RESUME OF METHODS EMPLOYED IN PREPARING QUADRANGLE MAPS IN TENNESSEE VALLEY*

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THOSE of us engaged on the surveying and mapping work of the Tennessee Valley area have had what is probably a unique opportunity to observe the effectiveness of various methods of preparing quadrangle maps, both planimetric and topographic. During the three-year period from 1934 to 1936 there was the valley-wide planimetric mapping program, covering more than 40,000 square miles of area, and requiring more than 800 map sheets on the 1-inch-equals-2000-foot scale. That project utilized one process exclusively, namely, radial-line compilation from 5-lens photographs. Its procedures have been described for this group many times.

Then in 1936, as the planimetric program neared completion, the Authority began topographic mapping, under an arrangement with the U. S. Geological Survey whereby the execution of the work was divided between personnel employed by the Authority and personnel supplied by the Geological Survey. That program has gone forward steadily during the last four and a half years, and at this date nearly a third of the more than 40,000 square miles have been mapped. The scale of these topographic maps is the same as the planimetrics, 1:24,000. The contour intervals are 40 feet for mountainous sheets, 20 feet for rolling terrain, and 10 feet for the sheets having low relief. On almost every sheet a broken-line half-interval contour has also been used to depict more precisely the topography and elevations of flatter terrain as well as the critical topographic features such as saddles. Accuracy specifications were adopted at the beginning of the project, and every topographic sheet so far mapped has been actually tested for compliance with these specifications. It is interesting to note that remarkably few sheets have been returned for redrawing because of non-compliance with accuracy specifications.

Both through force of circumstances and a desire to overlook no feasible methods, the project has been a sort of proving ground for various processes of preparing topographic quadrangle maps. All techniques used, incidentally, utilized photogrammetry in one way or another, in greater or lesser degree. It is the purpose of this paper briefly to list and describe some of the procedures which have been used in this program, and to present certain observations concerning them.

The original intent was to convert the planimetric sheets to topographic sheets by adding contours to the previously prepared 5-lens planimetric base. But, as is probably now well known by this group, that procedure did not prove to be as economical or as satisfactory as redrawing the planimetry whenever stereoscopic plotting instruments were used in preparing the topographic maps. The first topographic mapping work was actually accomplished as originally intended, that is, by having experienced plane-table parties plot contours in the field on metal-mounted blue-line prints of the previously prepared planimetric sheets. Only about 100 square miles were actually completed by this method, as it soon became apparent that progress would be slow and costs higher than anticipated. One of the aggravating handicaps of this method was that the plane-table topographers found it necessary in many places on the planimetric base sheets to make small changes in the base culture and drainage. Such minor

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changing in base inevitably caused annoyance and confusion, and did not help to keep costs down. The areas in which these minor changes predominated, incidentally, were mostly in the wing areas of the 5-lens photographs, where exact interpretation of road, trail, and drainage alignment was difficult. Another serious handicap of this method was that the 5-lens planimetric base sheets had shown only those features intended to be published, such as roads, trails, houses, main drainage, etc. Other features which would be useful to the topographer, such as field fences, were omitted. Consequently in many areas it was necessary to run long plane-table traverses across country untouched by roads.

In the meantime, early in 1936, the U. S. Geological Survey had purchased a Zeiss Multiplex instrument and placed it in Chattanooga for experimentation on the Authority's mapping program. These early experiments were so encouraging and impressive that the Geological Survey purchased several more instruments of the same general type for use on the work. The program was then scheduled for several years in advance on the supposition that most of the contour mapping would be by Multiplex.

It was obvious, however, that for the first year or two Multiplex plotting progress would be considerably less than the desired production, because the instruments and accessories would be slow in delivery, they would need to be set up and adjusted, and from 10 to 20 additional operators would have to be trained. Consequently other means of getting the required production during these early years were considered, with the result that contracts were awarded for two years in succession to the Fairchild Aerial Surveys, Inc., for preparing more than 2000 square miles of manuscript topographic maps by use of the stereoplanigraph instrument. The specifications as to accuracy of the maps delivered under this contract were substantially the same as had been previously adopted for Multiplex work. The tests for compliance with the specifications indicated that apparently the contractor had no difficulty in producing work within these accuracy specifications.

During the first three years of the project both Multiplex and Stereoplanigraph work had been limited to terrain requiring either 20- or 40-foot contours, with, in each case, the usual accompanying half-interval contours. The few quadrangles of lower-relief terrain which had been completed during this period, and which required 10-foot and half-interval 5-foot contours, were handled by plane-table topographers using two procedures, or variations of two basic procedures. The first of the two methods may be briefly described as plotting contours in the field directly on ratio-enlarged single-lens aerial photographs used as plane-table sheets, at the same time clearly marking all culture, drainage, and other features to be shown on the published map. In the office the planimetry as marked on the photographs was compiled on quadrangle-size map sheets by radial-line or any other available method. The contours were then projected to each map sheet from the photographs by use of vertical overhead projectors.

The second of the two plane-table methods was to prepare first a planimetric base map by means of Multiplex (any good type of plotting instrument would presumably do as well), on which were shown not only the usual features found on published planimetric maps, but also other culture, drainage and topographic features likely to be helpful to a topographer in the field. These extra features included such as fences, hedge-rows and tree-rows, boundaries of cultivated fields, *all* buildings, certain isolated and prominent individual trees and other land marks, sharp-ridge lines, and similar features. These planimetric base sheets, copied photographically and printed in non-photographic blue on metal-mounted plane-table-size sheets, were used by topographers for the addition of contours by plane-table methods. The maps prepared by this method proved to be remarkably accurate, and this, it is believed, is the plane-table method which, among the personnel on this project, is generally considered to be the most satisfactory and economical. The topographer is furnished a ready-made, complete and accurate base, which, because of its multiplicity of culture and other features, practically eliminates the necessity of plane-table traversing. The topographer generally merely needs to carry plane-table levels, take shots and sketch contours, and delineate in pencil or ink the culture and drainage features desired to be shown on the final published map.

But, even though this particular plane-table method was considered most satisfactory for the flatter terrain, the costs were disappointingly high. So consideration was given to trying the plotting of 10- and 5-foot contour maps by means of stereoscopic plotting instruments. The first attempt on this project was with Brock and Weymouth equipment, through a contract for one quadrangle of 60 square miles, awarded to Aero Service Corporation, of Philadelphia. This map was thoroughly tested as to accuracy, and found to be entirely acceptable, as well as lower in cost than similar plane-table work had been.

Thus encouraged, a somewhat similar terrain, of a 60-square-mile area requiring 10- and 5-foot contours, was assigned to the Multiplex instruments, with results as to accuracy and costs equally, or perhaps even more satisfactory. Within the last two months five additional quadrangles totaling 300 square miles, requiring 10- and 5-foot contours, have been flown for mapping by Multiplex.

So, to recapitulate at this point, there have been six different topographic mapping procedures so far utilized on the project. Three of these are by three entirely different types of high-grade stereoscopic plotting instruments, and three are adaptions of plane-table procedure. At this date, by almost unanimous agreement among the personnel on the project, all ground-survey plane-table work has been stopped, even for the lower-relief terrain requiring 10- and 5-foot contours, in favor of stereoscopic plotting instruments. The operators of these instruments seem to have proved quite conclusively that they can, on this project, at least, produce work of acceptable accuracy at considerably lower costs than can plane-table procedures.

The list of procedures seems notable for its complete omission of what is often called white-paper topography—that is, where the topographer starts with nothing plotted on his sheet except the projection lines and control points. It also should be noted that no experiments or trials were made with the smaller, lower-priced stereoscopic plotting instruments of such as the stereo-comparagraph type. It was felt that such instruments could not be expected to produce work economically of the accuracy demanded by the project.

The project seems to have demonstrated—at least, to the satisfaction of most of those connected with it—a number of points. In planimetric mapping, for example, it seems clear from the experiences of the early project that single-lens photographs are much to be preferred over T3A-five-lens photographs, for maps on the scale and of the accuracy required on this project. Also, if the original planimetric mapping project of the Tennessee Valley area were being done today, it is generally agreed that not only would single-lens photographs be used, but the compilation would be handled by stereoscopic-plotting instruments, of a high-grade type capable of fine accuracy—of such a type as the Multiplex, for example. It seems obvious to most of those who have observed the Tennessee Valley mapping from the beginning that for an extensive planimetric map project radial-line procedures can not compete economically with plotting instruments, assuming that the same accuracy is required of both processes.

In topographic mapping, the project seems to have demonstrated that the plotting of occasional half-interval contours across the flatter terrain, or on critical topographic features, is practical, and that the accuracy of these occasional contours is substantially the same, relatively, as for the regular-interval contours. This seems to be true, even though the airplane was flown at an altitude theoretically correct only for proper accuracy of the full-interval contours. The explanation must be that the half-interval contours only need to be shown in areas where the stereoscopic model is clear and sharp anyhow, and also that the operators of the instruments trace these particular contours with unusual, painstaking thoroughness. The accuracy of these half-interval contours proved to be about the same for work done by Multiplex, Stereoplanigraph, and Brock and Weymouth.

The inspection and testing of the topographic maps prepared by these instruments indicates that the weakest parts of such maps will be those areas covered by dense forest growths of tall trees, especially if the terrain within the wooded area is irregular. That condition had led to the adoption of a rule on this project that photographs for Multiplex topographic mapping must be secured during the winter and spring months when the trees are leafless. The later in the winter-spring season that these pictures can be obtained the better, since the light, length and density of shadows, and length of flying day, all improve as the season progresses.

Another point that the project seems to have demonstrated quite conclusively is that it is entirely feasible and practical to obtain first-class manuscript topographic maps through fixed-price contracts with reliable firms owning and operating high-grade stereoscopic-plotting instruments. Successful contracts seem to require principally the proper specifications, proper qualifications of the contractor and his employees, and through inspecting and testing of each map sheet before it is accepted.

Another obvious point is that even though the use of stereoscopic-plotting instruments becomes almost universal in topographic mapping, the plane-table topographer still will have an important job to do. Every map compiled in the laboratory from aerial photographs needs to be inspected, completed, and tested in the field, and that, according to the experiences in the Tennessee Valley area, is a job requiring a skilled plane-table man.

Now just a few words on the relative costs of mapping different contour intervals by stereoscopic-plotting instruments. The 40-foot contour interval, used on quadrangles in mountainous terrain, is of course the cheapest to map; the 20-foot interval used on maps covering the intermediate rolling and semi-mountainous terrain, is higher in cost; and the 10-foot interval, used on quadrangles for terrain of low relief, is still more costly. These differences in cost are largely caused by the lowering of the airplane's altitude as the contour interval becomes smaller—and the lower the plane's altitude the more stereoscopic models there are to set up and draw, and the more picture-point control stations there will be to establish in the field. The costs of the other operations, however, are only slightly affected, if at all. For instance, the costs of basic control, the flying, the field inspection of the manuscript maps, and the final reproduction of the maps will be approximately the same regardless of the contour interval used, so long as the final publication scale is the same. On the Tennessee Valley mapping project, the experiences to date indicate that the total cost, all operations included, of 20-foot-interval topography will be of the order of 10 to 20 percent higher than the 40-foot interval; and the costs of 10-foot-interval work will average about 40 to 50 percent higher than the 20-foot-interval.

As to the comparative costs of Multiplex, Stereoplanigraph, and Brock and Weymouth processes, nothing reliable is available at the present time. Since the Multiplex work is handled by force account, its costs are known. For the other two processes only contractor's bids are available, and these of course cannot be taken as indicative of actual costs.

As to the comparative costs of plane-table vs. plotting-instrument techniques, it can be stated as a positive fact that for terrain such as is found in the Tennessee River Basin, and assuming a project covering an extensive area, that ground survey plane-table costs for 40-foot and 20-foot intervals could not begin to compare favorably with the cost of maps produced by the stereoscopic-plotting instruments, always assuming the same accuracy in the final map. For low-relief terrain of the type found in the Tennessee Valley area, requiring 10-foot contours, the cost results so far obtained do not conclusively demonstrate that stereoscopic-plotting instrument costs will always be lower than plane-table costs, although so far the indications are certainly that way. It should be stated, for the benefit of those not familiar with the terrain of the Tennessee watershed, that there is very little of what could literally be called "flat" land, there being almost no areas comparable to such flat areas as are found along certain sea coasts, in prairie lands, in extensive swamps and marshes, etc. For flat terrain of the types just described it is believed that mapping the contours by plane-table, on a previously prepared planimetric base, would usually be more economical and satisfactory than use of plotting instruments.

These findings are in line with the generally accepted notions that the plotting instruments will excel in the steeper terrain, while the plane-table will be most advantageous in mapping contours in flat lands, and in getting actual "spot" elevations, where these are required. In the latter case the plotting instrument will usually be advantageous, however, in preparing the planimetric base. The principal disadvantage of the plotting instruments, in comparison with the plane-table, appears to be that the vertical accuracy of elevations or contours cannot be increased beyond a certain point for any given flight altitude, the limit of vertical accuracy being practically fixed by the taking altitude of the aerial photographs. Of course it is theoretically possible to get any desired degree of vertical accuracy from the plotting instruments merely by lowering the airplane's altitude correspondingly, but as the altitude lowers the cost goes up, and cost then becomes the practical limiting factor. The plane-table topographer, on the other hand, can vary at will the elevation and contour accuracy, varying it to suit the particular type of terrain being mapped at any time—if necessary getting elevations accurate to within a few tenths of a foot.

The foregoing statements contain a strong hint of what may likely become the standard topographic mapping procedure of the future, namely, to let each technique do the kind of work it is best fitted to do. For instance, let the operators of the plotting instruments draw the complete manuscript map—planimetry, contours, drainage and all—wherever the terrain runs from rolling to steep. Then in flat areas, in important industrial and other intensely developed areas, and in blemished-film areas or areas which have photographed poorly, let these operators draw only the planimetry, leaving for the topographer who will handle the field inspection and completion the job of completing the contours across these flat and important areas. The topographer can, of course, vary his procedure to map the contours in such areas with whatever degree of accuracy is required.