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USGS Mapping: The Last Three Decades

Gerald FitzGerald has given us an overview of USGS mapping over its first 100 years. Most of the happenings he described occurred before any of us here were around. With that historical background, we are in a good position to take a closer look at the events that have touched many of us more closely because they happened in our lifetime.

The period from the end of World War II to the present—roughly the last three decades—was a time of extraordinary progress in the broad field of mapping. This progress was by no means characteristic of the Geological Survey alone. Everybody got into the act—the other civilian agencies, the military agencies, the State and local agencies, the commercial map-makers, the instrument designers and manufacturers, the colleges and universities, the professional societies, and private individuals. If I start bragging about the accomplishments of the Geological Survey, let it be understood that responsible USGS people are fully aware that the story of postwar mapping goes far beyond the efforts of any one agency. But this is the Geological Survey's birthday and today's observance is aimed in that direction, with due realization that the major birthdays of our sister organizations, in and out of government, are deserving of similar recognition.

How does one measure accomplishments in a mapping effort? One way to approach this is to look at what transpired in each of the major aspects of the effort. These aspects are:

- Program—What are we trying to do?
- Techniques and equipment—How do we do it and what tools do we need?
- Personnel—What kind of people do we need to carry it out?

Evolution of a Modern Mapping Program

At the close of World War II, after the wartime strategic mapping assignments were concluded, the USGS mapping program was simple enough: complete the mile-to-the-inch 15-minute topographic mapping of the country as soon as possible, in line with the funding level available. This in itself was a formidable undertaking, for map coverage at a scale of 1:62,500 existed for only about 24 percent of the country, and much of this mapping was outdated.

But valuable experience had been gained during the war in utilizing the USGS photogrammetric plants at Chattanooga, Tennessee and Arlington, Virginia. To take advantage of the relatively new photogrammetric mapping techniques as fully as possible, the USGS embarked on a sweeping changeover from planetable to photogrammetric methods as the basic map-plotting operation. By the end of the 1940's, the Mapping Centers at Sacramento, Denver, Rolla, and Arlington were all equipped and going full blast on photogrammetric mapping.

With the means of accelerating map production thus at hand, the Geological Survey recognized a dual need in the management of the Topographic Division operations: (1) an entity to develop and control the mapping program so it would be properly responsive to the nation's needs; and (2) an entity to develop and control technical operations so that the most efficient mapping systems suitable for the program could be utilized. Thus, in 1947, two staff arms were set up: a program arm known today as the Office of Plans and Program Development; and a technical arm now known as the Office of Research and Technical Standards.

The Federal mapping community recognized early in the game that the nation's mapping program was not something to be based on guesswork or speculation. It was essential to find out what the mapping requirements were—in Federal, State, and local agencies, and in the private sector.

As far back as 1890, State agencies cooperating with the Geological Survey in the funding of mapping projects expressed their map needs on an annual basis, and this continues to this day. From 1919 to 1942, the Federal Board of Surveys and Maps gathered information and made recommendations on mapping priorities. In 1942, the

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Bureau of the Budget (now Office of Management and Budget) took over the responsibility for obtaining information on map needs from each Federal agency. In 1953, the Bureau of the Budget issued Circular A-16 which formalized the procedure for Federal agencies reporting their map needs. The 1967 revision of Circular A-16 designated the Geological Survey as the coordinating agency for Federal mapping activities and the Coast and Geodetic Survey (now National Ocean Survey) as the coordinating agency for geodetic activities.

To develop further information on local mapping requirements, a number of States set up State Mapping Advisory Committees, beginning in the early 1950's. These committees (now numbering 18) continue to provide valuable input to the Geological Survey's bank of map requirements data.

All of these inputs depended on the initiative of the map users, and it became apparent that the Geological Survey would have to play an active as well as a passive role in assuring that the available information was truly representative of the full scope of map needs. Accordingly, several map use studies were conducted to identify major users, uses of, and requirements for maps and related products. These include:

1958-60	(in-house) "Map Use Research Study"
1964	Federal Map Users Conference
1967	Federal Mapping Coordination Conference
1968	System Development Corporation, "Analysis of the National Topographic Mapping Program"
1969	(in-house) "Map Use in the District of Columbia Government"
1970	(in-house) "Ohio Map Sales-Benefit Study"
1972-73	OMB Federal Mapping Task Force Study, "Mapping, Charting, Geodesy, and Surveying"
1974	NCIC Coordination Conference of Federal Agencies

The findings of these successive studies led to the establishment in 1974 of a Mapping Requirements group in the Geological Survey. This activity is structured to conduct continuous, full-time mapping requirements collection, analysis, and review.

Of particular importance in the recent evolution of the USGS mapping program was the Federal Mapping Task Force (FMTF) study sponsored by the Office of Management and Budget (OMB). This comprehensive multi-agency study of the civil agency mapping and surveying programs is documented in a full report issued by OMB in 1973.

In 1975, the Department of the Interior responded to the FMTF findings by modifying, extending, and renaming its National Topographic Program to meet better the basic cartographic needs of the country. This new program, the National Mapping Program, includes those activities necessary to make available basic map data and a family of general-purpose maps. The Geological Survey was named as the lead agency for the administration of the National Mapping Program. This includes coordinating, defining, and approving the National Mapping Program categories, and assuring the availability of the resulting map data and materials to users.

Here are some pertinent facts relating to the evolution and execution of the USGS quadrangle mapping program in the last three decades:

- In the early 1950's the prevailing scale of USGS topographic maps was changed from 1:62,500 (15-minute quadrangles) to 1:24,000 (7½-minute quadrangles), with a corresponding adoption of smaller contour intervals. This was in response to a widespread demand for more detail on maps.
- In 1947, 24 percent of the United States (excluding Alaska) was covered by published 15-minute maps. Most of this area (75 percent) was later covered by 7½-minute maps; however, in 1978 15-minute map coverage had been expanded to 42 percent of the country (Figure 1).
- In 1947, there were no USGS quadrangle maps of Alaska, although the Army Map Service (AMS) had done some mapping there. Now, there are published 15-minute maps at a scale of 1:63,360 for about 85 percent of Alaska (Figure 1); some of these are civil editions of AMS coverage.
- In 1947, only 6 percent of the United States (excluding Alaska) was covered by published 7½-minute line maps. In 1978 this coverage had risen to 71 percent (Figure 1). Completion of 7½-minute line-map coverage (some 54,000 quadrangles) is expected in the late 1980's.
- Prior to the 1950's, there was "no such animal" as an orthophotomap or an orthophotoquad to provide a photographic image of the terrain in standard quadrangle format. As of today, USGS has produced about 650 orthophotomaps (with full color treatment) and some 19,000 orthophotoquads (in black and white) (Figure 2). With the addition of these orthophoto products to the line-map coverage, we now have some kind of 7½-minute coverage for virtually the entire country (about 98 percent) except Alaska.

The 7½-minute and 15-minute topographic maps are the best known USGS carto-

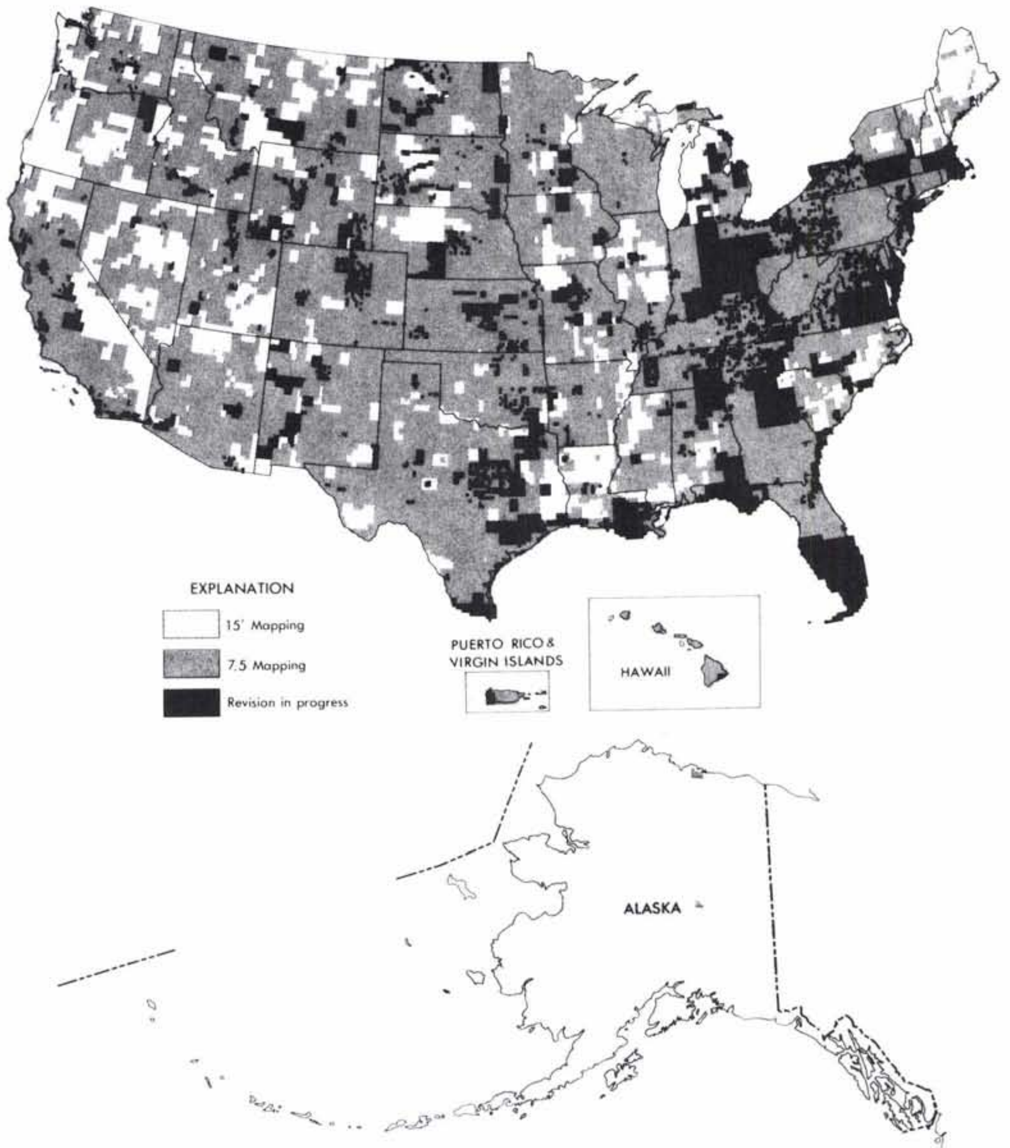


FIG. 1. Status of standard topographic mapping and revision, 1979.

graphic products, but the program has been greatly diversified in response to user needs. There are numerous USGS cartographic products most of which did not even exist three decades ago:

- Topographic maps at 1:50,000- and 1:100,000-scale prepared in the metric system.
- Complete coverage of the United States at 1:250,000-scale. (Originally prepared as military editions by the Army Map Service, these maps are now maintained by the Geological Survey.)
- State maps at 1:500,000 scale published in three separate editions: base map, highway and contour map, and shaded-relief map.
- United States 1:1,000,000-scale maps, available in two editions: International Map of the World (IMW) edition, and AMS compilation.
- United States wall maps at various scales.
- National Park maps at various scales.
- Metropolitan area maps at 1:24,000 scale.
- Antarctic maps at scales of 1:250,000, 1:500,000, and 1:1,000,000.
- Shaded relief editions of selected topographic quadrangles.
- Slope maps portraying the extent of

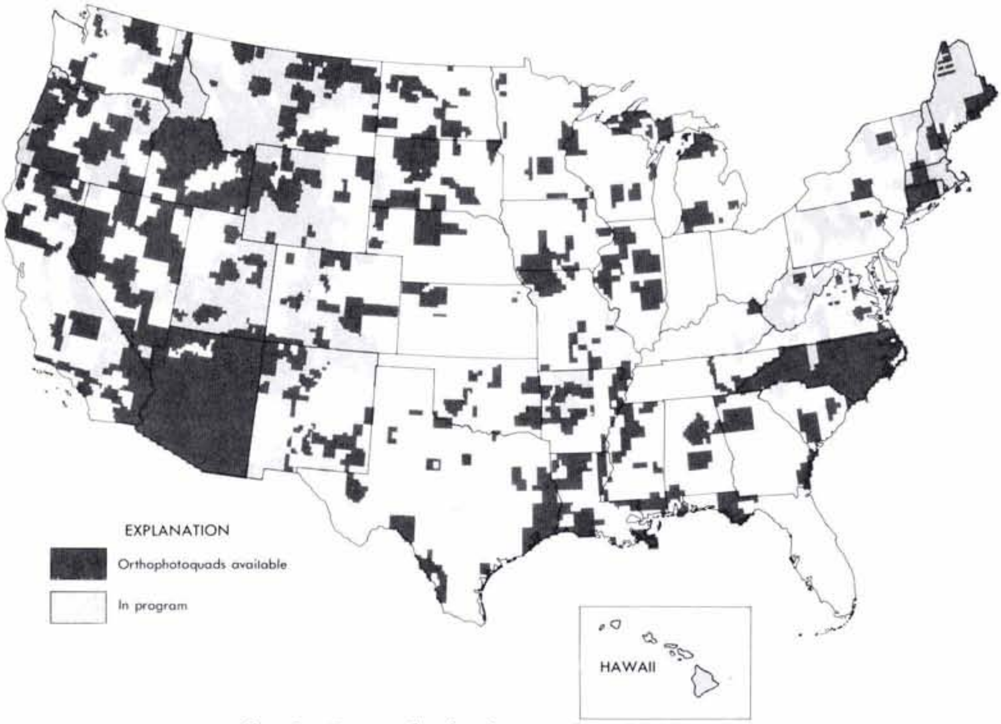


FIG. 2. Status of orthophotoquad production, 1979.

specified slope zones for selected quadrangles.

- Coastal zone maps, including topographic-bathymetric maps prepared in cooperation with the National Ocean Survey.
- Geologic maps showing the distribution and structure of rocks and surficial material.
- Hydrologic maps showing information about water resources.
- Land-use maps for the control of development and environmental quality.
- Satellite image maps providing synoptic data obtained from spaceborne systems.
- Thematic maps of various kinds obtained from remote-sensing systems.
- Digital cartographic data stored in and retrievable from a growing data bank.
- Special cartographic products developed for cooperating agencies.

Summing up this lengthy catalog, which is still only a bare-bones outline, it is obvious that the USGS mapping program has evolved in the last three decades from an essentially one-product effort to a diversified National Mapping Program with many ramifications, designed to meet the Nation's cartographic needs.

As the program became more complex, the need arose to provide an information service that could make cartographic data from all sources more readily accessible. Thus, the National Cartographic Information Center was established in 1974, replacing the old Map Information Office with a much more comprehensive system of providing data concerning maps and related products. A need also arose to provide ready access to Landsat imagery, Skylab and aerial photography, and other remote-sensing products. To meet this need, the EROS Data Center (EDC), operated by the Earth Resources Observation System Program of the Department of the Interior and managed by the Geological Survey, was established in the early 1970's and housed in its present modern facility at Sioux Falls, South Dakota, in 1973 (Figure 3).

Development of Mapping Technology

As the USGS mapping program became more and more complex in the decades following World War II, the technology of cartography kept pace with the burgeoning new requirements. Improvements and revolutions in systems for field surveys, photogrammetric operations, and cartography, resulting from painstaking research and development, were introduced in an unending sequence. Parallel developments were taking place throughout the mapping community, with various organizations exchanging

FIG. 3. Visitors to the EROS Data Center examine displays explaining the functions of the EROS Program.

FIG. 4. The elevation meter, developed in the early 1950's, afforded an automatic means of obtaining elevations of points along roads.

information freely; however, this discussion focuses on USGS participation in the overall technological advances.

FIELD SURVEYS

The postwar boom in photogrammetric mapping, far from reducing field operations immediately, gave rise at first to an expanded need for field control and field completion operations. About 1950, USGS research in field survey systems brought forth the pendulum alidade, the elevation meter (Figure 4), the electrical survey net adjuster (ESNA), improved barometric altimeters, and the use of helicopters for access to remote areas.

In the late 1950's the first electronic distance measurement (EDM) equipment was introduced by enterprising manufacturers. EDM was one of the truly significant breakthroughs in modern surveying. The Geological Survey, like many other organizations, quickly adopted the new system of distance measurement. These instruments have been improved so much in the last two decades that the surveyor's tape is becoming a museum piece.

As the demand for map control grew, the Survey sought better means of obtaining it. In the 1960's, a telescoping survey tower that could be transported by truck or helicopter was developed. For obtaining control in inaccessible areas, an airborne control survey (ABC) system was devised, utilizing a helicopter, a hoversight, and EDM instruments (Figure 5).

And now, in the 1970's, the Geological Survey is participating in research on the field survey systems of the future:

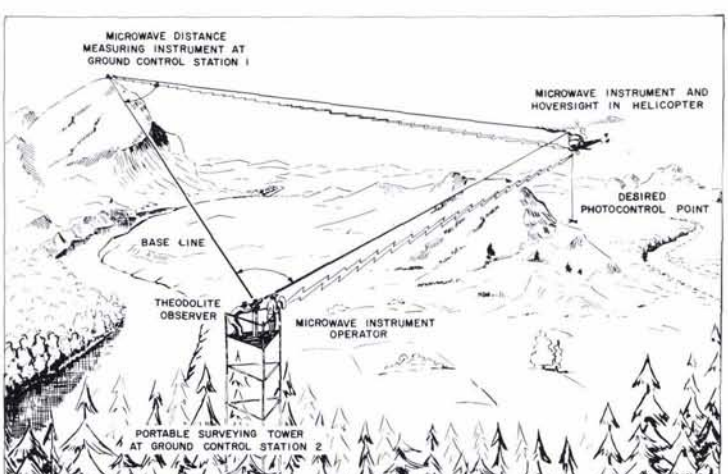


FIG. 5. Airborne control (ABC) survey system, developed by USGS in the 1960's.

- Doppler-satellite systems in which ground positions are determined by observations on Earth satellites with ground-based wave analyzers or satellite-borne retro-reflectors.
- Inertial systems in which continuous determination of position, elevation, and azimuth is obtained from an inertial package in a moving vehicle.

PHOTOGRAMMETRIC OPERATIONS

As the 1950's opened, the photogrammetric equipment at the USGS mapping centers consisted of multiplex plotters with ancillary hardware, and little else. There then began a period of research and development that brought forth a succession of new photogrammetric hardware.

The Kelsh plotter, patented by Harry Kelsh at the Department of Agriculture, originally had contact-size diapositives, but the projectors had huge lamp houses to illuminate the entire diapositive area and they gave off unbearable heat. After Kelsh transferred to the Geological Survey in 1949, the plotter was there redesigned to incorporate swinging compact light sources and a cam arrangement for continuous adjustment of principal distance. The Kelsh plotter later became one of the Survey's workhorse instruments, and the successively improved models are serving admirably today in many public and private organizations.

In the early 1950's, a team of researchers under R. K. Bean designed the Ellipsoidal Reflector Projector, known in the Survey as ER-55 and commercially as Balplex (Figure 6). This instrument incorporated a light source placed at one focus of a polished ellipsoidal surface, with the inner node of the projection lens at the other focus, thereby obtaining high efficiency in utilizing the available light. The ER-55 plotter was designed for use with vertical, convergent low-oblique, or transverse low-oblique photography. The ER-55 and the Kelsh plotters were used to compile thousands of maps in the 1950's and 1960's. Beginning in the mid-1960's, these instruments were gradually replaced by more modern stereoplotting instruments, mostly of foreign manufacture.

Concommitant with the development of the ER-55 plotter was the design and construction of the Twinplex plotter, intended for aerotriangulation with convergent or transverse low-oblique photography. It must be admitted that the Twinplex never became a fully operational instrument—which goes to show that "you can't win 'em all." Part of the reason for abandonment of the Twinplex

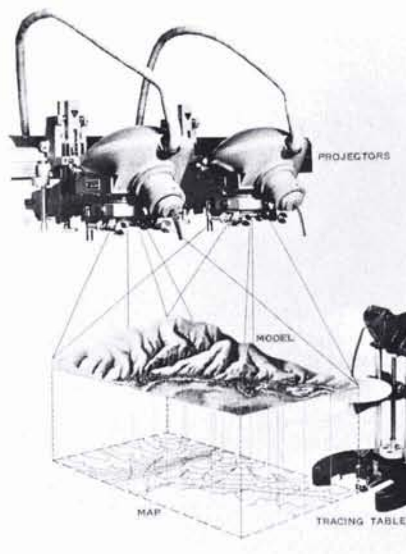
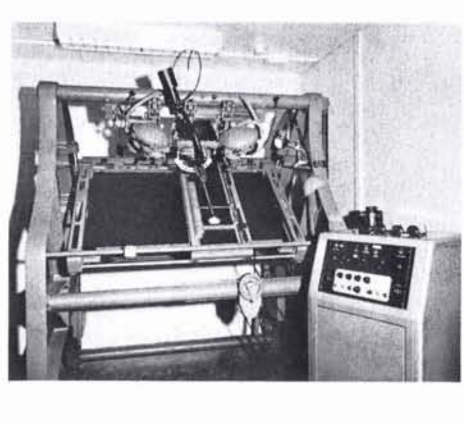


FIG. 6. Double-projection system with ER-55 projectors.

was the successful development of super-wide-angle photography, which eliminated the advantage of convergent photography.

The problem of control extension called for an economical solution, something better than "long-bar bridging." The stereotemplet system, devised by M. B. Scher in the late 1950's, provided a practical means of accurate control extension on an area basis. This system served for a time as the Survey's primary aerotriangulation system until replaced by mathematical adjustment by semi- and fully analytical methods introduced in the 1960's. The current USGS analytical aerotriangulation system, utilizing the powerful capabilities of modern computers, has reduced field-survey control requirements almost to the vanishing point.

Beginning in the mid-1950's, R. K. Bean's



research team designed and built the first orthophotoscope for producing photographs with no image displacements due to terrain relief and camera tilt (Figure 7). From this beginning, there came several generations of USGS orthophotoscopes, a number of commercially developed orthophoto devices, and a whole series of new photoimage products such as orthophotomaps and orthophotoquads.

During the 1960's, spurred by the potential of the computer and new sensing devices, an era of automation in photogrammetry was born. The USGS, using a combination of instruments on hand and commercially available hardware, has introduced

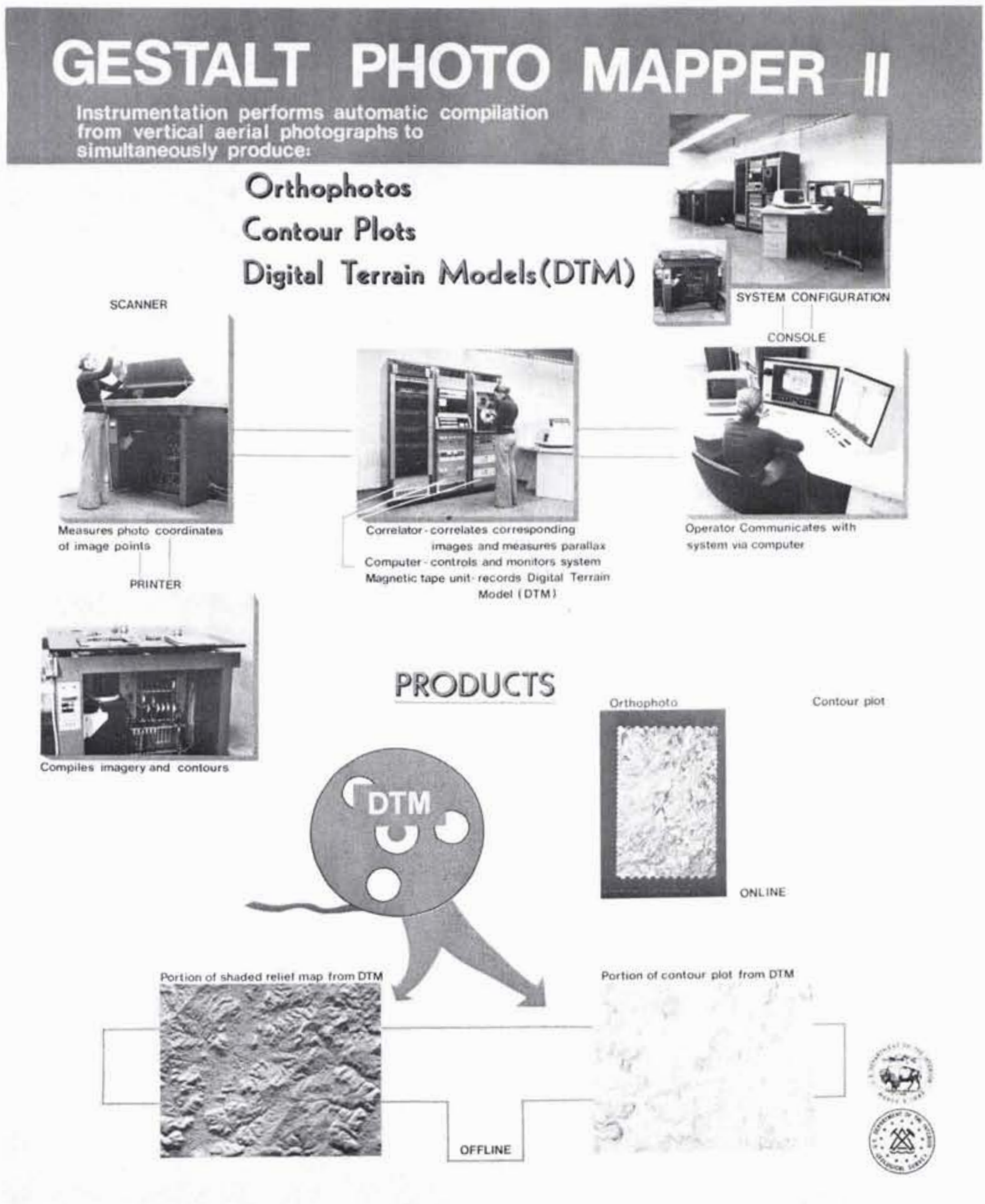


FIG. 8. A fully automated photogrammetric mapping system in which the photographs are automatically scanned and correlated to produce contours, profiles, digital terrain models, and orthophotographs.

automated photogrammetry in three principal directions:

- Interfacing analog stereoplotters with an online computer to provide digital storage and readout;
- Driving offline orthophoto systems digitally with separately obtained height data; and
- Producing contours, profiles, terrain models, and orthophotos by automatic scanning and correlation of images (Figure 8).

These systems are all now operational, but the problem is to improve them so that the high capital costs can be reduced to an affordable level.

Anyone who looks at ASP publications today has to realize that the name of the game now is "remote sensing." USGS is heavily involved in this space-age technology as it cooperates with other agencies in producing satellite-image maps (Figure 9) and thematic maps of various kinds. The development of space-age technologies is of key interest to the Survey, as evidenced by the many GS researchers who have served as principal and associate investigators on Landsat, Skylab, and similar projects.

CARTOGRAPHY

The big news of the 1950's in cartographic operations is expressed in one word: "scribing." Those of us who were cartographers when map manuscripts were drawn in ink on paper can well recall what onerous technical loads dropped off our shoulders when scribing was introduced. The procedure became practical as a result of studies and recommendations by an inter-agency committee, thereby providing a shining example of the benefits of cooperation. The Geological Survey, like the other major mapping agencies, made the transition almost overnight. There followed a period of intensive development of scribing tools and procedures, many of them suggested by rank-and-file USGS technicians. Today it is almost impossible to find an old-style pen or a bottle of ink in a Geological Survey mapping center (Figure 10).

In the 1970's USGS has introduced several new map formats with new kinds of symbolization intended to improve legibility and esthetic appeal (Figure 11). One example is the folded-format 7½- by 15-minute 1:25,000-scale topographic map with modern symbolization.

As of 1979, the key words in cartography are "digitization" and "automation." A Digital Applications Team is functioning in the Geological Survey with a primary mission of developing a cartographic data bank containing the principal types of base map data. Such data can readily be interfaced with other geographically related information, can be manipulated rapidly to produce maps at different scales and with different contents, and facilitates map maintenance (Figure 12).

That brings us to the subject of map

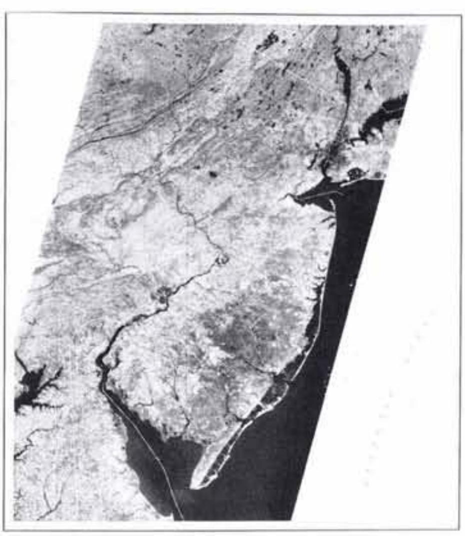


FIG. 9. Satellite-image map of New Jersey. (Original in color at 1:500,000 scale.)

FIG. 10. Final preparation of a contour-line scribe sheet used in the production of a USGS topographic map.

FIG. 11. Dual-use maps of the Washington, D.C. area, combining normal visual symbols with tactual symbols in relief, have been prepared for the blind and the normally sighted by USGS.

maintenance, frequently referred to as "revision." As the total number of maps increases, the problem of map maintenance becomes more and more formidable, as there are so many more maps to maintain. Beginning in the 1960's, USGS sought to expedite map maintenance by the process of photorevision, originally called "interim revision." This has helped greatly in keeping maps up to date, but the problem will not be solved fully until a practicable automated procedure based on a digital data bank can be put into operation. The Survey is working on this.

Just as instruments become outmoded, so do plant facilities. Thus, the postwar period witnessed the following changes in the housing of the Survey's mapping operations:

1948—The operation now called "Rocky Mountain Mapping Center" was newly established at the Denver Federal Center. This facility has recently been renovated to accommodate modern mapping systems.

1959—The operation now called "Western Mapping Center" was moved from Sacramento to a modern building on the Geological Survey's Western Region Campus at Menlo Park, California.

1968 and 1972—The operation now called "Special Mapping Center" moved from Silver Spring, Maryland, to two specially constructed buildings at Reston, Virginia.

1973—The Chief Topographic Engineer and the two headquarters staff arms moved from Washington, D.C., and McLean, Virginia, to the new USGS National Center at Reston.

1974—The Eastern Mapping Center moved

FIG. 12. Digital map data collected with two- and three-axis systems can be interactively edited and revised on the Digital Data Editing System.

from Arlington, Virginia, to the new USGS National Center at Reston.

1976—The Mid-Continent Mapping Center moved from scattered locations in Rolla, Missouri, to a modern specially constructed building at Rolla.

The People

Let us suppose you have a fine program, the most ingenious systems, the best tools, and the most modern plant. Does that guarantee that you will produce according to the plan? Obviously, there is another ingredient to be added—the people who can make the plan work.

The postwar period brought a change in the prewar practice of hiring civil engineers for the professional positions in USGS operations, mainly because of a shortage of available engineers. The new professional recruits, for the most part, had degrees in such disciplines as geology, forestry, and mathematics, plus a few engineers. These recruits were professionals in every sense of the word and they continued to uphold the high performance standards and traditions of the old-time engineers.

Technicians were recruited mainly from applicants with some college training. These people served admirably as field technicians, stereoplotter operators, and cartographic technicians.

Perhaps the key to the progress of the Survey's mapping program was the leadership. There was a succession of distinguished Chief Topographic Engineers, (even though the title has now been changed to Chief, Topographic Division). Gerald FitzGerald was the Chief in 1947, followed by George D. Whitmore in 1957, Robert H. Lyddan in 1968, and Rupert B. Southard in 1978.

The role of Geological Survey people in our two societies is so impressive that it is almost embarrassing to mention it. ACSM numbers five USGS men among its Past Presidents: George D. Whitmore, Gerald FitzGerald, Robert H. Lyddan, Earle J. Fennell, and William B. Overstreet; and four among its Honorary Members: Gerald FitzGerald, Richard T. Evans, George D. Whitmore, and Earle J. Fennell.

Twelve USGS men have served as President of ASP: Claude H. Birdseye, Thomas P. Pendleton, Gerald FitzGerald, George D. Whitmore, John I. Davidson, Harry T. Kelsh, William A. Fischer, William A. Radlinski, Frederick J. Doyle, Joseph P. Burns, Robert E. Altenhofen, and Hugh B. Loving. ASP numbers ten USGS men among its Honorary Members: Russell K. Bean, Claude H. Birdseye, William A. Fischer, Gerald FitzGerald, Thomas P. Pendleton, George D. Whitmore, Harry T. Kelsh, Frederick J. Doyle, Hugh B. Loving, and Morris M. Thompson.

This listing could go on at length, enumerating chairmen of Divisions and Committees, winners of awards, authors of articles, and editors of publications. The point is that USGS people cherish their association with these societies and the management has encouraged it.

Conclusion

So it is with equal measures of pride and humility that USGS contemplates its record on its 100th birthday. There is pride in what we have accomplished. There is humility in the face of what we have not accomplished and what remains to be done. Speaking for myself, I am thankful that I have had the opportunity to participate in these years of mapping progress. We who look back on these fruitful decades can draw some useful inferences from them to guide us in our active years to come.