Geological Survey, with particular emphasis on the vertical and horizontal stereotriangulation problems.*

THIS paper covers the photogrammetric phases of a 1:250,000 mapping project in Northern Alaska, better known in the Geological Survey as the Brooks Range Project (see Figure 1). It is intended to supplement and give perspective to the papers presented by H. B. Loving and J. E. Mundine at the meeting of the American Congress on Surveying and Mapping in the Spring of 1957.[1]

The 120,000-square-mile Brooks Range project extends some 250 miles north from the Yukon River and 500 miles west from the Canadian border. Not only is the area as isolated as any to be found in the United States or its possessions, but its character runs the gamut from the dead-flat plains of the Arctic Slope (see Figure 2) to the rugged mountains of the Brooks Range (see Figure 3).



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GENERAL PLANNING

The requirements for, and urgency of, the maps covering this area, took definite shape during the summer and fall of 1954. Technical specifications were set for a publication scale of 1:250,000, with a basic contour interval of 200 feet, and of 100 feet where needed, with a horizontal accuracy of 0.04″ at publication scale and a vertical accuracy of one contour interval. A target date of July 1, 1958 was set for delivery of materials for publication. In the general planning for the job, it was decided that the photogrammetric method offered the only possible system from the standpoint of both cost and time.

AERIAL PHOTOGRAPHY

In carrying out the specifications, the first photogrammetric problem to be solved was the design of the aerial photography. The need for using the maximum flight-height consistent with good performance of available aircraft led to the choice of 30,000 feet above mean terrain as the nominal flight-height. The contractor was encouraged to exceed this figure, if practical, to insure good side-lap between flights. The instruments, procedures, and experience in vertical photography were readily available, but coverage with vertical photography would require 30,000 lineal miles of flying. The prospect of obtaining this much photography in one season, in an area that is notorious for its bad weather, appeared very dim.

[1] Loving, H. B. and Mundine, J. E., Mapping Alaska's Brooks Range, *Surveying and Mapping,* July–September, 1957.

* Presented at the 25th Annual Meeting of the American Society of Photogrammetry, Washington, D. C., March 10, 1959. Publication approved by the Director, U. S. Geological Survey.

FIG. 1. Map of Alaska, showing general outline of the project.

Twin-camera transverse-low-oblique photography offered a solution to the problem of photographic time, since one flight would yield a strip with more than twice the width of coverage of verticals, but instrumentation and experience in procedures was very limited.

Mr. R. K. Bean of the Geological Survey had done considerable work on a twin-camera mount for this type of photography. His research group had also designed and built a prototype of a plotter to perform the stereotriangulation. This instrument—the Twinplex—had been used successfully under laboratory conditions but had not been used on a production job. Since timing was so critical, and careful study and planning indicated that the other problems could be satisfactorily solved, it was decided to perform the mapping with transverse photography. As a

FIG. 2. River plain—lakes and streams.

FIG. 3. Mountainous terrain.

result of competitive bidding, a contract for obtaining the photography was awarded to the Mark Hurd Aerial Survey Company. During the ACSM meeting of 1957, Mr. Hugh B. Loving ably covered the formidable problems encountered with weather and other natural conditions, in bringing this contract to a successful conclusion.

The decision to use transverse twin-photography was most fortunate. Earlier estimates of limited flying time were found to be true. In the eight photographic days which occurred during that first summer, the contractor was able to photograph 100,000 square miles (85%) of the project. Since good weather over certain limited areas was required all of the summer of 1956 was needed for photographing the remaining 25,000 square miles.

DIAPOSITIVE PREPARATION

Preparing the diapositives from the film procured under this contract was important. The urgency of the job, unequal lighting of the terrain, and scarcity of flying weather in some areas, compelled the use of film of less favorable characteristics than in normal operations. Preparing adequate diapositives from this film presented quite a challenge to the men in the Photogrammetric Laboratory. This challenge was more than adequately met.

HORIZONTAL AND VERTICAL CONTROL

A study of the triangulation in the area, either completed or planned, showed adequate control for the perimeter, and that in the summer of 1955, an arc was to be run north and south by the U. S. Coast and Geodetic Survey, through the central part of the area over Anaktuvik Pass. After completing this arc, another spur line was started north toward Arctic Village in the eastern portion of the project. During the summer of 1956, this was extended further north by Geological Survey parties into the heart of the southern flanks of the Brooks Range. Experience with stereotemplets indicated that this control framework would be sufficient to permit the extension of horizontal control to the required accuracy by means of the stereotemplet technique:

Good elevations had been determined for each of the triangulation stations; this provided a base for the further extension of the vertical control by either field or photogrammetric methods. After due consideration of the related factors, it was decided that 12 models would be considered a unit for vertical stereo-triangulation purposes, and that elevations by field methods would be needed in the terminal models. To accomplish this, 12 vertical-angle traverses were run north-south, perpendicular to the direction of the photographic flight lines, beginning and closing on the perimeter triangulation.

At the time the photography was designed, it was felt that it might not be possible for the men on the ground to run a traverse through the rough area of the main divide. To insure no gaps occurring in such cases,

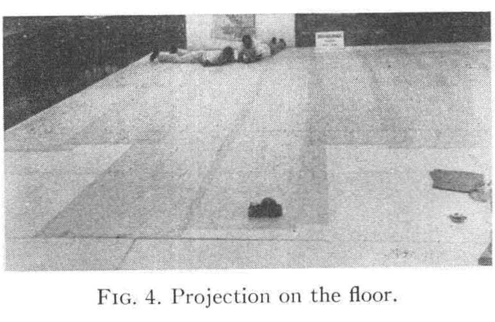

FIG. 4. Projection on the floor.

convergent photography, flown north-south, was designed to bridge across these possible gaps. It later developed that the field parties were able to find a way through and to close their traverses on stations on the Arctic slope.

During the winter of 1955–1956, the men who were to be assigned to do the field work were detailed to the Technical Planning Unit at the Rocky Mountain Region office in Denver which had been assigned the responsibility for executing the project. On the photography then available, they made a preliminary selection of the points needed for the vertical-angle traverse lines. At the same time, and in conjunction with the personnel in the Photogrammetry Section, they decided what would be required to control the remaining photography to be flown during the summer of 1956.

This study of the terrain for vertical control points also gave these field engineers a chance to make preliminary plans for their field operations. This advance planning proved invaluable later on when the men were actually carrying out the work.

During these planning operations, it was decided that this would be an excellent opportunity to test the "leap-frog" altimetry system on a large scale and under a variety of conditions. As will be shown later, this too proved to be a very fortunate decision.

Test Stereotriangulation

During the initial phases of the planning, it was assumed that the stereotriangulation operation would be done with the Twinplex. As time progressed, it became apparent that with 5,000 exposures to set up, it would be necessary to supplement this capacity by some means.

An area of some 10,000 square miles east of Kotzebue Sound had been controlled by the 30th Engineers in 1953, 1954 and 1955 in anticipation of the area being covered by vertical-photography from 20,000 feet and compilation for mile-to-the-inch publication. This area was covered by the transverse-photography instead. It presented an excellent opportunity to evaluate several proposed methods. These studies led to setting up a series of left- or right-facing exposures in the manner common to vertical-photography, using ER-55 projectors mounted on 14-foot stereotriangulation bars. It also provided time-study data for planning and estimating.

As a result of the work in the Kotzebue area, it was clearly evident that the proposed method would yield adequate results for the balance of the project. A median horizontal error of some 200 feet was indicated, with a maximum not exceeding 400 feet. Vertically, the middle ordinate varied from *plus 50 feet to minus 100 feet* and pass-point elevations had a standard deviation of *23 feet* from the mean of the gross closures.

These tests also showed that, given a good initial scale, several 12-model strips could be added laterally without introducing any serious change in scale. It was felt that if possible to hold this scale change to something like 0.5%, vertical curves could be drawn and good preliminary values determined for the vertical-angle traverses and various pass-points. This would save the time needed to reset the models for a firm vertical solution after a correct scale had been determined from the templet assembly, and the vertical-angle traverses computed.

With this in mind, the stereotriangulation was initiated in the perimeter areas containing the primary control. Inverse distances were computed for those triangulation stations covered by a given strip. The series of models were scaled to these distances, and all control and pass-point positions were plotted from the models to a blank sheet of manuscript paper, and the elevation data were recorded.

Time studies in the experimental area indicated that make-up time and instrument time were about equal. Since equipment was limited, it was decided to put two men on each instrument on each of two shifts. While one man was carrying out the relative and absolute orientation, and was reading needed data from the models, the other man was annotating the manuscript for delivery to those preparing the templets and springing vertical curves. This second man would also make a selection of the pass-points and set up the interior orientation of the subsequent strip.

Stereotemplets

The stereotemplets were usually prepared from two consecutive right- or left-facing models. The pass-points to be used as pivots were selected and the distances were ratioed down from model-scale (usually 1:20,000) to 1:63,360 along carefully drawn radials. These positions were pricked through to 0.030-inch binder board. All pass-points and templets were carefully annotated so that they could be readily identified.

The selection of the 1:63,360 scale was the result of a compromise between model-scale, pantograph-ratios, space available for the assembly, and the need for mile-to-the-inch compilations in some of the area.

Projection

After due consideration of the size, shape and location of the area, a special Lambert Conformal Projection was used (see Figure 4). This and the available horizontal-control were plotted by means of a coordinatograph on long strips of 0.007-inch grained Mylar 42 inches wide. The strips were registered one to the other through grid ticks and short studs. The assembly (see Figure 5) of the templets progressed smoothly and with a minimum of difficulty. There is every reason to believe that the accuracy was equal to that achieved in the test area.

Vertical Stereotriangulation

As soon as an adequately controlled block of templets had been completed, distances were determined between successive vertical-angle stations, and the elevations were computed. A correct scale was also determined for each series of 12 models. The preliminary values of the pass-points were then adjusted where relief and scale-error indicated the need. It is of interest to note that 70 per cent of the strips had a scale-error of less than 1 per cent.

The elevations that had been obtained by leap-frog altimetry were used extensively during the initial stereotriangulation and determination of preliminary values. The soundness of these elevations substantially reduced the work involved in reaching a final adjustment.

In his 1957 paper J. E. Mundine reported the results of first vertical-angle traverses. It is now possible to report on the completed job. A total of 14 traverses were run; they varied from 35 to 195 miles in length, with an average of 104. Nine closed within 10 feet, three between 10 feet and 20 feet and of the other two, one within 30 feet and the other within 57 feet.

Several methods were devised and tried to determine the middle ordinate of the vertical curves. One of these was to compute ground elevations, using the altimeter in the camera. This was soon abandoned, since the erratic nature of the results did not justify the time spent in getting the necessary data. A study of the area revealed that stream gradients provided a good solution to the problem. The field engineers were required to establish elevations on as many of the streams as could be readily reached from their traverses. From an analysis of these elevations, it was possible to determine enough gradients to control the direction and amount of the vertical curves. The unadjusted values of several joining strips were also studied to reduce the possibility of major errors.

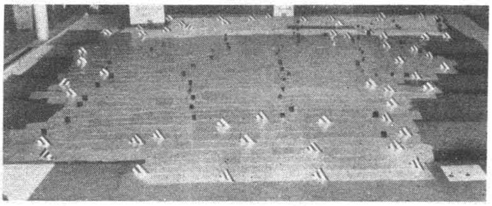

Fig. 5. Templet assemblies.

In the experimental phases of the job, while procedures were being developed, it appeared that the mid-ordinate might not exceed 100 feet. Subsequently, larger values were found; for the job as a whole, some 80 per cent of the strips varied from plus 100 feet to minus 300 feet. While these values appear large in comparison to normal operations, it must be remembered that the basic contour interval was 200 feet and that any evaluations would be based on the whole rather than $\frac{1}{2}$ an interval. It was amazing to most people connected with the project that the vertical curves were so flat.

The Army Map Service had been working for some time on a series of 1:50,000-scale quadrangles joining the Brooks Range Project on the northern boundary. As the edges of these quadrangles have become available, they have afforded an independent evaluation of the vertical stereotriangulation. Rarely has there been a difference exceeding 50 feet and much of the time the differences are in the order of 20 to 30 feet. Since the Army Map Service pass-point elevations were established from vertical photography and a first-order plotting instrument on a minimum of field control, it would appear that the correlation speaks well for both methods.

While discussing errors, it is desirable to point out some of the operational difficulties encountered during the stereotriangulation. It must be remembered that this project was one of the first where ER-55 instruments were used in quantity, and that the personnel had to become accustomed to the differences between these instruments and the well-known Multiplex. In oblique models, the fact that a horizontal error between pass-point positions from model to model is greater than the vertical error, made everyone try to the best of

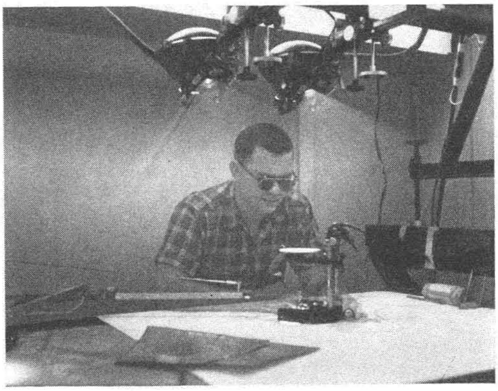

FIG. 6. Compiler at work.

his ability to get good vertical closures. It quickly developed that interior orientation was very critical. This would include not only the recovery of the principal-point but also firm seating of the diapositive plate on all bosses and proper seating of the plate holder. These problems were noticed especially with the first models of the ER-55s. The control of diapositive scale was soon found to be far more critical than anything experienced in the past. It was found necessary to exercise special care in the preparation of the diapositives to control small changes in film size in order to maintain consistent scale in the plates.

Plate flatness gave considerable trouble; not that the plates were warped excessively, but rather that in the oblique position, the effect of small deviations upon the model was much greater and therefore more noticeable. When trouble developed and the plates were suspected, a closely controlled remake would invariably yield good results. The men in the Diapositive Lab soon learned to set an exceptionally high standard of flatness in their plate preparation. Relative orientation, in the oblique position, required extra care but presented no great problem. A growing awareness of possible sources of error, coupled with a refinement of technique, resulted in satisfactory solutions.

COMPILATION

The projection and the position of pass-points resulting from the templet assembly were pricked through to scribe-coated Mylar compilation sheets (see Figure 6). The size of these sheets was a matter of convenience in handling and usually contained 12 models, 6 left-facing and 6 right-facing. Each model contained about 25 square miles. This permitted putting several men to work on a single 1:250,000-scale quadrangle, thus expediting delivery of individual quadrangles to the Cartography Section.

The contours and planimetry were compiled and scribed on the same plate, while the vegetative cover was compiled on a separate overlay registered to the original.

Since the topographers were viewing models at a scale of 1:18,000 to 1:22,000 and compiling at 1:63,360, for publication at 1:250,000, it was evident that some guide to appropriate detail must be furnished. This guide was prepared by drawing a model at 1:20,000 scale; this was reduced, photographically, to 1:63,360 and 1:250,000. A print of the 1:250,000 scale copy was scribed and then enlarged to both 1:63,360 and 1:20,000. This guide provided the needed bridge between model and publication-scale, and resulted in clear copy for the finish scribers.

This visual aid, in addition to the guidance of the supervisor, appeared to give excellent results as evidenced by the speed of compilation and the quickness with which the topographers changed from their normal large-scale compilation to the small-scale.

Save for the need for tight scheduling and the number of people involved, the compilation, as a whole, proceeded in a relatively routine manner. Eighty per cent of the area was drawn between October 1, 1957 and January 1, 1958.

COMPILATION REVIEW

Following completion of the manuscripts, they were sent to the Compilation Review Unit where they were given an examination for consistency in the portrayal of detail between the various squads, completeness of information, and over-all uniformity of product. The Review Unit also acted as a depositor for the various manuscripts covering a 1:250,000 quadrangle and delivered the various parts to the Cartography Section as soon as a 1:250,000 quadrangle was completed.

A brief report was prepared for each 1:250,000 quadrangle by the man making the review. It contained a record of the methods used, problems that developed during compilation, their solution, a reference to any material that was used in the compilation of the area, and a statement regarding the highest point in each 1:250,000 quadrangle.

FINISHING OPERATIONS

The Cartography Section, using photographic methods, reduced the manuscripts to 1:250,000 scale and combined the various negatives into quadrangles; from these they prepared their color scribing guides. They found that the manuscripts gave them quite legible copy and, considering the detail, relatively easy to scribe.

An interesting facet of mapping, that is normally secondary to the engineering aspects and problems but very important to the map user, is that of names. In completing the field operations in the Brooks Range, every effort was made to apply locally recognized names to the features. Because of the difficulty with the phonetics of the area, it is evident that the spelling and placement of some of the names may be in error, or at least the subject of much discussion. Only sound, constructive criticism by the map users will resolve this difficult problem.

From the maps prepared in the project, it now develops that what was formerly described as the highest peak in the area (Mt. Michelson) to which some publicity had been given as being the highest, is now secondary to two unnamed peaks. Due to the new compilation. the elevation of Mt. Michelson is lowered from 9,239 to 8,855, some 384 feet. Because it is good policy to have the most prominent physiographic features identified by name, consideration is being given by the Board on Geographic Names to naming the new-found peak Leffingwell, for the prominent geologist who spent so much time in the area. The unnamed peak is some 10 to 15 miles east and south from Mt. Michelson.

Conclusion

Three important questions should be answered:

(1) *Was the standard for quality met?*

(2) *What were the unit costs?*

(3) *Was the job completed on the target date?*

In answering the first: Testing a compilation in such an isolated area by the usual methods could not be justified from the point of view of economics. However, no insurmountable problems were presented during the stereotriangulation and compilation phases; the meager opportunity to sample fringe areas all point to adequate quality. Topographic detail can be reviewed from the photographs and, in addition, favorable comment has been received from those who know the area and have had the opportunity to review advance prints.

As to the second question: The direct unit costs in dollars can be broken down as follows:

	Per square mile
Photography	$1.70
Diapositives	0.10
Field Operations (GS)	2.25
Planning	0.05
Base Sheet Preparation	0.09
Stereotriangulation	0.60
Compilation	0.97
Inspection	0.06
Cartography Operations	0.29
	$6.11

To some, these figures might have more meaning in terms of models:

	Hours per model
Stereotriangulation	3.93
Compilation	7.42

Regarding the third question: For all practical purposes, the target date was met. This was due in no small part to the whole-hearted cooperation of such organizations as the Alaskan Air Command, Civil Aeronautics Authority, the 30th Engineers, the Army Map Service, U. S. Coast & Geodetic Survey, 1371st Mapping and Charting Squadron, 58th Weather Squadron. In the field of private enterprise, we give a great deal of credit to Wein Air Lines and the Mark Hurd Company. This list may seem long; if so it must be remembered that in a project of this kind, the specialized skills from many fields are required to bring it to a successful conclusion.

APPLICATION OF DOPPLER NAVIGATION TO AIRBORNE SURVEYS

This is the title of a paper in the No. 3, 1959 issue of the *Hunting Group Review*. The author is Roy Hall. Those interested by Hans Meier's paper in the September issue of this Journal may desire to read Mr. Hall's paper.