COMPUTER-ASSISTED PHOTOGRAMMETRIC MAPPING SYSTEMS FOR GEOLOGIC STUDIES—A PROGRESS REPORT

By

C. L. Pillmore[1], K. S. Dueholm[2], H. S. Jepsen[3], and C. H. Schuch[4]

ABSTRACT

Photogrammetry has played an important role in geologic mapping for many years; however, only recently have attempts been made to automate mapping functions for geology. Computer-assisted photogrammetric mapping systems for geologic studies have been developed and are currently in use in offices of the Geological Survey of Greenland at Copenhagen, Denmark, and the U.S. Geological Survey at Denver, Colorado. Though differing somewhat, the systems are similar in that they integrate Kern PG-2 photogrammetric plotting instruments and small desk-top computers that are programmed to perform special geologic functions and operate flat-bed plotters by means of specially designed hardware and software. A Z-drive capability, in which stepping motors control the Z-motions of the PG-2 plotters, are an integral part of both systems. This feature enables the computer to automatically position the floating mark on computer-calculated, previously defined geologic planes, such as contacts or the base of coal beds, throughout the stereoscopic model in order to improve the mapping capabilities of the instrument and to aid in correlation and tracing of geologic units. The common goal is to enhance the capabilities of the PG-2 plotter and provide a means by which geologists can make conventional geologic maps more efficiently and explore ways to apply computer technology to geologic studies.

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Photogrammetry has played an important role in geologic mapping for many years; however, only recently have attempts been made to automate mapping functions for geology. Computer-assisted photogrammetric mapping systems for geologic studies have been developed and are currently in use in offices of the Geological Survey of Greenland at Copenhagen, Denmark, and the U.S. Geological Survey at Denver, Colorado. Though differing somewhat, the systems are similar in that they integrate Kern PG-2 photogrammetric plotting instruments and small desk-top computers that are programmed to perform special geologic functions and operate flat-bed plotters by means of specially designed hardware and software. A Z-drive capability, in which stepping motors control the Z-motions of the PG-2 plotters, are an integral part of both systems. This feature enables the computer to automatically position the floating mark on computer-calculated, previously defined geologic planes, such as contacts or the base of coal beds, throughout the stereoscopic model in order to improve the mapping capabilities of the instrument and to aid in correlation and tracing of geologic units. The common goal is to enhance the capabilities of the PG-2 plotter and provide a means by which geologists can make conventional geologic maps more efficiently and explore ways to apply computer technology to geologic studies.

INTRODUCTION

For about 25 years high-order photogrammetric stereoscopic plotting instruments have been used for making geologic maps. Though designed primarily for topographic mapping purposes, these machines have proved to be versatile and very useful for many types of geologic studies. At offices of the Geological Survey of Greenland (GGU) in Copenhagen, Denmark, and the U.S. Geological Survey (USGS) in Denver, Colorado, U.S.A., systems are now being developed to automate some of the photogrammetric functions and provide computer assistance to geologists for interpretation and construction of geologic maps. This report describes the history of the use of photogrammetry in geology and the status of development of computer-assisted photogrammetric mapping systems at the USGS and at the GGU.

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Methods of Geologic Mapping

A geologic map is a means of recording and portraying information such as the distribution and nature of identifiable units of rock, the surficial material which covers the rocks, and the occurrence of structural features that affect the rocks. Geologists can show the relationships of geologic units by mapping the contacts (boundaries) between these units as they occur on the Earth's surface and portraying these relationships and the structural features that affect them by various lines and symbols on a base map. Topographic base maps are preferred because three-dimensional relationships between geologic units and the topographic surface can be shown.

Geologists have traditionally prepared geologic maps by field-surveying techniques, by sketching geologic information on a topographic or planimetric base map, or by annotating the information on an aerial photograph or a transparent overlay on the photograph for later transfer to a base map. Geologic mapping using only a topographic base map is still common, but use of aerial photographs for geologic mapping has become widespread. In regions of difficult access or in remote areas, such as in parts of Greenland, use of aerial photographs is especially critical for geologic mapping; however, by using photogrammetric mapping devices, aerial photographs can also be an aid in most geologic mapping problems, especially those that require considerable accuracy.

Use of Photogrammetry for Geologic Mapping
in the U.S. Geological Survey

As discussed by Ray (1960), geologists who employ aerial photographs for geologic mapping can fully utilize the three-dimensional aspect of the stereoscopic model and the wealth of inherent image detail portrayed for interpretation and accurate delineation of geologic features. However, geologic data mapped on the photographs must be transferred to a base map, and much of the accuracy gained by careful annotation can be lost by inaccurate transfer procedures. Excessive amounts of radial displacement due to relief and distortions caused by tip or tilt of the aerial camera must be corrected in the transfer process; this correction can be made either visually, by careful and skillful terrain interpretation and free-hand sketching, or instrumentally, by use of photogrammetric correction devices. In areas of low relief where radial distortions are small, geologic detail mapped on aerial photographs can usually be accurately transferred to a base map by tracing or by using a simple optical projector to make necessary adjustments for scale differences; in cases where tip or tilt presents problems, a simple tilt-correcting device, such as a sketch master, can be used. However, the best exposures of rocks are commonly found in rugged areas of high relief where radial distortion is significant and correction by photogrammetric methods is required for accurate compilation.

During the 1940's and early 1950's, use of aerial photographs for geologic interpretation and mapping increased considerably. Many photogeologic techniques for using paper prints of aerial photographs were developed during this period and remain in common use today. Though limited in capability, the radial planimetric plotter was used extensively for construction of planimetric base maps and transfer of geologic annotations from aerial photographs because of its relative ease of operation. During this period, higher order, double- projection-type photogrammetric plotters, such as the Kelsh[1], were being used routinely by topographers to make control nets by stereotemplet methods for photogeologic base-map control; however, the use of these plotters by geologists for geologic studies was not attempted by the USGS until 1954, when altitudes along a geologic contact were measured on a Kelsh plotter and used for construction of a structure-contour map of an area in Utah, as described by Ray (1960).

[1]Use of brand or manufacturers' names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

In early experiments using the Kelsh for geologic studies, it was considered necessary that photogrammetrists set up stereomodels and make measurements for various projects as directed by the geologist; however, experienced photogeologists soon learned to set up and orient models, map geologic contacts, and take measurements unassisted (Pillmore, 1959, and Witkind et al., 1960).

Development of a U.S. Geological Survey photogrammetric plotter laboratory for geology

The advantage of simultaneously performing geologic interpretation and mapping in the stereomodel was quickly recognized, and training of geologists in use of the technique was begun in 1955. As interest grew in this new method of acquiring geologic data, more equipment became necessary, and during the following 10 years, several surplus Kelsh, ER-55, and multiplex plotters were acquired and set up at the Denver, Colorado, office of the USGS. This equipment formed the basis for a photogrammetric plotter laboratory to which USGS geologists could come for assistance and training in the use of these various machines, as described by Pillmore (1979). Experienced compilation photogrammetrists were available on an on-call basis to set up models for geologists desiring to use the plotters. After the glass diapositives had been set properly in the plotter and the pantograph adjusted, geologists could begin tracing geologic features in the model using the floating mark and compiling the information on a base map with little additional guidance. Interest in the facility continued to grow. By the mid 1960's, the number of geologists who mapped on a plotter during the winter months had increased to about 60-70, and the equipment used for geologic map compilation in the laboratory included three Kelsh and six ER-55 plotters.

The major drawbacks to the projection-type plotting instruments in the laboratory were that they required film or glass diapositives, which meant that paper prints containing annotated geologic data could not be used. Additionally, many users experienced discomfort from the leaning-over posture required when working on the plotters, and the laboratory had to be kept darkened, which made reference to annotations and field notes inconvenient.

Because of the viewing limitations and other disadvantages of the Kelsh and ER-55 plotters, the decision was made that some other approach to the problem of equipment should be considered. Certain requirements were established and various machines were examined. Finally, the Kern PG-2, an optical mechanical plotter, was selected and tested for geologic-mapping purposes in 1972. At this same time, a photogrammetrist was employed in the laboratory full-time to schedule and maintain the equipment, advise geologists on problems related to the use of aerial photographs, and set up models for geologists.

The PG-2 Plotter

The PG-2 was selected for evaluation in the laboratory because it offers an excellent viewing system for stereoscopic inspection of aerial photographs coupled with high accuracy in plotting data on a base map. Also, it was the only instrument available that filled the basic requirements for a geologic-mapping plotter: a capability that allows use of black-and-white or color paper prints and film or glass transparencies with equal ease, a high-quality viewing system incorporating a variable magnification that can be readily changed, an illuminated floating mark that can be easily seen in dark portions of the image, and a basic ease of operation permitting geologists readily to use the machine for mapping after the model has been oriented. Though designed for topographic mapping, the PG-2 plotter was an instant success for geologic studies, primarily because the paper prints that had been used to plot geologic information in the field could now be set directly in the plotter, and because the field annotations plus additional data observed in the stereoscopic model could be plotted directly and accurately onto a topographic base map. Another important reason was that geologists could sit comfortably in a well-illuminated room and view a greatly improved image.

Shortly after introduction of the first PG-2, additional PG-2 plotters were acquired in response to an ever-increasing demand by geologists. In keeping with the goal of constantly improving the geologic-mapping capability of the laboratory, viewing systems that enable two people to study the same image simultaneously were added to several of the plotters to aid in interpretation and training. In addition, Z-readout devices that display elevation data by light-emitting diodes were introduced to facilitate the acquisition of vertical measurements. By 1976, eight PG-2's were in use for geologic mappping by the USGS; the Denver laboratory contained six and one each had been installed at the Menlo Park, California, field center and the National Center in Reston, Virginia. Since then, two more PG-2's have been added at the Menlo Park facility and one each at the Hawaii Volcano Observatory, Hawaii, and at the Casper, Wyoming, field office.

THE GREENLAND GEOLOGICAL SURVEY SYSTEM

During the period when the USGS was incorporating the PG-2 into the photogrammetric plotter laboratory in Denver, geologists of the GGU in Copenhagen, Denmark, were conducting experiments—completely independent of those of the USGS—to investigate the application of photogrammetry and computerized mapping systems to geologic-mapping problems experienced in Greenland. They developed similar requirements for a photogrammetric plotter for geologic mapping; in addition, compatibility with a desk-top computer was needed for on-line calculation of geologic structures.

The vastness of the relatively unexplored and unmapped regions of northern Greenland, coupled with the difficulties for geologic investigations presented by climate, remoteness (logistics), and the lack of base maps, requires the most effective use of aerial photographs. These conditions more than justified acquisition of a computerized photogrammetric mapping system to make and improve base maps and to aid geologists in geologic interpretation, structural analysis, and geologic mapping. After conducting several experiments, as described by Jepsen and Dueholm (1978) and Dueholm (1979), a variety of instruments and their capabilities were tested and evaluated in 1976. As a result of this investigation, the Kern PG-2 plotter and DC-2B digitizing module connected to a Hewlett Packard 9825A desk-top computer were selected as constituting the most convenient system available on the market at that time, considering budget restrictions. The design of the GGU system was based on the requirements of geologic mapping projects underway in northern Greenland.

Fundamental Concept

By means of the floating mark, which is guided by the tracing carriage of the PG-2, the spatial position of any point in the stereoscopic model can be occupied. A geometric representation of a point occupied in the model can be developed by use of a 3-axis digital recording system. Digital impulse generators known as encoders, placed on the X and Y guide rails of a coordinatograph on the PG-2 and on the Z-column of the tracing carriage are activated by any movement of the carriage and are prerequisite for acquisition of digital data. Thus, the basic components of any computerized photogrammetric mapping system include 3-axis XYZ encoders on the tracing carriage of the photogrammetric plotter; a hardware interface and computer programmed to assign model-coordinate values to the counts generated by the encoders, to compute grid positions and perform other required mathematical calculations, to store data, and to drive a 2-axis XY plotter capable of reproducing movement of the PG-2 carriage.

Development of the GGU System

At GGU photogrammetric plotting instruments, such as the PG-2, are considered to provide an excellent means for tracing and mapping geologic features observed in the stereoscopic model. Visible geologic features, such as contacts and discontinuities expressed as lineations (faults or joints), can be traced in the stereomodel and compiled onto a base map with considerable speed and at an accuracy superior to that of all other known mapping methods. The fact that measurements can be taken in the three-dimensional model aids in structural interpretation, and this capability can be used to advantage in extrapolation of geologic data across the stereoscopic model or from one model to another. The GGU system is designed to acquire and store digitized geologic information. In order to expand the potential of the system, the HP-9825A also serves as a terminal to a larger computer, the PDP-11, which enables large amounts of data to be stored and later displayed on a drum plotter. An important component of the GGU system is the Z-guiding facility, described by Dueholm (1979), which is termed the Z-drive in this report.

Mathematical models for structural interpretation

Geologic boundaries are sometimes true planar surfaces, but rarely are these planes horizontal. Therefore, the capability common to all conventional topographic mapping instruments of tracing a contour around the stereoscopic model along a horizontal plane is of only limited value to geologic mapping. Instead, geologists would prefer to follow an inclined plane that represents a geologic horizon. Elevation measurements can be made on geologic horizons or boundaries and stored digitally for development of mathematical models of structures influencing the geology and also for mathematical computation of the attitudes (dip and strike) of geologic boundaries or strata (planes) and of the thicknesses of stratigraphic units. The measurements required for these computations, when done manually, are usually time consuming and commonly not obtainable by mere inspection of the stereoscopic model. Also accuracy of interpretation is influenced by the general nature of geologic boundaries and by soil and vegetation cover. As the field of view is limited at any one time to a small part of the stereoscopic model, the geologist must exercise extreme care in tracing of outcrops and identification of features as he moves from outcrop to outcrop within the model and, especially, when he moves from one model to another.

Description and use of the Z-drive

In order to facilitate the acquisition of measurements for structural interpretation and to enhance the accuracy of geologic interpretation, software was developed to generate and store mathematical planes from digital XYZ measurements that represent geologic boundaries (planes or structural elements). These data can be obtained from the stereoscopic model either incrementally, as geologic features are traced with the floating mark, or individually, when measured point by point. Basically, the Z-drive program is used for the formulation of mathematical models of the geology, which the geologist can then compare with the photographic image of the geology that he observes in the stereoscopic model of the plotter. This comparison is accomplished by making the computer drive the Z-motion of the plotter so that the floating mark is constantly maintained on the precalculated mathematical plane throughout the stereoscopic model. A stepping motor mounted on the Z-column of the tracing assembly continually adjusts the floating mark as the tracing assembly is moved. Geologists can thus check how an isolated outcrop fits into the precalculated structural model and, likewise, inspect the stereoscopic model for unidentified or misidentified outcrops. Perhaps most significantly, geologic boundaries can be traced through covered areas and projected across valleys or from ridge to ridge.

The Z-drive program is useful in many additional ways. As each plane is generated, the HP-9825A computer can also display and store the calculated data concerning that individual plane: an identification code of the plane, the number of points used to generate the plane, the dip (inclination), the strike (azimuth of the direction of inclination), the standard error on the dip, the standard error on the strike, and the standard error of the distance, which is a function of the distribution of points. The observations made along a particular geologic boundary are compressed into a data set designated a point group, which defines a particular plane. It is stored in absolute ground coordinates for later recall, enabling planes from adjoining or separate photogrammetric models to be combined or compared. For example, two or more point groups on a geologic horizon can be recalled and added together to calculate a common (average) plane; in addition, point groups on different horizons within a stratigraphic unit can be added to generate a composite plane that represents the attitude of the entire unit. This capability is comparable to the field geologist's technique of averaging a large number of strike and dip readings obtained in the field in order to portray the clearest representation of structure.

The Z-drive program also has the capacity to make other calculations useful to geologists. The perpendicular distance, which represents stratigraphic thickness, between planes generated on separate geologic horizons or from any point to any plane can be calculated and displayed. These measurements can be made and displayed continuously for rapid determination of thickness variation throughout the stereoscopic model. Likewise, two planes developed on the same geologic horizon but calculated on either side of a fault can be used to determine the amount of displacement along the fault. Utilizing another function of the program, the orientation and plunge of fold axes can be calculated using the combined effect of several established planes lying in different positions.

Application to Geologic Mapping in Greenland

Due to little or, in some cases, no geodetic control in Greenland, the orientation of photogrammetric models at GGU is based on aerotriangulation. A subroutine for digitizing and storing data on tape for topography as well as geology has been developed for the HP-9825A and used by geologists on nearly all projects. Using this subroutine, the mapping can be automatically corrected if subsequent field control is obtained that improves the triangulation net.

Evaluation and Status

The GGU computer-assisted photogrammetric mapping system has been designed for fast, efficient acquisition and storage of geologic information. Each user is provided with an HP-9825A tape cartridge that contains the geologic mapping programs and sufficient storage capacity for several stereoscopic models. The functions described above are readily accessible subroutines, initiated by pressing only a single pre-programmed function key on the HP-9825A. Any plane that the geologist wishes to retain can be stored on the tape cartridge under an alpha-numeric code. All stored planes can be recalled at any stage in any stereoscopic model to guide the Z-motion of the floating mark for any desired purpose. The observation of points and calculation of strike and dip on a geologic horizon can be made in as little as 15 seconds, commonly with an accuracy of 1/2° or less. All subsequent calculations and recalls of stored planes are so rapid that the geologist is not required to wait more than a few seconds for the results. The system has proved useful and efficient in many projects at GGU that involved both simple and complicated geologic structures. Development and improvement of the system are continuing at GGU.

THE U.S. GEOLOGICAL SURVEY SYSTEM

Most areas of the United States have been geologically mapped, and the majority of studies underway in the USGS are designed to improve the quality of geologic information and prepare better geologic maps. In the continuing search for ways to improve geologic mapping, development of a computer-assisted photogrammetric system that utilizes the PG-2 plotter was the next logical step to be taken at the USGS photogrammetric plotter laboratory for geology. When it was learned that geologists at GGU were pursuing similar goals, correspondence began and it was determined that sharing of techniques and ideas would be mutually beneficial and that the basic configuration of the USGS system would be patterned after the system being developed at GGU.

The USGS System
Goals and requirements

The primary goals of the USGS system are to enhance the capabilities of the PG-2 plotter for geologic mapping, provide a means by which geologists can make geologic maps more efficiently, and develop ways to apply computer technology to geologic studies. The basic requirements of the system are to produce geologic maps and geologic map products, such as structure-contour and isopach maps, overburden and interburden maps, and surface profiles for geologic cross sections, from data generated using the PG-2 plotter in combination with subsurface data entered from a 2-axis digitizing table.

Because no one affiliated with the USGS photogrammetric plotter laboratory for geology had the expertise to choose the hardware or write software for the system, a development contract was awarded to HASP, Inc., a photogrammetric engineering firm located near Denver in Loveland, Colorado. HASP was selected because of its experience in automated photogrammetric mapping systems and in the design of hardware interfaces and software for integrating the PG-2 and the HP-9825A with a 2-axis Talos digitizer and a Data Technology 3454 flat-bed plotter.

Description and basic operation

Patterned after the GGU system, the USGS photogrammetric system is designed basically to provide computer-assisted procedures for stereoplotter operations and manuscript map preparation. It differs somewhat from the GGU system in the hardware and software interfaces between the PG-2 and the computer, but the basic concept is the same in both systems. The XYZ position of the floating mark in the stereoscopic model is continuously monitored and transformed by means of the HP-9825A to a three-dimensional control grid (State plane coordinates with elevations) using a least-squares best-fit procedure. After control information has been entered into the computer and points have been identified and occupied in the stereomodel, northing, easting, and elevation can be obtained for any position the floating mark occupies. These data can be stored, or plotted in map form on the flat-bed plotter. In order to provide quick access to the USGS programs and sufficient and adaptable storage space for geologists to use on their own projects, a flexible-disk drive was selected rather than the tape cartridge of the HP-9825A computer used at GGU. In addition to the flat-bed plotter, a Talos 2-axis digitizing table was added to enable the digitizing of drill-hole data and other kinds of map information into the system.

During operation of the system, the HP-9825A computer constantly reviews and updates the position of the floating mark in the stereoscopic model; as the tracing carriage is moved, the positions are continually being transformed to ground coordinates. Data are recorded and/or plotted in correct planimetric position at any designated scale on the flat-bed plotter without the need to mechanically orient the base map or to physically level the model in the stereoplotter as would normally be necessary on noncomputerized systems. Because the computer calculates a

mathematical solution for leveling the model, aerial photographs can be used that contain more tilt than the mechanical adjustments of the PG-2 can normally accommodate. Data points can be recorded and/or plotted in a continuous mode in which data are taken each time the computer examines the spatial position of the floating mark or in a point-by-point mode whenever the operator presses a footswitch. In the continuous mode, the pen on the flat-bed plotter in essence follows the tracing of the floating mark. In the point-by-point mode, control points or geologic and geophysical data stations and their elevations can be plotted and identified by selected symbols upon command.

Geological Applications of the USGS System

In addition to the basic photogrammetric mapping functions of the system, several capabilities have been developed or adapted especially to fill geologic-mapping requirements. These capabilities include a Z-drive, profiling, structure-contour and isopach mapping, and storage of data for development of a data-base management system and later plotting of data.

The Z-drive

The Z-drive of the USGS system differs somewhat from the Z-drive of the GGU system. At GGU, the Z-drive data are stored, then later plotted on the drum plotter. At the USGS, the flat-bed plotter can be driven while the Z-drive is operating. Using either system, the intersection of a geologic plane with the ground surface as viewed in the stereoscopic model can be mapped. In areas where the rocks are obscured by soil or vegetation cover, the projected precalculated trace of a geologic boundary or plane can be mapped in the stereomodel nearly as routinely as following the floating mark around to map contours. The subsurface elevation control on particular geologic horizons can be entered from the PG-2 to compute planes and control the Z-drive. This feature permits the delineation of geologic planar features (contacts or coal beds) that are partially or completely obscured and determination of probable lines of outcrop from only drill-log data. Also, the elevation of any selected point on a plane in the model can be displayed; this allows determination of the position that a particular plane should occupy in adjacent drill holes, which is useful for correlating units or coal beds, or of the depth at which the plane should be encountered at a proposed drill site. Unlike the Z-drive in the GGU system, using the original HASP version of the USGS Z-drive, the number of points that could be entered along the outcrop or from drill hole records was limited to only 10 points. In order to improve upon the USGS system, late in 1979, most of the GGU geologic programs were incorporated into the USGS system. As a result, the capabilities of the GGU Z-drive described previously can be performed using the modified USGS system. Planes generated from the model during mapping, as is done with the GGU Z-drive, can now be incorporated into the USGS Z-drive to control the floating mark in the plotting mode of the program, thus greatly increasing the capabilities of the system.

Profiling

Profiles are used to construct geologic cross sections that display geologic features intersected along the line of profile and show the geologist's concept of the geology beneath the surface of the profile. Profiles across the stereoscopic model can be drawn on the flat-bed plotter as a function of X and Z. The transformation computations of the system allow the profiles to be displayed at any chosen scale and the vertical (Z) element of the profile can be exaggerated as desired to enhance topographic relief that might aid in geologic interpretation. The profiling feature can also be used to plot stream profiles, show the changes in gradient along a stream, and construct cross sections of stream channels.

Structure-contour and isopach maps

The USGS system is being developed to automatically produce structure-contour maps from data entered into the system from both the 2-axis digitizer and the PG-2. Subsurface configuration can be shown by means of structure contours, which are lines joining points of equal elevation on a particular geologic surface such as a formation contact. Elevation points on a geologic horizon are entered into the computer from random field control stations or drill holes. From these data the computer calculates a gridded model, which is then interpolated by the computer, contoured, and displayed on the plotter to show the configuration of the surface.

In a similar mode, data are then entered from the same. drill-hole records on a surface above or below the surface just contoured, such as the top or bottom of a coal bed. By subtracting the two sets of data, the difference between the elevations on the top and bottom of the bed is calculated, gridded, and contoured, yielding an isopach map that shows changes in thickness of the geologic bed or unit. Volumes of areas circumscribed by gridlines can be calculated for resource measurements, and volumes of overburden above coal beds or interburden between beds also can be measured.

Data-base management system (Store and plot)

The most difficult problem encountered in design of the USGS system has been development of a useful data-base management system (DBMS) for geologic mapping. A DBMS allows the storage and retrieval of coded digital geologic data; complete or partial geologic maps can be recalled and displayed to show particular aspects or attributes of the data. Geologic data are entered and coded at the same time that boundaries or structural features are traced in the stereoscopic model. The data can be entered as a continuous string (20 XYZ points per second), as string data taken at longer intervals, or as point-by-point data selected and entered by activating the footswitch. The computing and storage capacity of the small HP-9825A computer limits the amount of data that can be manipulated. New programs for digital storage and analysis of geologic data are presently being evaluated for possible incorporation into the USGS system. In order to fill future geologic mapping needs, programs are also being developed to interface the present system with a larger computer.

Evaluation and Status

A rapid interchange of information between the computer and the operator is a very important attribute of any automated system. The nearly instant generation of mathematical planes in the Z-drive program as the tracing carriage is moved about the stereomodel provides the kind of information the geologist needs for structural interpretation, and the ability to switch rapidly from one subroutine of the program to another is a very desirable feature.

Future modifications and improvements of the system will be directed toward simplifying the operation and expanding the system's capability to perform a wider variety of geologic tasks. Many of the procedures now required are cumbersome and time-consuming; they need to be streamlined. Some of the programs must be combined so that capabilities such as the Z-drive can be accessed and incorporated into the profiling package for construction of cross sections. The Z-drive program is presently limited to the mathematical representation of individual planes scattered throughout the model or stored for use in other parts of the map area, the next step is to develop mathematical formulas to merge the planes so that areas between planes will be represented as curved surfaces rather than sharp lines of intersection. Also, mathematical models could be developed to portray nonplanar geologic surfaces and to deal with discontinuities, such as faults. In addition, responsive and useful DBMS must be developed for geologic mapping.

SUMMARY

Many complex and powerful computer programs are available for geologic application in both government and industry, but nearly all require special formatting of data and the assistance of trained personnel. Both the GGU and USGS systems are designed so that after routine photogrammetric adjustments have been made, geologists can access special functions on the computer to aid in basic geological investigations without the direct assistance of professional computer operators. The goals are to keep the operation simple and to make sure that the results are useful for a wide variety of geologic problems.

Development of software programs for computer-supported geologic interpretation is at a very preliminary stage, but the software that is in operation has been extremely useful and results to date are very encouraging. Development of photogrammetric equipment that would enable interpreters to view the entire stereomodel at 1:1 scale and to enlarge selected areas at least 10X by means of zoom optics is badly needed, as is the ability to use a wide variety of aerial and terrestrial photography with a range of camera focal lengths.

The new family of computer-operated photogrammetric analytical plotters that is now being developed will include some of these desirable features. Geologic interpreters should make their special needs known to company representatives involved in developing these plotters so that special geologic requirements can be met and desirable features can be considered for inclusion in new equipment being designed and built. When computer-driven analytical plotters can be incorporated into the computer-assisted geologic mapping systems being developed in the GGU and USGS, a very powerful interpretation and mapping system will be the result.

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