*New Developments in Photogrammetric Training for Geologists**†

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ABSTRACT: *Within the U. S. Geological Survey many geologists have been applying certain photogrammetric techniques and using some of the less elaborate photogrammetric instruments in their geologic mapping problems since 1930. Also, photogeology has been used in field and office procedures for many years although the refinements in techniques and equipment are of more recent origins. The present emphasis on training many geologists in the Geologic Division in photogrammetric techniques is broadening their understanding of the potential of these techniques and with an excellent effect. An introduction to the fundamentals of photogrammetry and a familiarization with the most widely used stereoplotting instruments appears to be the most effective approach in introducing photogrammetric techniques for the first time; it is also important to convey a knowledge of their limitations.*

INTRODUCTION

THE United States Geological Survey has been conducting, over the past two years, an interesting experiment in training large numbers of geologists in the fundamentals of photogrammetry and in the application of stereoscopic plotting machines to the problems of geologic mapping. The results of this experiment have been, on the whole, so conclusive as to warrant communication of our experiences to our colleagues abroad; and to point out, in addition, the advantages of introducing training in photogrammetric instrumentation not only in geology, but in all the earth sciences through a training program which includes instruction in stereoscopic plotting methods. Some of the newer instruments and materials are being applied to both the qualitative and quantitative aspects of geology.

FAVORABLE CLIMATE FOR PHOTOGRAMMETRIC TRAINING

Several factors contributed to the adoption of extensive training programs for Survey geologists. One of these is the practical nature of photogrammetry itself; as a science of measurement it becomes, in due time, applicable to many of the problems of surveying and measurements that are normally found in this field. The most compelling reasons, however, seem to be found in the expanding requirements for geologic mapping in recent years and the need for more detailed mapping. There are also unique organizational advantages in the Geological Survey; these have made it possible to develop a program of photogrammetric training in geology as an organization activity, under unified control.

* Publication authorized by Director, U. S. Geological Survey.

† This paper is a contribution to Commission VI of the International Society of Photogrammetry.

‡ United States Reporter, Commission VI, Education, Terminology and Bibliography.

Underlying Factors

Many geologists already were using aerial photographs as contact prints or enlargements for plotting field geology, and were combining field work with photographic information to obtain quantitative data such as dips, strikes, thickness of beds, profile measurements, and the like to a high degree of accuracy. A few geologists were combining aerial geologic mapping with contouring by photogrammetric methods to develop structure contours.

For maximum results in the use of aerial photographs for geologic mapping a greater familiarity with photogrammetric instruments is required and especially a knowledge of their limitations. In addition it was believed that, as much of the national economy was dependent on the search for minerals and fuels, and we had on hand many new instruments and techniques brought about by research in recent years, these instruments could be applied to the task.

Need for Training

Since 1945 many problems have come up which primarily concerned the application of instruments that were developed for topographic mapping to the problems of geologic mapping. As aerial photographs were being used as contact prints or enlargements on which to plot detailed geology, one of the recurring problems was that of relating, or transferring, geologic data from aerial photographs to base maps. Double-projection instruments, because of their simplicity, are able to supply the link between the perspective of the aerial photograph and the orthographic projection of the map, and so are immediately applicable to this type of problem. To effectively use instruments, however, requires considerable training.

From the viewpoint of the photogeologists, who had already made considerable use of the stereoscope in the field, photogeologic mapping under double-projection instruments might prove even more attractive, since in many cases these instruments could combine stereoscopy with the ability to make many measurements similar to those he was now making on the ground. Only a few geologists, however, had training in these instruments, which heretofore have not been available for their use.

Organizational Advantages in the Geological Survey

Our organization is unique in that it has always been one of the largest operators in the United States engaged in both topographic mapping employing photogrammetric means, and geologic mapping. Actually, this close association of topographic and geologic mapping goes back more than 75 years, to the formation of the U. S. Geological Survey, for the authorized purpose of classifying public lands, and examining the geology and mineral resources of the United States.

During the past fifteen years, there has been a very great increase in the application of photogrammetric methods to topographic mapping. The Geological Survey also developed during this time an integrated program for research and development in the three major elements of photogrammetric mapping: aerial photography, plotting equipment, and technical procedures. The results of this research program led to the development of new and more efficient photogrammetric instruments. Among these was the ER-55 Projector designed to be used with either vertical or twin-low oblique photography and the Twinplex plotter; these instruments replaced, to some extent, the use of standard Multiplex equipment for bridging and for some stereoplotting procedures. During this time, also, the Kelsh plotter went through a rapid development which led in 1951 and 1953 to two standardized Geological Survey models. The latter models incorporated many improvements for facilitating topographic mapping; these improved models made possible releasing a small number of earlier Kelsh instruments for training and experimentation in the special problems of geologic mapping. Similarly, a quantity of other photogrammetric equipment—cameras, stereometers, stereoscopes, and allied equipment—became available due to changes in our technical procedures.

Our organization also has a staff of scientific and technical people from both the geologic and topographic fields that can concentrate on new problems and developments, and collaborate in a training program for geologists in the newer photogrammetric methods. The operations of a group such as this must be guided by a long-range plan. In this respect, an enlightened management which represented the two major fields of work, topography and geology, saw an opportunity to develop a program which could lead to more and better geological mapping at lower cost.

Work of the Interdivision Committee

As a means of expediting joint efforts towards more efficient utilization of photogrammetric techniques in geology, the Chief Topographic Engineer and the Chief Geologist, in 1953, formed an Interdivision (Topography and Geology) Committee on Photogrammetric Techniques in Geology. Three representatives from each Division were appointed to form the committee. Among the objectives of this committee were the following:

(1) Advising geologists in the proper use, limitations, and value of air photographs.

(2) Conducting a research program in photogrammetric instrumentation for field and office use in geologic mapping.

(3) Considering problems brought to the committee's attention and assisting in preparing plans and procedures.

(4) Providing a training program to acquaint geologists with basic understanding of photogrammetry.

As the work of the committee progressed, it became increasingly clear that a training program in the fundamentals of photogrammetry was one of the most pressing needs. The committee first explained the rudiments of photogrammetry to any geologist desiring it, using the Multiplex for demonstration. This was considered an ideal instrument for the purpose; through its simplicity and directness most of the fundamentals of photogrammetry could be shown in a short time. Training soon became one of the early enterprises of the committee.

Later it was decided to set up a more useful and comprehensive training course by providing a ten-day training period in which the basic principles could be given. Learning by doing was to be emphasized; students would learn by operating the different instruments to construct their own maps. Instruction was to be given by the members of the interdivision committee and by instructors provided by the Topographic and Geologic staffs. Selection of candidates for the course was made by the Chief Geologist. Instruction at first was limited to groups of ten geologists in order to emphasize individual instruction in the operation of photogrammetric equipment; this was later increased to groups of sixteen. Provision was also made at a later date to include engineers and geologists from other divisions of the Survey.

Scope of the Introductory Course in Photogrammetry

During the first week, following a description of the aims and purposes of the course, instruction is given in the use of double-projection instruments of

American and European make, instruments that are normally employed in the production of standard accuracy maps. Discussions are informal and the student is encouraged to present his own problems so that his training might be guided to fit his particular needs.

Geologic Origins of Photogrammetry

A review of the important photogrammetric developments in the United States is given. Here one learns that photogrammetry in the United States began with the work of two brother geologists, Clarence W. Wright and Fred E. Wright, who first employed a panoramic camera for recording geologic details in Alaska in 1904. This review serves to tie together the present with the not too distant past when photogrammetry and geology first came together.

Brief information is given on methods and instruments used by different organizations in order to suggest possible application to present geologic mapping problems. The new trends and developments in photogrammetry are discussed; these are expected to have a considerable effect upon geologic mapping.

Stereoscopy

Since stereoscopy is the foundation for many of the photogeologic studies, considerable attention is given to the underlying principles, namely how stereoscopic vision is formed and the factors affecting visual acuity, and how the visual model is formed under the stereoscope and under the double-projection stereoplotting instrument. Some of the factors producing vertical exaggeration in viewing pairs of photographs under the stereoscope are discussed; this is an important factor in photogeologic interpretation. The principle of anaglyphic projection is demonstrated as a prelude to description of the modern stereoscopic plotting machines, such as the Multiplex, Kelsh, and ER-55 which employ this principle in constructing a geometrically-correct stereoscopic model of the terrain. Arrangements are made whenever possible to give each student an orthorater test to measure his visual acuity and ability to see stereoscopically.

Stereoplotting

The student is given a prescribed course of exercise in handling the Multiplex and Kelsh plotters, the two instruments most widely used in the United States. Experience tells us that there is a good reason for an early acquaintanceship with these instruments; it is best to permit the student to learn the physical characteristics of each machine first; then the theory on which the instrument is based; finally back to the instrument for the practice stage, with a better knowledge of each mechanical adjustment.

In addition to practice with the double-projection instruments employing the principles of anaglyphic projection such as the Multiplex, Kelsh, and ER-55 plotters, the student obtains a brief introduction to the so-called heavy plotters of European make employing the principles of mechanical projection: the Zeiss Stereoplanigraph (usually included in this group although based on the principle of optical projection), the Wild A-5 and A-6 Autograph and the Wild stereoplotting machine. A step-by-step explanation of the instruments is given describing as closely as possible the procedures followed in a practical mapping operation.

Map Planning

Here the student learns that to obtain maximum benefits from photogrammetric techniques, careful planning is required at the beginning of every project. It is often cheaper to fly new photography correctly designed than to attempt to use older photography that may be designed for some other purpose, even when such photography is provided gratis. The best opportunity to save time and money is at this point, by judicious planning and careful design of the photography to fit the scale, accuracy and use of the final product. The importance of base-to-height ratio for spacing along the flight lines, and width-to-height ratio for spacing between the flight lines, is stressed. Sample problems in design of aerial photography are worked out. The importance of seasonal variations, vegetative and forest cover, snow cover, and local conditions affecting photographic quality are brought out.

During the first week much of the instruction is given to the orientation procedures and individual practice with the Multiplex and Kelsh, instruments which produce geometrically-true spatial models in a simple and easily-understood fashion. It should be remembered that many of the students have never handled instruments of this type before. Here the relationship of the photographs to the taking lens-camera combination, the relative relation between successive photographs and the relation of the stereoscopic model to external conditions of control is explained. The student-operator having found that he, too, can level a model begins to draw his map; he finds that he too can make certain measurements of geologic features, an impressive discovery since he proves to himself that the floating mark—like his Brunton compass, hand level, aneroid barometer, planetable, and telescopic alidade—can become another useful tool for making measurements.

Stereoscopes and Stereometers

During the second week, photogeology, the interpretative aspect of geologic mapping with aerial photographs, is covered. Here the student learns to use correctly his most important tool, the stereoscope. Fortunately, the stereoscope is also the simplest of all the photogrammetric instruments. It is useful to learn that there are many different kinds of lens, mirror and prism stereoscopes available, but that some stereoscopes have serious drawbacks for study of photogeology; also, that there is a need for further improvement in stereoscopes for geologic use. In addition to good quality photography and a good background in geology, the techniques of photogeology should include: (1) integration of photo-interpretation with field work, (2)good stereoscopic vision, and (3) training and experience in photo-interpretation and use of appropriate photogrammetric instruments.

In the laboratory exercises some of the simpler measuring devices, the stereometer (parallax-bar) and slope-reading instruments, are demonstrated. The student learns to make measurements for dip, strike, thickness of beds, and the like; measurements which he has often made in the past on the ground.

Radial-line Plotting

The principles of radial plotting, one of the fundamentals of photogrammetry, are demonstrated. The student is shown how to construct a graphic triangulation net using vertical photographs, and later he translates these principles into mechanical triangulation systems. A wide variety of graphic and mechanical radial methods is shown: the continuous radial plot; "hand" transparent templets; slotted mechanical templets made of metal or cardboard; and stereotemplets, a new scheme for mechanical triangulation which incorporates the geometrically-correct precise measurements of the stereoscopic plotting instruments into a convenient, mechanical templet system for extending horizontal control. Stereotemplets are considered by the geologist to be one of the outstanding recent developments in photogrammetry.

Plotters Employing Paper Print Photographs

Following construction of a control base the student learns to transfer planimetric detail by applying the various optical transfer devices such as the sketchmaster. Later, more elaborate plotting devices are demonstrated; these instruments make use of photographic prints and have come to be known as the "paper-print" instruments. Some examples of these instruments are the Kail, KEK, and Mahan plotters. These instruments are useful for certain types of work, although considered less accurate than the double-projection instruments. They are sometimes used as transfer devices enabling one to transfer geologic detail, identified on the photographs, onto a topographic base.

Graphic Methods

The sections of the course dealing with graphic methods of using aerial photographs have been found to be very useful since a geologist spends much time in the field with his notebook and aerial photographs only. Graphic methods, also, are another means for teaching the fundamentals and demonstrating how theoretical principles can be applied to extracting useful information from vertical, oblique and terrestrial photographs. A knowledge of graphic methods increases one's self-reliance and can be used to solve many of the problems with simple tools when the more elaborate ones are not at hand. Some typical examples of the graphic methods are extraction of vertical and horizontal angles from oblique and terrestrial photographs, and how they are used to obtain position of features and their elevation.

Oblique Photographs

Some instruction is given in the theory and use of oblique photographs and the photoalidade. Oblique photography, an outgrowth of the need for aeronautical charting on a worldwide basis, is still used in reconnaissance work, and remains a special interest of our Alaskan Geology Branch. Oblique photographs present a comprehensive view of the terrain and enable a geologist to tie together many geologic details over a wide area. Their greatest value lies in displaying physiographic, geologic, and geographic features in natural perspective, and they can be studied under the stereoscope, facilitating reconnaissance geology and the planning of field work. In order to obtain a better understanding of the basic principles of photogrammetry, some instruction is given in the photoalidade. Photoalidade work is very similar to planetable and alidade work in the field. Vertical and horizontal control can be extended by photoalidade means; sometimes it is an only means for establishing control in remote, inaccessible regions.

Newer Photogrammetric Techniques

The training course is most effective for conveying information of some of the newer techniques of photogrammetry that can be applied to the geologist's problems. One of the common problems is that of transferring field geology from photographs to the topographic base map. Fundamentally, this particular problem concerns the differences between the perspective of the aerial photograph and the orthographic characteristics of the map. The geologist has already learned to solve this problem by means of stereoscopic plotting instruments or by means of new techniques developed under the auspices of the Interdivision Committee.

One of the methods developed as a result of geologic interest in photogrammetry is the stereo-plotted grid, a systematic means for organizing the perspective field of the photograph and the map field by a precisely plotted grid. A one-centimeter grid is photographically transferred to one of a pair of diapositives and placed in a Kelsh model or other appropriate double-projection instrument, where a stereoscopic model is formed. The grid lines, which appear monoscopically in the model, can, however, be plotted precisely upon a map. Both the gridded photograph and its counterpart, the stereoplotted grid, are now available to the field geologist as a means of communication between photograph and map.

Another photographic material, also developed as a result of the exchange of ideas of the geologist and photogrammetrist, is the orthographically-restituted photograph. This is a photograph in which distortions due to tilt and relief are methodically removed by mechanically scanning a stereoscopic model of the terrain, and re-photographing the images, corrected for relief and tilt, upon a fresh piece of film. A new stereoscopic photo-scanning instrument, which rectifies the relief perspective of a photograph to that approaching orthographic presentation, is called an "Orthophotoscope." The photographic product of the instrument, still in the development stage, is called an "Orthophotograph." Many geologists believe that the Orthophotograph will have an important application in geologic mapping.

A number of new photogrammetric instruments that have been designed for geologic use are demonstrated; among these are a photogrammetric profile plotter for double-projection instruments, and other devices for making dip and strike measurements.

Related cartographic techniques employing plastic-coated materials for photographs and maps are shown; these materials, which can be scribed by a pointed graver, are rapidly replacing pen-and-ink drafting, in many cases.

Other important developments and their possible effect on geologic mapping are discussed. Among these are the new ER-55 photogrammetric projector, which is replacing the Multiplex, and the Twinplex, a new device for plotting with twin low-oblique photography. These technical advances are, in a practical sense, indirectly hastening the adoption of photogrammetric instrumentation by geologists by making available older but by no means outmoded equipment. Geologists of the U. S. Geological Survey have already acquired Multiplex and Kelsh plotting equipment and are employing these instruments in their work; more recently the ER-55 projector has been ordered.

Summary and Discussion Feature

One of the unusual features of the course is a general summary and discussion at the end in which both the students and instructors participate. The graduates are invited to present their criticisms and suggestions; the instructors are thereby kept alert to provide first-class instruction. Some of the most attractive features of the course have resulted from this open discussion. A better understanding of mutual problems of the two largest Divisions of the Geological Survey has been made possible through the informal contacts the course has provided.

Outline of the Course

It will be interesting to many of our colleagues to have an outline of a typical ten-day course in familiarization with photogrammetric principles, instruments and methods, as follows:

First Week

1st Day Aims of the course
Background of photogrammetry
Principles of stereoscopy

Inspection of stereoscopic plotting instruments
- a. Multiplex plotter
- b. ER-55 plotter
- c. Kelsh plotter
- d. Universal plotters

2nd Day Geometry of the photograph
Aerial cameras
- a. T-12 precision camera
- b. Camera calibrator
- c. Optical bench
- d. Comparator

Diapositive preparation; 153/30, 153/55, and 153/153 diapositive printers
Orientation procedures: Interior, relative and absolute orientation.

3rd Day Demonstration of orientation procedures
Map preparation (lecture)
Control, basic and supplemental
Map preparation (demonstration)
- a. Base sheet preparation
- b. Stereotriangulation
- c. Compilation procedures
- d. Compilation data

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4th Day Map compilation practice
Newer instruments and techniques
- a. ER-55 projector
- b. Orthophotoscope
- c. Twinplex projector

Scribing techniques
Cartographic procedures

5th Day Map planning
- a. Technical planning for standard-accuracy topographic maps
- b. Programming of work
- c. Technical planning for special purpose maps

Inspection of procedures having individual interest
Practice with stereoplotting equipment
General summary of course
- a. Summary and discussion of problems
- b. Technical facilities available
- c. Suggestions by students

Second Week

1st Day Tour of Special Maps Branch
Principles of radial plotting
- a. Continuous radial plot
- b. Hand templets
- c. Slotted templets
- d. Metal templets
- e. Stereotemplets

2nd Day Construction of radial line plot
Geological interpretation of aerial photographs
Stereometers and slope-reading devices
Application of stereoplotting instruments in geologic mapping

3rd Day Stereoscopes for geologists
Theory and practice of sketchmasters
Plotters employing paper-print photographs
- a. Kail plotter
- b. KEK plotter
- c. Mahan plotter

4th Day Graphic photogrammetric methods
Practice in Kail, KEK, and Mahan plotters
Applications and limitations of "paper-print plotters"

5th Day Geometry of terrestrial and oblique photographs
Application of terrestrial and oblique photographs
Theory and demonstration of photoalidade
General summary and discussion with students

Plans for the Future

Six training courses in photogrammetry for geologists were given during the 1954–1955 period at the Washington headquarters of the Geological Survey. Additional courses are scheduled during 1956.

A second training center for geologists was organized at Denver, Colorado for geologists operating in the Rocky Mountain region. The first course, given in September 1955, was made identical to those given in the Washington area. Plans are being made to give this course over an extended period to about one hundred additional geologists and engineers from the Geologic, Water Resources, and Conservation Divisions.

The possibility of a third training center, to be located in the Pacific Coast area, is being considered; if approved, this center will provide training for geologists in the far west and those engaged in Alaskan work.

Conclusions

The most frequent observation made by those who have completed the course is that every geologist who does field work and map compliation should benefit by this type of training. Experience in giving the courses also indicates that training should include a knowledge of basic photogrammetric principles and the most comprehensive training possible in photogrammetric instruments, as well as in the techniques of photo interpretation.

It seems appropriate to report to our colleagues abroad that the training courses described appear to have been built on a sound and practical basis. The information and skills acquired can be put to immediate use by the geologist. The courses have stimulated interest in the application of photogrammetry to making measurements of dips, strikes, thickness of beds, profile elements and the like; measurements heretofore largely made in the field.