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Progress in Orthophotography*

Since its hobby-shop beginning in 1954, orthophotomapping has produced a revolution in cartography.

Abstract: *Less than 20 years ago orthophotomapping was practically non-existent. Today the entire science of cartography is being stimulated by the new developments in producing and using orthographic aerial photographs. Either as a complement or a substitute for the conventional line map, the orthophotomap must have uniform scale, a geographic reference system, and possibly some cartographic enhancement; the relative accuracy of the image map is generally an improvement over the line map. Progress and attributes of orthophotomapping are discussed over a wide range of map scales, as well as recent applications in the U. S. Geological Survey towards a National mapping program.*

Format Considerations

Since 1954, when orthophotomapping was first introduced in the United States by the U.S. Geological Survey (USGS), orthophotomaps have progressed from a scientific curiosity to a widely accepted complement or substitute for the well-known topographic maps. As we become aware of the scientific, engineering, industrial, commercial, and military uses for orthophotomaps, the map specifications—publication scales, accuracy standards, and detail criteria—must be practically designed to satisfy a wide range of public needs.

In planning orthophotomapping, the scale of the map is the first consideration and most important specification. It determines the shape and size of the map for a given area, the accuracy needed in the ground surveys and aerotriangulation, and the amount and complexity of detail that can be shown. If contours are to be added to the orthophotomap, the scale determines the range of contour intervals that would best portray the topography. Overall, scale directly affects the cost and rate of production.

When the USGS first undertook the task of mapping the United States, economic factors dictated only two or three map scales for the nation-wide mapping program. Of these, the 1:250,000 scale was virtually abandoned by 1890. (1:250,000-scale mapping, reactivated by the Army Map Service and reassigned to the USGS, now constitutes the only completed coverage of the U.S.) Around 1910 the principal scale was 1:125,000, with 1:62,500 used to show better the more densely populated areas. As the country developed and the population grew, the proportion of manmade features also increased. It became necessary to increase the proportion of mapping at successively larger scales: 1:62,500 standard, 1:31,680 and 1:24,000 for greater detail (1920); 1:24,000 standard (1945). Since the introduction of orthophotomapping, the use of even larger map scales has resulted from the need for detailed maps of urban areas, transportation and communication maps, highway design maps, and tools for more intensive resource investigations. Metrication in the U.S. will no doubt have an impact on map scales, perhaps giving rise to a 1:25,000/1:50,000 series. Table 1 summarizes the scales and map formats in greatest demand today in the United States.

To gain a point of view not limited to strictly government policies and practices, I asked several private companies engaged in orthophotomapping about their practices, types of terrain mapped, scales, accuracy, and costs. D. H. Refoy, principal requirements engineer, Autometric Operation/Raytheon

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TABLE 1. SUMMARY OF USGS MAP SERIES

USGS Map	*Format*	*Type*
1:2,400 (contract mapping)	0.5-1.0 square mile	Orthophoto
1:7,200 (experimental)	3.75 X 2.50 minutes	Orthophoto
1:12,000 (experimental)	3.75 X 3.75 minutes	Orthophoto
1:24,000 standard quadrangle	7.5 X 7.5 minutes	Line & Orthophoto
1:50,000 (experimental)	15 X 15 minutes	Orthophoto
1:62,500 standard (now obsolete)	15 X 15 minutes	Line
1:63,360 standard (Alaska)	15 X 20-36 minutes	Line
1:100,000 (experimental)	various	Orthophoto
1:125,000 (experimental)	various	Orthophoto
1:250,000 standard	1 X 2 degrees	Line
1:250,000 (experimental)	1 X 2 degrees	Orthophoto
1:500,000 (experimental)	various	Orthophoto
1:1,000,000 standard (IMW)	4 X 6 degrees	Line

Company, Wayland, Mass., has permitted me to share his reply with you.

> . . . In recent years Raytheon has been producing orthophotos as a service, using its own automated equipment as well as the French SFOM 693 . . .

In general, over the years, we have made the following observations:

- The orthophoto has its widest acceptance for medium-to-small-scale mapping (1:12,000 and smaller). At larger scales automated equipment has problems with above-ground detail—vegetation, buildings, bridges—although we have successfully produced orthophotomaps at 1:1,200 in suburban areas where buildings are not higher than two stories.
- The planning community accepts orthophotomapping more readily than does the engineering community. In applications where public examination of the maps is required, property mapping, zoning, etc., it has been found that the average person cannot read the conventional line-and-symbol map. Of course, in property mapping in rural areas, the advantage of being able to see apparent property lines (changes in vegetation, etc.) is tremendous and, although the orthophotomap is gaining in acceptance in the United States, it is difficult to understand why it is not being used to an even greater extent.
- The greatest use of the orthophoto, in our opinion, is as a base for thematic mapping. The advantage of being able to produce overlays of photointerpreted or ground-truth data directly on an orthographic projection are tremendous and provide a direct tie between the interpretive and mensuration sciences.
- Accuracy tests conducted by Autometric have shown orthophotomapping to be well within Class-A map accuracy standards provided that slopes do not exceed about 40 percent and magnification from the original photographs does not exceed six times.
- With regard to cost, we have found that in rural areas, where little detail is to be plotted, the orthophoto is comparable in cost to the line-and-symbol map produced on photogrammetric instruments. As the density of detail increases, the orthophoto becomes more attractive in cost . . .

ORTHOPHOTOGRAHY APPLIED TO PROBLEM TERRAIN

Extensive flatlands—swamps, coastal beaches, deserts—are the types of terrain least suited to topographic representation and oftentimes are the ones most difficult (and costly!) to gain access to for the necessary fieldwork. Perspective photographs of flatlands require only simple rectification, the fastest and least costly means of producing an orthophoto. Consequently, several such areas were prime targets for pilot projects in orthophotomapping: the great Okefenokee Swamp area of Georgia and Florida, the frozen marshlands of Prudhoe Bay area in Alaska, and the Great Salt Lake flats in Utah. The very favorable reception of the first orthophotomaps generated interest in States with similar terrain—Florida, Minnesota, Gulf Coast States, and Arizona.

Another impetus has been the availability of high-altitude jet photographs, taken at flight heights of 12,000 to 21,500 m (40,000 to 70,000 ft). Covering greater area with fewer photographs means savings in many steps of orthophotomap production. In fact, even without cartographic enhancement, the orthophotos provide an abundance of discernible detail not found on conventional line maps. So a new series has been added to the USGS product line—the orthophotoquad. Having the geometric attributes of a map (in standard quadrangle format) and offering the benefits of the actual monochromatic photo-image (with reference grid superimposed), orthophotoquads are recognized as interim substitutes for areas lacking topographic map coverage and as valuable complements to published topographic maps, particularly those needing revision.

ORTHOPHOTOQUADS FROM HIGH-ALTITUDE PHOTOGRAPHS

The Lockheed U-2 airplane is capable of sustained flight up to 21,500 m (70,000 ft). In April 1971, the National Aeronautics and Space Administration (NASA) acquired two U-2's for high-altitude photography and research in mapping. The photography was intended to support two earth-resources space-flight programs, the Earth Resources Technology Satellites (ERTS) and the manned orbiting station, Skylab. Selected test sites were photographed for comparative studies.

Using 1:138,000-scale (152-mm focal-length) photographs, USGS prepared several orthophoto products: 1° X 2° 1:250,000-scale, 7.5-minute 1:24,000-scale, and 15-minute 1:50,000-scale orthophotoquads. The site was the Phoenix area, Arizona, so that processing was mainly by rectification. Production at the two larger scales was speedy and inexpensive compared with line-map production. Considering the required magnification, the products retained high image quality. Both diazo and lithographic methods of printing produced good results (the diazo method is attractive because it is relatively inexpensive for reproducing small quantities). The Mesa, Arizona, 1:24,000-scale orthophotoquad was also printed back-to-back with the standard topographic map, not only for the sake of comparison but also to emphasize how the two types of maps complement each other as tools.

STANDARD ORTHOPHOTOQUADS OF SALT RIVER VALLEY, ARIZ.

The first of a new map series—49 orthophotoquads at 1:24,000-scale and covering 3,000 mi² of the Salt River Valley, near Phoenix—were recently printed and placed on public sale. These photoimage maps were produced from 1:79,000-scale photographs taken with a KC-6A camera. In this project, the photomosaic assemblies were controlled by analytical aerotriangulation. The orthophotoquads provide the most recent information for the area, which has topographic map coverage dated from 5 to 15 years ago.

ORTHOPHOTOMAPPING THE EAST COAST

Coastlands, largely flat and supporting a wide variety of vegetation, are ideal applications for orthophotomap portrayal. The photoimage captures the extreme tonal ranges due to coral, marl, and mangrove, and the subtle contrasts in marginal lands with a transition from wetlands to drylands.

Six projects are underway to orthophotomap portions of the East Coast. Three projects will use quadrangle-centered 152-mm (6-in.) photographs at scales ranging from 1:76,000 to 1:84,000. The 152-mm photographs are usually preferred to super-wide-angle (85-mm) photographs for orthophotomapping because of superior resolution and more uniform tonal range. Areas with minimum planimetric detail record satisfactorily in super-wide-angle photographs, as we have seen in some Florida orthophotomaps. All areas have low relief, and therefore the photographs can be processed by conventional rectification.

ORTHOPHOTOMAPPING THE ANTARCTIC

Of special interest to scientists engaged in polar exploration is a first attempt at orthophotomapping in a polar region. Eight orthophotomaps of Antarctica's Taylor Dry Valley, an oasis of dry land free of ice and snow, will be compiled at 1:50,000-scale. Black-and-white 1:60,000-scale photographs taken during the 1970-71 austral season will be used to form the orthophotobase. Horizontal and vertical control was established by a USGS field party during the 1971-72 austral season. Scientists, particularly geologists, will be interested in experimenting with the orthophotomap as a means for organizing their data.

ORTHOPHOTOGRAPHY FOR URBAN AREA STUDIES

NEED FOR ENVIRONMENTAL DATA

It has been estimated that by the year 2000, 80 percent of the U. S. population will live in 43 cities, each containing more than a million people, an increase in urban population of 120 million in 40 years. With rapid urban growth, population and economic pressures produce undesirable effects on the environment—land erosion, fire hazards, inadequate solid waste disposal, pollution of streams and the water table, and housing on land unsuitable for development, such as flood plains and filled-in marshland. Urban areas prone to earthquakes and landslides present even more problems.

Government authorities, urban planners, engineers, and architects must have access to timely scientific and engineering data, or urban resource data (Landen, 1965). Currently, the data are available in the form of specialized maps—topographic, geologic, and hydrologic. However, experience is showing that the available data are usually out-of-date, lack detail, and need standardization. Users of urban maps have come to appreciate the orthophotomap, as evidenced by a request from the Department of Housing and Urban Development for orthophotomaps of 25 of the largest cities in the United States, encompassing about 56,000 mi².

URBAN AREA 1:24,000-SCALE ORTHOPHOTO PRODUCTS

As you know, the basic topographic map produced by the USGS is the 7.5-minute quadrangle map, with traditional contours and cartographic symbolization. The maps are basic tools for community planning as well as for highway construction planning, industrial development, and environmental protection. Accordingly, one of the most important applications of orthophotography in ubran areas has been to produce orthophotoquads to complement the outdated line maps. Orthophotoquads of standard accuracy can be produced quickly and economically. They are generally produced from single high-altitude photographs, processed to quasi-orthographic form, formatted as standard 1:24,000-scale quadrangles, and lithoprinted in black-and-white. Orthophotoquads are in great demand for use as base maps (Lyddan, 1973).

Other variations of the urban-area orthophoto combine the photo-imagery with contours, and the orthophotomap virtually amounts to a standard topographic map printed on an orthophotobase. The latter has been produced experimentally for a few urban areas at 1:7,200-scale. Three different experimental orthophotomaps of the same area are being prepared for Chicago, Ill., to determine ways of minimizing the perspective slant of tall buildings in urban areas. The several maps will be made from photographs taken by cameras of different focal lengths and at different flight heights.

Some of the latest instrument developments should greatly facilitate preparation of orthophotomaps. The USGS Orthophotomat, for example, is part of a new system to automate orthophoto production. The ultimate success of the photomap program in urban areas depends on the expertise of planners, engineers, and economists in using orthophoto products. Consequently, the real challenge to the photogrammetrist and cartographer is to reduce the essential environmental data to a form which can be understood and used by people who are not trained in making earth-resources inventories (Bermel, 1972).

Toward Completion of National Coverage

At the current production rate, 1:24,000-scale standard topographic map coverage of the conterminous United States is not expected to be complete before 1982. Therefore, experiments are underway to determine whether orthophotos in various forms can economically provide complete coverage well before 1982.

The formats and the processing are designed to permit the printing and distribution of a map after any of three major phases:

- ★ *Phase I. Production or orthophotoquads.* Summary specifications: distortion-corrected monochromatic photoimage; UTM grid and State plane-coordinate ticks; selected geographic names for orientation; and marginal data conforming to standard practice.
- ★ *Phase II. Intermediate publication of contoured orthophotoquads.* Monochromatic orthophotoquad over-printed with contour lines, perhaps feature names, and cartographically enhanced drainage, highways, land net, and civil boundaries; selected elevations labeled.
- ★ *Phase III. The final map,* published as a standard line map, fully annotated orthophotomap, or hybrid product, with rapid updating always available through new photographs.

Substantial savings in time and money are expected. Quadrangle-centered aerial photographs will eliminate mosaicking. Aerotriangulation in large blocks to control the quad-centered photographs is practical. Each map can be economically updated by new photoimagery. Unpublished manuscripts will be used in Phase II for such information as contours, drainage, civil boundaries, and land net, all confirmed by field inspection.

ORTHOPHOTOGRAPHY FOR INTERIM REVISION

Map revision is a critical element in the USGS mapping program. With the current methods of interim revision, the planimetric content of a map can be updated and published in as little as six months. The process includes compiling from aerial photographs, modifying existing color-separation drawings, preparing a new drawing of specifically revised features, and reprinting the map in its original colors plus revisions in purple.

Orthophotography offers several possibilities for further improving on the interim-revision process. Orthophotographs, especially quadrangle-centered, can be used for updating in lieu of conventional aerial photographs, eliminating the need for a projection instrument for compilation. On a California project, 1:80,000-scale quad-centered photographs were processed to 1:24,000 and used, not only to update planimetry in 1970, but also to orient

1:30,000-scale photographs taken in 1971 for another revision. Orthophotographic interim revision is a new method under evaluation whereby new orthophotoimagery is combined with line drawings of out-of-date maps. Consequently, the tasks of photointerpretation, compilation, and color separation of new map content are eliminated or minimized. An added dimension—photoimagery of all visible features—would be available to the map user.

EXAMPLE OF A NATIONAL ORTHOPHOTOMAPPING PROJECT—BELGIUM

Aero Survey, a private company of Sint Niklaas, Belgium, is the first to produce orthophotomaps covering an entire country—Belgium. The 1,687 maps are called orthophotoplans (ORTO) and cover 30,000 km² (about the area of the State of Maryland). According to the director, Walter Bonne, the aerial photographs were taken at 6,100 m in 25 flight-days (1972) in a fairly low-speed Pilatus Turbo Porter airplane.

Horizontal control for the 1:10,000-scale maps was already available as the many churches in Belgium with steeples generally have geodetic coordinates. Vertical control was obtained from a new 1:25,000-scale map of Belgium. All other phases of the work—aerotriangulation, orthophoto production, mosaicking, photographic density control, cartographic enhancement, and printing—were completed in 10 months.

SFOM equipment was used to produce all of the orthophotographs; in flat terrain, the instrument was used as a conventional optical rectifier. The projection and grid are referred to the national Lambert coordinate system. Accuracy of the printed orthophotoplans is considered to be within 0.30 mm. A 150-line magenta screen was used in making the pressplates. The maps are printed on a special paper, heavy coated on the side with the screened image.

The maps are being sold to a wide gamut of users, including the Belgian Government. An orthophotoplan sells for 100 Belgian francs ($2.28), with discount of 25 percent for orders of 6 maps or more. The company quoted 6,000 francs ($136.80) per sheet (orthophotoplan) for processing photographs (of an area with sufficient control) to the screened films for offset printing.

ORTHOPHOTOIMAGES FROM SATELLITE PHOTOGRAPHS

Within certain limits, conventional rectification of high-resolution, ultra-high-altitude jet photographs and satellite imagery can produce orthophotographs of the earth's surface. The important factors are flight height, the terrain type, and distribution of control points. A computer program has been developed in which the project parameters can be entered as input in a simulation run; image displacements at specified peaks and other selected elevation points are computed. Thus, it can be determined in advance whether the photographs need to be scanned in an orthophotoprinter or can be processed by simple rectification.

The Lake Tahoe area, California-Nevada, 1:1,000,000-scale experimental orthophotoimage is the first example of satellite imagery which has been rectified by electronic processing. The orthophotoimage was produced only 15 days after exposure on July 25, 1972, by the Multispectral Scanning System (MSS) on the Earth Resources Technology Satellite (ERTS-1. ERTS-1 is continuously orbiting the Earth at an altitude of 915 km (568 statute miles), recording multiple images of each scene with sensors of various wavelengths. For the Lake Tahoe map, original 1:3,369,000 image data were corrected to ground control points and enlarged to 1:1,000,000-scale. Three images representing different spectral band responses from the same scene were merged and lithographed as a composite with arbitrarily assigned colors. A fine-line UTM grid was superimposed on the photoimagery. These first cartographic products from ERTS images contain much useful information which can be correlated with line maps by means of any geodetic reference grid.

CODA

Since its hobby-shop beginning in 1954, orthophotomapping has produced a revolution in cartography. Lower costs, shorter map cycles, timely products, and accuracy are qualities any mapping organization finds appealing. The greatest economies in mapping can be realized through a national orthophotomapping program wherein larger-scale orthophotomaps are complemented by corresponding conventional line maps at smaller scales.

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Forum

Orthophoto Articles

Dear Editor:

The juxtaposition of two articles in the November 1973 issue has caused some confusion and misinterpretation by your readers. The articles are: "Quality of Production Orthophotos" by Mrs. E. A. Fleming and "A New Concept in Orthophotography" by Joseph O. Danko, Jr.

Reference is made in Mrs. Fleming's article to one of the five instruments tested as having been a Kelsh Orthophotoscope. Reference is also made on page 1155 to a deterioration of imagery at longer projection distance in Z. On page 1156 is outlined the number of photographic reproduction steps each with its resultant loss in quality of final image.

Judging from comments coming in to us from the field, some readers have assumed that the Kelsh instruments referred to in both articles are one and the same. They definitely are not, and in actuality bear only minor resemblances.

The Kelsh instrument of Mrs. Fleming's article should properly be referred to as "Kelsh-built". This instrument is the T-64 Orthophotoscope designed by the U. S. Geological Survey and frequently referred to as the "Russ Bean design". It employed two Balplex ER55 projectors and one Kelsh 23 × 23-cm projector. It was built, under contract, by the Kelsh Company prior to acquisition of Kelsh by Danko Arlington, Inc. Danko Arlington has not built any T-64 Orthophotoscopes.

The Kelsh K-320 ORTHOSCAN, outlined in Mr. Danko's article, employs *three* 23 × 23-cm standard-size diapositives if a full double model is desired; only two are used in making a single model.

The outboard projectors use Hypergon lenses (as did the center projector on the T-64); however, the center projector on the ORTHOSCAN uses a new six-element inverse lens which has a remarkable resolution and depth of field, thus making the resolution over the full ten inches of travel in Z much better than on the T-64.

The Kelsh K-320 ORTHOSCAN is built around a nominal magnification of 5× with capabilities of going from 3.8× to 5.8×. The T-64 had a design magnification of 2.75× The essential difference here is that we can produce with the ORTHOSCAN an orthonegative which is at standard Kelsh-plotter scale, retains the maximum resolution by emulsion-to-emulsion contact printing using a point-source light and thus avoiding one of the major imagery-loss steps. To refute the argument of poor imagery, we have taken an ORTHOSCAN negative which is 5× flight scale and blown it up twice (10× flight scale), four times (20× flight scale) and even eight times (40× flight scale). Admittedly, the 40×-enlargement is grainy, but the imagery is surprisingly good. The 10× and 20× enlargements have been considered as saleable items by customers who have seen them.

Mrs. Fleming refers to image quality as being a deciding factor in limiting the degrees of enlargement that can be useful. We agree, but we feel that we have attained an imagery level superior to any other in the market today—certainly far better than the T-64—throughout the Z-range.

Careful reading of Mr. Danko's article should make it obvious that the ORTHOSCAN and the T-64 are not the same instrument. However, Mrs. Fleming's paper mentions only *Kelsh* with no other designation.

—*A. C. Schettler*
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