ever, it may result in slight overestimates if a mirror stereoscope is used.

Selected References

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*Mapping of Glaciers in Alaska**

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ABSTRACT: *As a part of its contribution to the International Geophysical Year program the American Geographical Society is mapping a number of glaciers in Alaska. The author is the photogrammetrist for this project. A pilot project was first undertaken using available ground-control and photography of the Lemon Creek Glacier in Alaska. In preparing the map of that glacier, the author was able to develop the procedures used in mapping several more glaciers during the summer of 1957. These procedures included both terrestrial and aerial photogrammetric methods. A triangulation network of high accuracy was put in on each glacier, and a sufficient number of points was determined so as to insure a check on the accuracy of the mapping procedures used. A comparison of these mapping methods is now being made.*

INTRODUCTION

INCLUDED among the many activities of the International Geophysical Year is the preparation of accurate topographic maps of a number of selected glaciers. As its part in the IGY program, the American Geographical Society is sponsuring IGY Project Y/4.11, the mapping of glaciers in Alaska. The author is photogrammetrist for this project. The maps are being plotted using the Wild A-7 Autograph at the Institute of Geodesy, Photogrammetry, and Cartography of The Ohio State University. The map manuscripts are being prepared at scales of 1:5,000 and 1:10,000 with a contour interval of 5 meters.

These maps will be used primarily for correlating long-range changes in the weather and corresponding changes in the glaciers. A method for determining such changes in glaciers as advance or retreat, and annual accumulation (snowfall) and ablation (snow and ice melt and evaporation) have been thoroughly described by Dr. Richard Finsterwalder.[1] In his method a comparison is made between maps pre-

[1] Finsterwalder, R., "Photogrammetry and Glacier Research with Special Reference to Glacier Retreat in the Eastern Alps," *The Journal of Glaciology*, Vol. II, No. 15, pp. 306–315, April, 1954.

* Presented at the Society's 24th Annual Meeting, Hotel Shoreham, Washington, D. C., March 28, 1958.

James B. Case

pared during successive years or periods of time; the changes in height, length, and volume are then determined using his simple formulas.

Glacier maps can also be used as a base for scientific planning and research, and for determining changes in water storage. In the latter case glaciers have gained a considerable economic importance in the alpine regions of Europe and even in some parts of the United States, as sources of water for hydro-electric plants, irrigation, and city water supplies.[2]

The use of photogrammetry in glacier surveys is not an innovation. Dr. Finsterwalder, in the above mentioned paper, traces the historical development in Europe and other parts of the world and gives a fairly complete bibliography. In recent years a number of glacier mapping projects have been undertaken in this country. These include the work of Walther Hofmann[3] on Mount Rainier, the work of a group from the University of Washington[4] on the Coleman Glacier on Mount Baker, and Arthur Johnson's[5] work in Washington and Montana for the Geological Survey. In almost every case, however, the work has been carried out using terrestrial photogrammetric methods, necessitating the use of plotting machines which are available only in Europe or to a very limited extent in this country.

The author is carrying out his work on IGY Project Y/4.11 as a Research Fellow of the American Geographical Society and as a part of his studies in photogrammetry at The Ohio State University. As such, it was found desirable to divide the project into three phases: 1) A pilot project on the Lemon Creek Glacier in Alaska, 2) the actual production of maps for IGY Project (Y/4.11, and 3) and evaluation of various methods in glacier mapping.

The Lemon Creek Glacier, Alaska

During the summer of 1955 Edward R. LaChapelle, field leader of the Juneau Ice Field Research Project, carried out a control survey and terrestrial photography on the Lemon Creek Glacier, located about four miles from Juneau, Alaska (See Figure 1, number 8). The glacier is about four miles long and one mile wide. A Wild P-30 phototheodolite was used for terrestrial photography giving about 90 per cent stereophotographic coverage from the five established photo baselines. Also, at this same time, the U. S. Air Force flew vertical aerial photography, but used an uncalibrated, twelve-inch focal-length, reconnaissance camera. However, in September, 1957, six-inch aerial photography was obtained by the U. S. Navy.

The survey data, terrestrial photography, and Air Force aerial photography were turned over to the author in February of 1957 when he began his work for Project Y/4.11. It was felt that in preparing a photogrammetric map from these data, the author would be better able to determine the most suitable field survey and plotting procedures for the 1957 summer mapping program. However, due to discrepancies in the survey data and other difficulties, the author did not complete the map until November, 1957, when the later aerial photography was made available. A complete discussion of these problems is included in the author's Master's

[2] Camp, F. A., "Sierra Nevada Glacier Measured," *Civil Engineering*, Vol. 28, No. 2, pp. 34–35, February, 1958.

[3] Hofmann, W., "Photogrammetric Glacier Measurements on the Volcanic Peaks of Washington," *The Mountaineer*, Vol. 45, pp. 7–16, December 15, 1953.

[4] Harrison, A. E., "Photogrammetry of Glaciers," *The Trend in Engineering at the University of Washington*, July, 1957.

[5] Johnson, A., Personal correspondence with James B. Case, November 1, 1957.

FIG. 1. Location of glaciers being mapped for the IGY program.

thesis "Photogrammetric Mapping of the Lemon Creek Glacier, Alaska."[6]

IGY PROJECT Y/4.11

In the spring of 1957 the author was provided with a tentative list of glaciers to be mapped during the next two summers. The criteria for their location was that they be distributed throughout the various climatological regions of Alaska (see Figure 1) that they be easily accessible, and that they be of a suitable size (from two to five miles in length and up to a mile in width and with a minimum of tributaries). Flight plans were then prepared for these glaciers. Based on the plotting scale (1:5,000), contour interval (5 meters), plotting instrument (Wild A-7 Autograph), and aerial camera (six-inch metrogon lens), a flying height of 15,000 feet above the lowest part of the glacier was chosen.

FIELD SURVEY OPERATIONS

During the summer of 1957 control surveys were completed on three glaciers; the Worthington Glacier near Valdez, the West Gulkana Glacier near Paxson, and the Polychrome Glacier in Mount McKinley National Park (Figure 1, numbers 1, 2, and 3). The survey party consisted of Austin Post as field leader, the author as surveyor and photogrammetrist, and Richard Long, an expert mountain climber, as assistant. A jeep pickup truck, belonging to the field leader, was used for transportation.

The three glaciers were all less than five miles from roads and easily accessible on foot. In each case a camp was set up about halfway up the glacier. Two trips were usually required to get all the equipment in to the camp. (The survey equipment alone weighed about 115 pounds.) Travel on the glaciers required the strictest adherence to mountaineering procedures and safety techniques. Food consisted of Army "C" and "5-in-1" rations supplemented by locally purchased groceries. Late in the season some parachutes were obtained and food was air dropped into the camp sites, a very satisfactory arrangement.

During the 1958 summer season, because of the inaccessibility of several of the glaciers, it is planned that aircraft will be used to transport the survey party into the glaciers and greater use will be made of airdrops. Elimination of terrestrial photography is being considered, which would reduce the weight of the survey equipment by some 60 or 70 pounds.

SURVEY PROCEDURES

Standard triangulation survey procedures were used.[7] A reconnaissance was

[6] Case, J. B., Unpublished Master's thesis, The Ohio State University, 1957.

[7] Gossett, F. R., *Manual of Geodetic Triangulation*, U. S. Coast and Geodetic Survey, Special Publication No. 247, U. S. Government Printing Office, Washington, D. C., 1950.

first made and then all triangulation stations were marked with brass tablets cemented in rock. The triangulation stations were signaled with stripped poles topped with panels of red bunting and guyed with wire. A base line was then measured from which quadrilaterals were extended. (The Worthington Glacier survey was connected to existing USC&GS triangulation.) All triangulation stations were occupied by the survey instrument. Picture points, usually prominent peaks or cairns, were observed by intersection. Some photogrammetric bases were located by resection. Figure 2 shows such a photo base on the Polychrome Glacier. The elevation datum on the Worthington Glacier was determined from previous surveys, on the West Gulkana Glacier by altimeter, and on the Polychrome Glacier from the USGS 1:63,360 scale map of that area. Elevations were then extended throughout the glaciers by vertical angle measurements.

SURVEY INSTRUMENTS

Measurements of directions and vertical angles were made using a Wild P-30 phototheodolite. (For a short time on the Worthington Glacier a Wild T-2 theodolite was also used.) A Wild two-meter subtense bar was used for baseline measurements and a Wallace and Tiernan aneroid altimeter was used to determine the elevation datum.

SURVEY STANDARDS

Survey standards were adopted that would insure against blunders and assure the necessary accuracy for plotting a map at a 1:5,000 scale and five-meter contour

FIG. 2. Polychrome Glacier from the west end of photo base GREEN.

interval. For these purposes, it was determined that no control point should be in error by more than one meter in position or elevation. Third-order methods as set forth by the USC&GS were used, as the author felt that these methods would fulfill the necessary requirements.

For horizontal direction measurements, a set of four positions was turned at each station. A position consists of a round both direct and reverse, the circle being advanced 45° for each position. Vertical

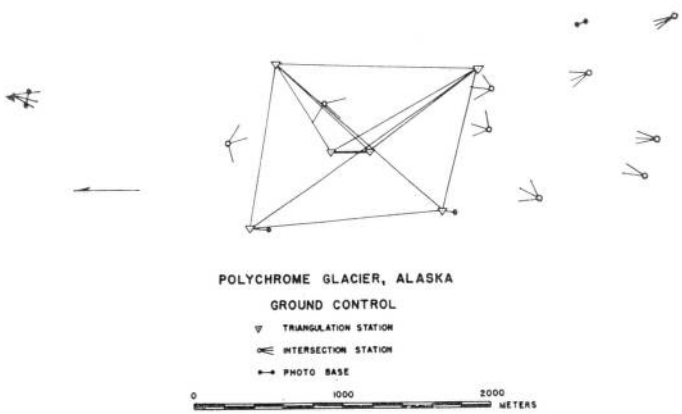

FIG. 3. Control survey scheme for the Polychrome Glacier.

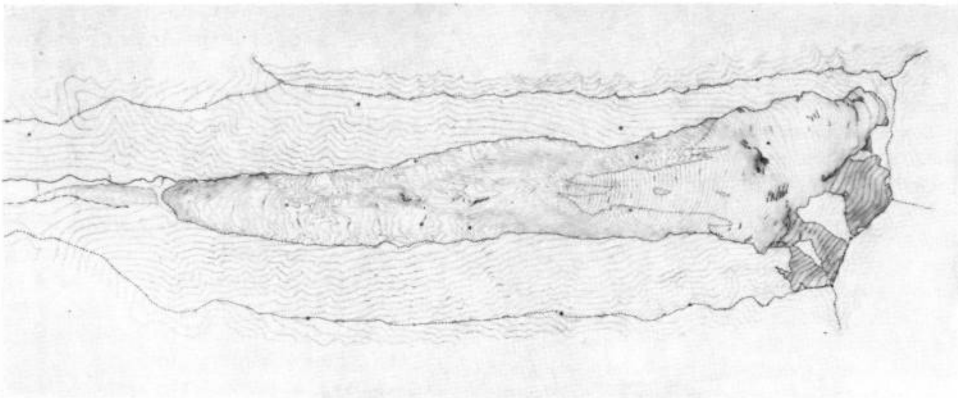

FIG. 4(a). Map of the Polychrome Glacier plotted in the Wild A-7 Autograph from aerial photography.

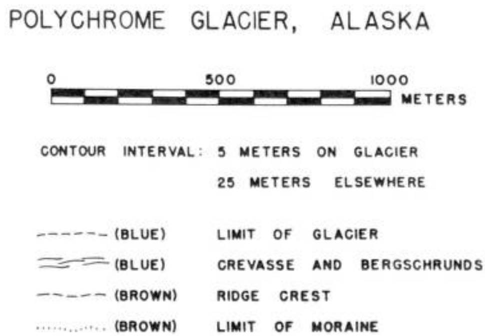

FIG. 4(b). Legend for Fig. 4(a).

angles were measured three times, both circle left and circle right. Subtense bar baselines were broken into segments of no more than 75 meters each and measured both forward and backward.

Triangulation figures consisted of quadrilaterals of overlapping triangles. Intersection stations were observed from at least three triangulation stations and resection stations observed upon at least four triangulation stations. Figure 3 shows the triangulation scheme for the Polychrome Glacier, and is typical of this project's survey work.

REDUCTION OF FIELD DATA

Standard field books and survey forms of the USC&GS were used. Observations were recorded and computed in the field. The field books were checked and directions abstracted at camp in the evenings. Computations of triangles and elevations were made during inclement weather and while moving from one glacier to another. Seven place logarithms were used.

Final computations are now being completed. No adjustment of triangles, beyond that of balancing the sum of angles to 180°, has been found necessary. A constant value of atmospheric refraction was used for elevation computations on intersection stations. The results obtained show errors to be generally less than 0.1 meter in both position and elevation.

PHOTOGRAMMETRY

Aerial Photography. Aerial photography was provided by the U. S. Navy Heavy Photographic Squadron 61, Detachment "Tango." A T-11 mapping camera with six-inch Metrogon lens was used in a North American AJ2-P "Savage" aircraft. Aerial photography was completed on the following glaciers: Worthington, West Gulkana, Polychrome, Salmon Creek (near Seward), Skolai (near Nizina), Porcupine (near Haines), and a glacier in the Kilbuck Mountains. Additional photography, both vertical and oblique, was taken for other projects, including the Lemon Creek Glacier. Glass diapositives of all the aerial photography have been prepared on a LogEtronic printer at the Ohio State Department of Highways.

Terrestrial Photography. Terrestrial photography for mapping was taken at all three glaciers during the summer of 1957. Because of the rugged terrain, it was found almost impossible to locate photogrammetric bases so as to give complete stereoscopic coverage of the glaciers. Kodak Super Panchro Press photographic plates were used.

Photogrammetric Plotting. At this time a topographic map of the Polychrome Glacier has been completed (see Figure 4).

Evaluation of Glacier Mapping Methods

The nature of IGY Project Y/4.11 has allowed the author the unique opportunity of investigating and evaluating various methods and procedure in the mapping of glaciers (or, for that matter, in the mapping of any small, mountainous area). A large number of superfluous control points were put in on all the glaciers surveyed during the summer of 1957, allowing for the determination of the accuracy of various methods. Both aerial and terrestrial photography were obtained so that a direct comparison can be made between these two basic photogrammetric methods. A Wild A-7 Autograph and a Kelsh Plotter are available to the author, thus making possible an evaluation of these two instruments for glacier mapping.

A COMPARISON OF TERRESTRIAL AND AERIAL PHOTOGRAMMETRY

As was stated previously, most glacier surveys in the past have been carried out using terrestrial photogrammetry. There are a number of reasons why this should be. First of all, terrestrial photogrammetry might prove more economical in that a ground party operates at a low cost, and the phototheodolite equipment is relatively inexpensive when compared with the cost of operation of an airplane, its crew, and their equipment. Quite often other types of research are being done on the glacier, requiring occasional return trips, and ground photography can be very easily taken as an adjunct to that work. Ground photography can also be carried out under a low cloud cover that would obscure the glacier from an aerial view.

It is this author's feeling, however, that in many instances aerial photogrammetry should prove to be a much more satisfactory method. A recent project at The Ohio State University involved the preparation of a topographic map of the Blue Glacier which is located on Mount Olympus in the State of Washington. A local aerial survey firm was hired in Seattle and in one day was able to complete the aerial photography for that glacier at a cost which compares very favorably with that of obtaining ground photography. However, in a region such as Alaska, obtaining aerial photography can become very expensive unless a number of glaciers can be photographed at the same time or, as in the case of IGY Project Y/4.11, the support of the Armed Services is obtained. In the case of projects involving repeated mapping of a glacier, the terrestrial photogrammetric method requires that a ground party return to the glacier each time photography is required. On the other hand, once permanent, identifiable ground-control has been established, aerial photogrammetric mapping can be accomplished at any time in the future, with no need of a ground party going into the glacier. This would be particularly important in inaccessible regions.

Due to the nature of the terrain, it is sometimes impossible to obtain complete stereoscopic coverage of a glacier with terrestrial photography, and the coverage obtained may require a large number of photographs. For instance, for the Lemon Creek Glacier fourteen pairs of terrestrial photos gave about 90 per cent coverage, while only four pairs of aerial photos gave 100 per cent coverage. For the Polychrome Glacier the author took ten pairs of terrestrial photos but was able to map the glacier from only two pairs of aerial photos. Because of this large number of photos, terrestrial photogrammetry requires a greater number of ground-control points and a considerably longer time for plotting the map.

Until the author has plotted a map using the terrestrial photos (a project now being undertaken), a complete comparison of the two methods with respect to accuracy cannot be made. However, in photogrammetric plotting the accuracy is strongly dependent upon the distance from the camera to the object being plotted. Thus, in aerial photography the accuracy of plotting is fairly uniform throughout the map whereas the accuracy of terrestrial photogrammetry decreases as the square of the distance from the camera stations.

AN EVALUATION OF PLOTTING PROCEDURES

In making a comparison between terrestrial and aerial photogrammetric methods, factors which must be considered are the plotting methods and equipment to be used. A universal plotting instrument with the capability of setting in known elements of interior and exterior orientation is required for the plotting of terrestrial photography. Only a very few of these instruments and the personnel to operate them are available in this country. For this reason, much of the plotting of terrestrial photography has been done is Europe. On the other hand, inexpensive instruments such as the Kelsh Plotter, which are used by almost all mapping organizations in this country, can be used for plotting a map from aerial photography.

In order to determine the suitability of the Kelsh Plotter for mapping of glaciers at the specified scale and contour interval, the author plotted maps of the Polychrome Glacier in both the Wild A-7 and the Kelsh Plotter. It was necessary to plot the maps at a scale of 1:6,000 in order to be within the range of the Kelsh Plotter. In each of the two models required for plotting there were eleven control points, five points being common to both models. For the Wild A-7 a standard elevation error of ±0.5 meters was obtained, and for the Kelsh Plotter a standard elevation error of ±0.9 meters was obtained. These values are entirely satisfactory. There was no significant difference in the plotting time of the two instruments. Although the Kelsh Plotter does not give nearly as large or well-defined an image as the Wild A-7, a comparison of the contours and planimetry of the two maps showed very good agreement. However, for the best results the author would recommend lowering the flying height from 15,000 feet to 12,000 feet, for plotting in the Kelsh Plotter.

Conclusions

Many important and interesting applications have been found for terrestrial photogrammetry in recent years. The author feels, however, that, where economically feasible, aerial photogrammetry in most cases offers a more satisfactory solution to the problem of mapping glaciers.

A Geographic Approach to the Study of Photo Interpretation

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ABSTRACT: *Since the air photo is a representation of the landscape, no photo can be interpreted without an understanding of what makes up the landscape. A curriculum in photo interpretation should include the following stages: the rudiments of morphology, geology and other earth sciences; after these have been assimilated, the basic principles of air photography; later, the more advanced principles of physical geography and the study of man-made features in the landscape; and only then photo interpretation. Interpreters trained by this method will be successful both in forestry and civil engineering and will be able to take up independent research in the earth sciences.*

If the scientific and technical world has not already learned to exploit all the potentialities of air photography, this is largely due to a shortage of experts of the required caliber in interpreting air photos.[1] Because of the long period required to amass adequate experience in interpretation, an insufficient number of students attain the required standard,[2] either in the United States or in smaller countries, where the problem is serious. Those who teach photogrammetry and photo interpretation must try to shorten this period, and at the same time must attempt to raise the standard.[3]

Let us not delude ourselves by thinking that photography is only a tool in obtaining information about some aspect of the landscape we photograph. The photo interpreter cannot do a top job of interpretation unless he has acquired a real grounding in one of the earth sciences and he has more than nodding acquaintance with the other sciences dealing with the element of landscape. Experience has shown that the students who had mastered a real understanding of these elements achieved a satisfactory level of

For Footnotes[1,2,3] see bottom of next page.