*Improvements in the Stereo-Mosaic**

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ABSTRACT: *The technique of the stereo-mosaic was first described by the author in 1950. This early technique required the use of two panels and a large mirror stereoscope for three dimensional viewing; this was a distinct handicap. Since then improvements have been made so that the mosaic may be printed on a single sheet, with its stereo-mate printed beside it, or on the back of the sheet. By folding the sheet the two images may be brought to within interpupillary distance and viewed with a pocket stereoscope. One member of the mosaic has, as an overprint, the standard USGS topo sheet, so that it combines the advantages of the mosaic and the topographic map. This development permits field use and opens the door to possible substitution of stereo-mosaics for standard topographic maps.*

HISTORICAL

STEREO-MOSAICS were first described in PHOTOGRAMMETRIC ENGINEERING by the author (3) in 1950. The technique was based on the use of two mosaics, one made for the left eye and the other for the right eye. This was accomplished by cutting each photo in two through the center at right angles to the line of flight, provided, of course, that there was at least 50 per cent overlap. All the left halves were set aside to make up the right-eye mosaic and all the right halves were used to make up the left-eye mosaic. When completed the panels were viewed with a stereoscope, and the successive stereo-pairs blended together to form a continuous three-dimensional model. The technique was intended as a compromise between the use of the conventional mosaic and contact prints, each of which had drawbacks. The mosaic lost the third dimension and contact prints had no map symbols or reference points, making them difficult to use. It was felt that a stereo-mosaic would include the advantages of both and so would be superior to either for field use.

A comment on the paper describing the stereo-mosaic was published by Teller (5) the same year, and he described his efforts to compile a stereo-mosaic seven years earlier, using the anaglyph principle. He was able to solve the technical problems, but he found no one interested in making practical applications, although he demonstrated it widely in both government and private mapping circles. It has been the author's observation that the public is intrigued by the anaglyph as a curiosity, but it is afraid to depend on them, knowing they would be useless if the colored glasses were lost.

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The following year the author received

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[1] The opinions expressed in this paper are those of the author and do not necessarily reflect the opinions of the U. S. Forest Service. Subsequent to presenting this paper, the author transferred to a different federal agency.

a letter from Percy Tham, of Stockholm, stating that he and an associate had been producing anaglyphic stereo-mosaics, and he enclosed a lithographed copy of a six-photo mosaic. More recently it has been learned that the Germans have been using stereo-mosaics for the last 25 years.

The stereo-mosaic technique used by the author was an adaptation of earlier vectograph techniques. However, it had the serious disadvantage of being mounted on separate left-eye and right-eye panels, which had to be viewed with a large mirror stereoscope. This was so cumbersome that it precluded field use, and the advantage of the third dimension was out-weighed by practical considerations.

Despite the many problems weighing against the success of a stereo-mosaic, it was the author's belief that a successful method which is simpler than the anaglyph, vectograph, or his own mirror stereoscope method could be found. He finally hit on the idea of keeping one member of the mosaic as copy to be viewed normally as a photo-map; on this a topographic map would be overprinted. Its stereo-mate would then be printed either on the back of the sheet or to one side; this would be folded so that any part of it could be placed within interpupillary distance of its counterpart on the map member. The mosaic could then be viewed in the third dimension with a pocket stereoscope, as seen in Figure 1, or directly by those with stereoscopic vision. This would free the mosaic for field use by such as soldiers, foresters, or geologists, who could make the most use of it.

FIG. 1. A stereo-mosaic in use in the field. One member is folded over to within interpupillary distance of the second member. Then they are viewed with a stereoscope.

Compilation Procedure

The following procedure is used to produce the example demonstrated in this paper.

High-quality mapping photography was available in two scales for an area on the Cumberland National Forest in Kentucky. The scales were 1:21,120, taken with a 6″ lens, and 1:15,840, taken with a $8\frac{1}{4}''$ lens. The author chose the latter because the longer focal length causes less relief displacement. The area had been mapped by the Geological Survey, and, from the photos standard 1:24,000 topographic maps, with 20 foot contours, had been produced, as shown in Figure 2. The author was able to secure the original control board and the color separation boards, from which the culture and contour color plates were produced, through cooperation between the Forest Service and the Geological Survey.[2] Also available were the original mapping photos, on which the control and radial plot points were marked. This made possible constructing a controlled mosaic, which would match the topographic map.

The Commodity Stabilization Service of the U. S. Dept. of Agriculture makes large numbers of mosaics. Consultation with it revealed that the most desirable procedure was to determine the scale correction ratio for each photograph, and to have each photo printed to the map scale; which the Service is able to do with great accuracy. However to lessen the cost[3] it was decided to lay the mosaics at the average scale of the photos on hand, and to enlarge the control board to this scale. While there would be a loss in accuracy, the mosaic procedure could still be demonstrated.

Orientation of each photo in the mosaic was assured by increasing the number of control points on the control board with map points, recognizable on the photos, so that there would be at least three control points on each section of photograph to be laid down. These points were pin-

[2] The author is deeply indebted to Mr. J. E. King, of the Forest Service, for his material help and advice, and to Mr. D. H. Watson, of the Geological Survey, for his permission to use USGS map data.

[3] This project was a work improvement proposal largely produced at personal expense.

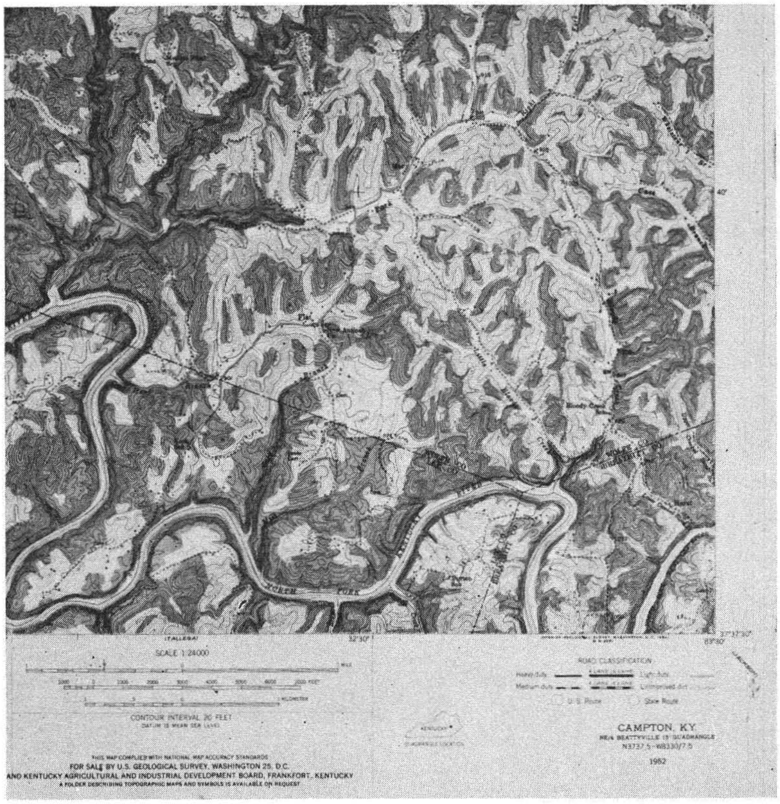

FIG. 2. Map of the area mosaiced. This area, in the Campton Quadrangle in Kentucky, is moderately rough terrain, with local elevation differences of 500 feet and many vertical cliffs. Contours were drawn to a 20 foot interval.

holed in the photos, which were placed over fine holes in the control board, over a light table, as they were cemented down. When both the left-eye and right-eye panels had been completed by this procedure, they were compared with the map. As the left-eye panel was found to have the lesser amount of error, it was selected as the panel which would bear the map symbols.

The panels were then examined with a mirror stereoscope to check the three-dimensional quality. It was discovered that, despite the care exercised in laying the mosaics, slight variations in scale between the prints and relief displacements caused enough error to create "cliffs" between prints. Most of this was corrected by lifting the photos of the right-eye panel, where "cliffs" appeared, and shifting them either to right or left in order to raise or lower the image stereoscopically. Careful manipulation of the right-eye prints could theoretically place all the stereo-models in the same plane. However slight adjustments in the right-eye panel do not affect mosaic accuracy, because this member supplies only stereoscopic vision, and it can accommodate slight errors.

It would have been simpler to have used an enlargement of the map itself as control. It was felt, however, that a procedure should be developed which would utilize ground control, rather than add mosaic errors to those already present in the map.

When the panels were completed they were edged with black to provide a background for map data, which would be superimposed. The panels were then copied photographically. The mosaic dimensions were carefully measured on the copy negatives, and the culture and contour boards were copied to the same size. Diapositive transparencies were then made from the culture and contour negatives. The transparencies were superimposed in sandwich fashion on the negative of the left-eye mosaic and taped in place. The three sheets

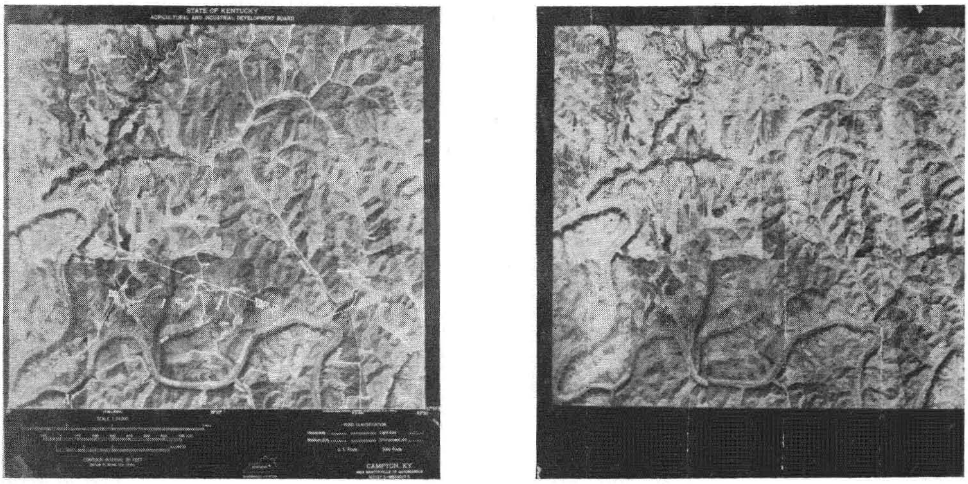

FIG. 3. Mosaic with only the culture overprint. This reveals the maximum amount of photographic detail. New map symbols need to be devised which will hide even less.

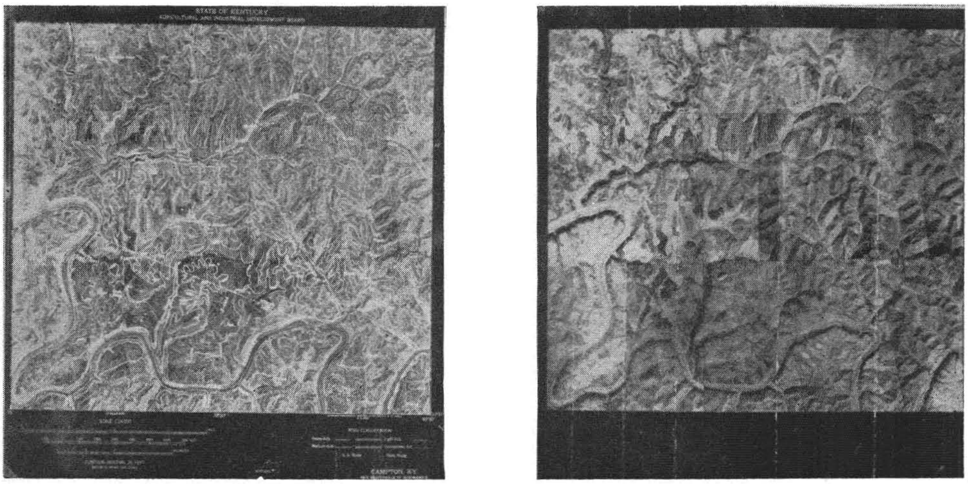

FIG. 4. Mosaic with culture and contour overprints. Some detail is obscured but the mosaic can now be used as a topographic map.

of film were placed in a negative holder, and an enlargement was printed through them at the final mosaic scale of 1:24,000.

In the examples shown in Figures 3 and 4, one print was made with only the culture transparency over the mosaic negative. This was done because the large number of contour lines tended to obscure the mosaic image and could have prevented the use of contours. This difficulty can probably be overcome by substituting a contour board having very fine contour lines. These would be cut with a scribing tool, instead of the inked lines appearing on the original contour board.

To complete the stereo-mosaic, the left-eye and right-eye prints were joined together. The right-eye print was creased so that it could be folded every $2\frac{1}{2}$ inches from left to right. The right-eye print was finally folded under the map print, until it might be needed for stereoscopic viewing. To be most effective in photographic form, mosaics should be printed on thin document-weight paper, treated with an emulsion softener. This permits folding and creasing without appreciable damage. In mass production, mosaics would be lithographed, with the stereo-member printed on the back of the sheet.

Analysis of Accuracy

It should be kept in mind that the mosaics used in this demonstration were laid to the average scale of three flight lines. This produced many small differences in scale from photo to photo, and introduced errors which are intolerable to the topographic engineer. Contributing factors were the use of unstable printing paper and the ferrotyping of the prints. If each print had been ratioed to the map scale, and each photo rectified and printed on dimensionally stable paper, most of these errors would have disappeared. Those remaining would be due to relief displacement.

The greatest relief displacement in this mosaic is in the photo at the lower right, where there is a difference in elevation of 260 feet between the photo center and the river bottom, at the photo edge. This produces a horizontal displacement of 130 feet, or 3/50 inch on the mosaic. This is three times the allowable 1/50 inch horizontal error permitted by national map standards. However, displacements reach their maximum at the outer edge of each photo, and parts of the photo near the center are comparatively free of displacement. It can be assumed, therefore, that this large error occurs only once, and that other sizeable displacements happen only when there is a coincidence of a high relief point and an outer edge of a photo. This would mean that large parts of the mosaic would be accurate to acceptable limits. Moreover, the displacement errors in controlled mosaics are not cumulative.

Theoretically each photo center is without error, with errors increasing toward the edges, to be brought back to zero again at the next photo center. The Air Force recognizes this fundamental difference between maps and mosaics in its accuracy standards. It is stated (1) that 90 per cent of the check points on maps must fall within accuracy limits, while on mosaics it is specified that only 75 per cent of the check points need meet these standards.

Rosenfield (4) has described a method of rating the accuracy of mosaics. By applying this technique it was found that there is a Maximum Relative Position Error in the mosaic of 267 feet. Seventy-five percent of the ground control points used in making the mosaic were used as check points. Air Force standards permit errors of 100 feet for Class *A* mosaics of this scale, 200 feet for Class *B*, 400 feet for Class *C*, and 1,000 feet for Class *D*. This mosaic would fall into Class *C*. It is believed that if the scale of the photos were ratioed to the map scale, and if the tip and tilt were rectified, the *MRPE* could be reduced to less than 100 feet, thereby placing it in Class *A*.

Another check of accuracy was made by tracing on an overlay, shown in Figure 5, the greatest differences between the mosaic and the overprinted map. This revealed that the two prints at the upper left contained quite large differences, and must have been erroneously laid down. In other prints the differences were quite small, averaging not more than 100 feet. In a large number of prints in the center of the mosaic no appreciable error was visible, other than small relief displacements on the hilltops—indicated by circles—which were in the neighborhood of 50 feet. The allowable national standard of 1/50 inch error is 40 feet at this scale.

Costs

Because a comparison of costs often arises in a discussion of mosaics, the author kept a record of his time and expenses in producing the experimental model. This amounted to $107, when all "trial and error" costs were deleted. It is estimated that if ratioed and rectified prints were used, the cost would be increased to $137. According to Army Map Service estimates, lithographic reproduction for these two mosaics would cost approximately $92, assuming this as the proportional cost of full $7\frac{1}{2}$ minute quadrangles. This would give a total production cost of $229.

The standard 1:24,000 topographic map costs approximately $100 per square mile, or about $1,800 for the 18 square miles in the sample shown here. Therefore the cost of producing stereo-mosaics after this is done is approximately 13% more, or $13 per square mile.

The Need Which Stereo-Mosaics Can Fill

The possible applications of stereo-mosaics are many. They were outlined in previous publications (3), (5). The uses can be summarized as follows:

> Stereo-mosaics are nearly the equal of topographic maps on a purely carto-

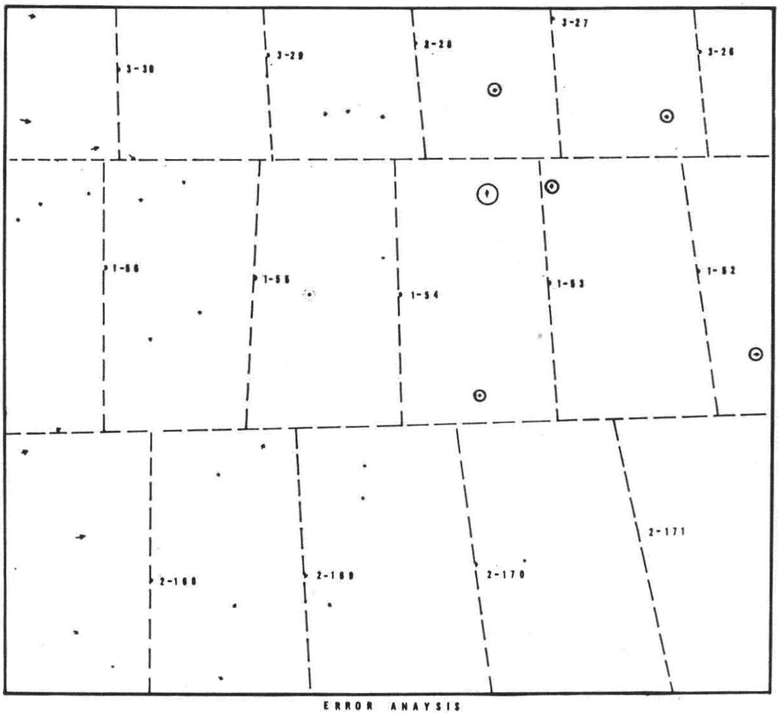

FIG. 5. Error analysis. Points of maximum error in each photo were selected and their displacements represented by arrows. The circles indicate errors due largely to relief, where hilltops are displaced outward from the photo centers.

graphic basis, because the topographic map, with all its original accuracy, is incorporated into the mosaic. Only the drainage and vegetation patterns are replaced by photographic images. In addition, the stereo-mosaic has a wealth of pictorial detail, which fills the otherwise blank spaces on maps, also it has the third dimension.

Stereo-mosaics can be viewed stereoscopically, with or without a stereoscope, and can be projected on a screen, by means of polarizing filters, for briefing and conference purposes.

Stereo-mosaics can fill a need in the armed forces, where the difficulty of reading topographic maps has long been a problem. The author remembers that in his OCS training, the map reading course was the worst stumbling block for the future officers.

With the stereoscopic effect there is much less doubt about slopes and grades.

Pilots and observers find mosaics easier to read than maps on close support missions, because of the similarity between the images and ground features.

A stereo-mosaic could well be used as the map supplement to accompany intelligence reports, because many of the photo interpretations in the report could be illustrated.

In stereo-mosiacs enough of the original photo quality is preserved so that considerable photo interpretation is still possible.

Many of the rock structures, vegetation types, and cultural patterns can still be identified. This would permit steromosaics to fill a need in the Geological Survey and in various agencies of the Dept. of Agriculture, providing an efficient base for geological mapping, land classification surveys, the delineation of crop control acreages, and other land surveys.

FURTHER IMPROVEMENTS

As can be expected, this technique has both its advocates and its friendly critics. Those favoring it are generally the field men, who see possibilities for the solution of field problems. They realize the advantages and minimize the errors involved. Those who regard the technique with misgivings are usually the engineers, because of the displacements and mismatches between photos. Probably both groups are right. The technique has both advantages and limitations. Probably the soundest approach would be to consider how to lessen the weaknesses and, when the limit of improvement has been reached, what alternatives remain.

The greatest problem to overcome is the reduction of relief displacement. The following remedies might be applied:

1. Whenever possible use long focal lengths, such as $8\frac{1}{4}''$ or $12''$. The $6''$ focal length photo, which the topographic engineer needs because of its relief exaggeration, is the mosaic maker's anathema. However, $6''$ focal lengths are usable for fairly level terrain.

2. Even with long focal lengths, areas of high relief should be avoided for mosaics made with conventional photos. Avoid using quadrangles where there are numerous relief displacements within the usable portion of photos, which exceed the national standard of $1/50''$. This would automatically bar this technique from all rough country and relegate it to hilly, rolling and level land, such as the Great Plains, the Mississippi Valley and the Atlantic Coastal Plain. The terrain in this example is just over this limit, when $8\frac{1}{4}''$ focal lengths are used, but it would probably fall within acceptable limits for $12''$ focal lengths.

3. In areas where numerous relief displacements exceed $1/50''$, orthographic photos produced by the orthophotoscope, developed by Bean (2), of the Geological Survey, should be used for the map-member of the stereomosaic. In these photos the relief displacements are removed, although some loss in resolution is suffered. The stereo-member of the mosaic should be made up of conventional photos to provide for stereoscopic viewing, when matched with the orthographic photos of the map-member. This seems to be a contradiction, but despite the removal of displacements in one member a difference in parallax still exists between the two members, although it is decreased toward the center of the normal perspective photo, weakening the stereoscopic effect in this area. This combination would compensate somewhat for the loss of resolution in the orthographic photo, because one eye would be focused on a normal photo with its sharper detail.

The orthographic photo, in the author's opinion, is one of the most important advances in recent photogrammetric history, and when fully developed it will produce mosaics which are far superior to those of the present day. They will provide even greater accuracy than is possible with topographic maps. Orthographic stereo-mosaics will also fit into the new convergent oblique system of mapping being developed by the Geological Survey and the Corps of Engineers. Orthographic photos can be produced as well from convergent obliques as from verticals, and normal perspective photos, for the stereo-mates, can be produced by rectifying the 20 degree obliques of the new mapping system.

Conclusions

By following a research program incorporating the above features, it is altogether possible that a breakthrough could be achieved which would provide a photo map of accuracy well within national standards for topographic maps. If this could be achieved, the stereo-mosaic would immediately become superior to the topographic map in its present form, because of its pictorial detail and its three dimensional quality. For this reason it is felt that this research is worth the effort.

Literature Cited

(1) Air Chart & Information Center, USAF, 1953, "Production Specifications, Target Material Reliability Data," 1st ed., RM-401.

(2) Bean, R. K., 1935, "Development of the Orthophotoscope, PHOTOGRAMMETRIC ENGINEERING, Vol. XXI, No. 4, pp. 529–535 and Vol. XXIII, pp. 170–179.

(3) Heath, G. R., 1950, "The Stereo-mosaic, a New Mapping Techinque," PHOTOGRAMMETRIC ENGINEERING, Vol. XVI, No. 2, pp. 152–154.

(4) Rosenfield, G. H., 1955, "The Accuracy of Mosaics," PHOTOGRAMMETRIC ENGINEERING, Vol. XXI, No. 5, pp. 670–673.

(5) Teller, W. M., 1950, "The Stereo-mosaic, a New Mapping Technique, A Discussion," PHOTOGRAMMETRIC ENGINEERING, Vol. XVI, No. 4, pp. 620–621.