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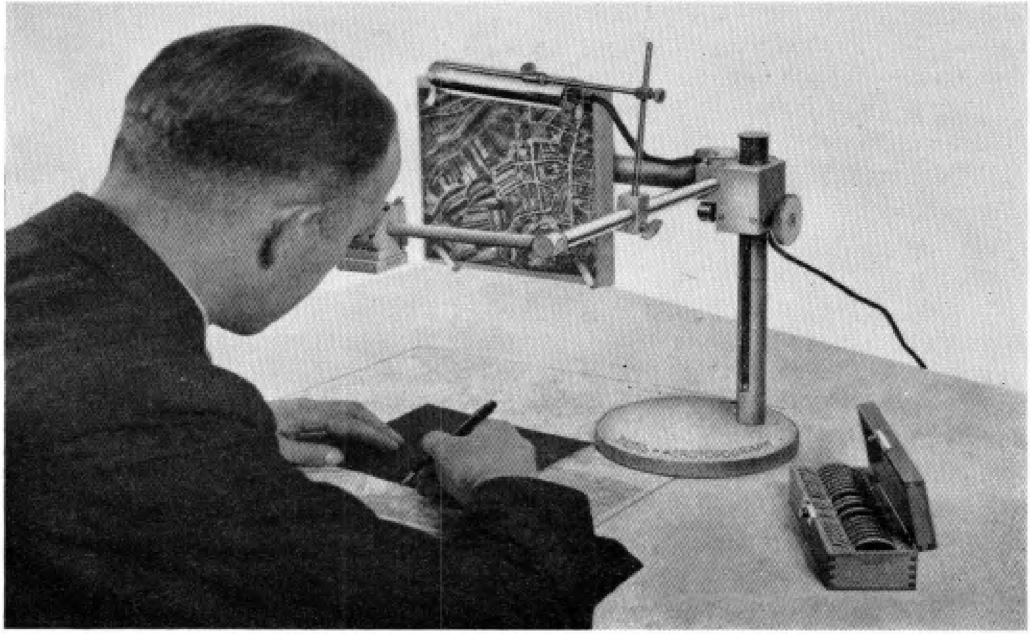
PLANIMETRIC MAPPING

INTRODUCTION



ZEISS AERO-SKETCHMASTER
(Zeiss Aerotopo)

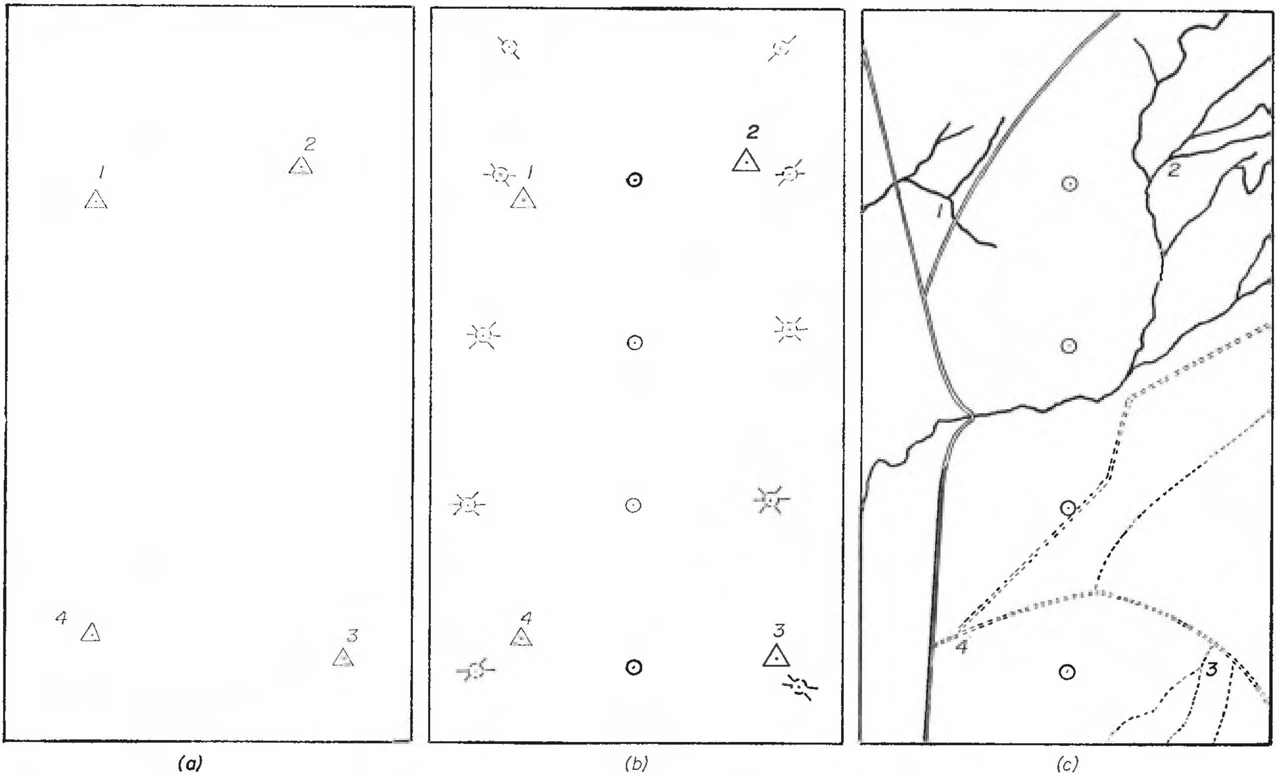
A choice has to be made between planimetric maps and topographic maps. Planimetric maps of an acceptable standard can be prepared using the simplest of instruments and methods as outlined shortly in section (a); and fortunately the requirements of the photo-interpreter can normally be satisfied by studying a planimetric map in conjunction with aerial photographs of appropriate scale. Details relating to micro-areas of interest and not shown on the planimetric map can often be obtained directly from the photographs. Frequently the magnitude of errors arising from the use of a planimetric map is smaller than the magnitude of errors occurring in the field collection of pertinent data for an inventory and the overall accuracy may not be improved by using a topographic map. Several simple techniques used in the preparation of planimetric maps will be considered in conjunction with the methods of radial line triangulation previously outlined. Topographic mapping will be left to the skilled photogrammetrist using one of the first-order machines mentioned later; and will not be considered further in this text, beyond the description of an easy method of contouring a planimetric map in section (b).

A *planimetric map* is a map presenting the horizontal positions only of the ground features recorded on the photograph; and is distinguished from the topographic map by the omission of relief in measurable form, i.e. no contours. It is important to appreciate that a planimetric map is not a direct tracing of the ground features shown on the photographs, but is an accurate drawing to scale of the features in relation to each other. A carefully prepared planimetric map or an orthophotomap will have been corrected for the radial displacement of objects on the photographs. The aerial photograph, an enlargement of the photograph, a photo-map, an index mosaic and controlled and uncontrolled mosaics are therefore not strictly maps. These will be briefly discussed in section (c), under the heading 'Photographs as maps'.

A few generalizations on map scale may be helpful, although there will be exceptions. For agricultural and ecological studies, maps normally need to be at 1/10,000 or larger. For studies of intensively managed forests, maps at 1/10,000 (or 1/10,500), 1/15,840 and sometimes 1/20,000 are convenient. For less intensively managed forests, regional biological surveys, plant associations and land unit surveys, maps at 1/25,000, 1/50,000 and 1/63,360 are suitable. For geomorphic and geological studies land systems and plant formations/sub-formations, possibly maps at 1/50,000, 1/63,360, 1/100,000 and 1/125,000 will be preferred. These latter groups, when simplified, can also be shown on maps at 1/250,000 to 1/1,000,000. 1/250,000 to 1/1,000,000 is popular for mapping regional geographic data. The Directorate of Overseas Surveys, London, produces maps showing land-use, land-form and vegetation patterns at scales between 1/50,000 and 1/500,000 (Brunt, 1966). The vegetation of northern Tunisia is being mapped at 1/50,000 and finally reduced to a scale of 1/200,000 (Floret, 1966).

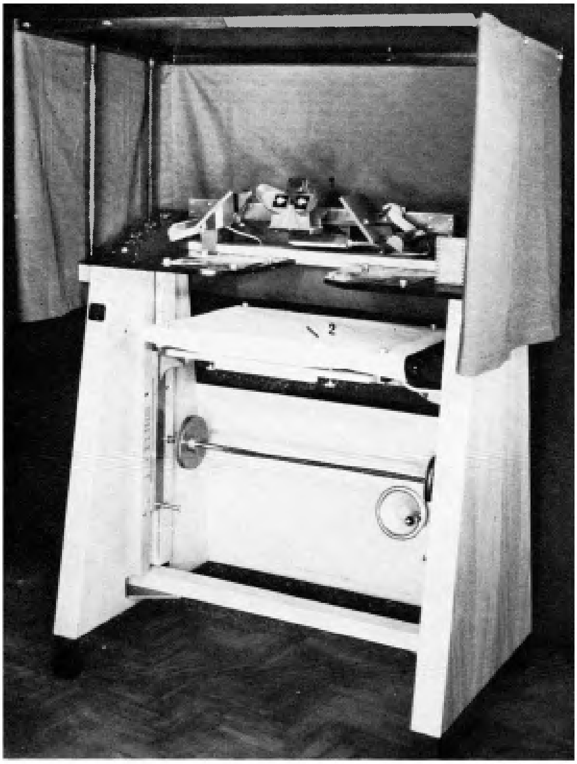
(a) Planimetric mapping

The overlay method. The simplest method of providing an approximate map of an area, covering only a few photographs, is to use the overlay method introduced in the previous chapter. The method is suitable for one to three flight lines and having only a few photographs in each flight line. The map scale will vary as the scale within each photograph. The map will be fairly accurate, provided the terrain is level; but as it is not corrected for radial displacement, it will be inaccurate in mountainous country and when tip and tilt exceed 3°/5°. The map provided by the overlay method is suitable for planning a forest inventory (timber cruise), for preliminary surveys of farm-land, land-form and land-use, for preliminary ecological, forest, soil and hydrological typing, and for use as a general map where an accurate map does not exist.



(a) (b) (c)

The preparation of a planimetric map (see text). (a) Ground control points plotted. (b) Principal points and wing points plotted. (c) Physical and man-made features plotted.



Stereosketch

The wing points and transferred principal points on each photograph provide the boundaries of the photograph's effective area.

The reader will recall that each photograph is being placed under the transparent map base for a third time and aligned, so that the control points and the flight lines on the photographs and map base coincide. Important features are then transferred to the map base by pencil. It will be found that when an adjoining photograph is aligned with the map base, the outline of previous features transferred to the map base will not coincide with the same features in the periphery of the photograph. This is due to radial displacement. A compromise between the two photographic positions has therefore to be drawn on the map base. This is not the object's true position, but is close to it. The true position of major features, such as a peak or a cross-road, can be located by additional radial ray intersections from the principal points. The network of points provided by the wing points and principal points will prevent errors accumulating from photograph to photograph, but will not eliminate errors occurring within the sections formed by the principal points and wing points.

Three-photograph method. If only a strip of three photographs of the same flight line are required to cover the area to be mapped, then the map base can conveniently be prepared directly on drawing paper by firstly pricking through the wing points, transferred principal points and principal point of the centre photograph. The direction of the wing points is then extended outwards in pencil before finally locating the flight lines of photographs one and three over the pin-holes of the flight line of photograph one. Pin-holes are pricked on to the drawing paper to show the location of the wing points of photographs one and three. Rays are extended in pencil to these points on the drawing paper and their true positions are located at the intersection of the radial lines. Photographic detail is transferred by a sketchmaster or other suitable equipment.

The hand template method. Instead of using a transparent overlay, hand templates may be used as described previously to provide the map base. Details from the photographs are transferred either as outlined in the overlay method, or, if the map base is opaque, then the detail is transferred by a sketchmaster or other suitable equipment.

The slotted template method. A more efficient method by far, which has been widely used, is the template method. Much of Australia, 2,974,000 square miles, has been mapped planimetrically in the manner to be described. The method has the advantage of being simple, providing a planimetric map with hill shading, eliminating accumulative errors and not requiring elaborate equipment. For large areas and most satisfactory results, small scale photographs (e.g. 1/50,000) are to be preferred.

For large lay-downs of templates, sheets of welded aluminium (about 26 gauge in the U.S.A.) or polyethylon (30 in. by 36 in. in Australia) are spread on the floor. On this base, the map projection is marked off at the desired scale and ground control points accurately located. The commonest map projections are the orthographic, Lambert, Conformal, Polyconic and Mercator. In Australia, for example, the national grid is a transverse Mercator with 5° parallels. Errors due to curvature of the earth and atmospheric refraction are so small that they may be ignored, when compared with other sources of error. For long flight strips, electronic computers offer a satisfactory approach to extension control and bridging.

On the aluminium sheets the slotted templates are assembled within the overall boundary provided by the map projection at the desired scale. The principal points and wing points are pricked on to the aluminium foil or polyethylon before removing the templates. If tinfoil or aluminium sheeting has been used, a semitransparent medium, e.g. matt acetate, is laid over it and the points transferred. Next the semi-transparent sheets are placed on a work bench, and by means of a vertical sketchmaster or other appropriate equipment the photographic detail is transferred to the sheets to provide the planimetric map. Steep slopes, mountains, etc., can be shown on the planimetric map by careful shading to represent the gradient and change in elevation. If a small scale map is required, the map is assembled from 'ratioed photographs' of the planimetric sheets.

If only a few templates are used, the ground control points are plotted to scale on good-quality drawing paper, e.g. 80 lb cartridge paper and the assembly of slotted templates is then fitted into these points. At least four carefully chosen, well-spaced control points are needed. The location of all principal points and wing points are then pricked on to the paper. The templates are removed and at the same time the principal points on the map base are numbered. Finally, the principal man-made features and physical features are transferred on to the base map using a sketchmaster or simple stereoscopic plotting instrument.

The maximum and minimum scales of the map depend on the size of the slots in the templates and the scales to which the sketchmaster or plotter can be adjusted. Overall scale will be uniform between the triangles formed by the wing points, etc., and errors will be confined within each triangle.

Transfer of land-form, forest and ecological detail. After preparing the planimetric map by one of the methods described previously it is suggested that each stereo-pair of photographs of the map area should be carefully examined stereoscopically for the purpose of interpreting, classifying and delineating the pertinent details and transferring this detail to the planimetric map in accordance with the objective of the study. It will be appreciated that up to now a planimetric map has been prepared which shows man-made features (e.g. roads, railways) and terrain features (e.g. water courses, ridges, peaks). To this must be added the boundaries of areas occupied by each class of growing stock to provide a forest stock map or the boundaries of the photo-communities to provide an ecological map , or land units for a terrain map. The procedure to be adopted in transferring the detail may be considered as stage four.

Sketchmasters are popular, as the data already on the map provides a satisfactory network into which ecological or land units or forest stock details can be fitted. This procedure should always be treated ocautiusly and each case must be considered on its own merits. The I.T.C. reported that in Europe the Zeiss sketchmaster, as compared with other sketchmasters, is preferred for transferring detail; but for mountainous terrain a radial line plotter is the more satisfactory. In the U.S.A., the Multiscope was popular for this type of work a few years ago; but a radial line plotter is now more often used.

The importance of carrying out the forest or ecological studies in continual association with field visits cannot be emphasized too strongly. At least 10% and up to 50% of the total time normally requires to be spent in the field. The length of time allocated to field work depends considerably on the purpose of the survey.

Cadastral maps. These are planimetric maps showing the legal boundaries. When an adjoining property comes under new ownership or if it is found necessary to adjust the forest boundaries due to logging or afforestation, it may be advisable to carry out an additional survey using aerial photographs. The field worker will possibly visit the owners of all common boundaries and record on his forest map any disputes in ownership for legal verification later. Frequently, it will be found useful to have stereo-pairs of photographs at the meeting, as this will help in locating additional ground points when in discussion; and can frequently help in settling what could be a legal dispute, since a neighbour will often accept evidence from a photograph even if he cannot use a stereoscope himself. The writer (1960) used aerial photographs in a boundary dispute at Pembrey in South Wales, and Huguet (1958) reported the successful use of aerial photographs for cadastral survey in Mexico. An up-to-date cadastral map can serve as a valuable map base when preparing forest stock maps, ecological maps, etc.

INSTRUMENTS

Monocular mapping instruments. Both sketchmasters and reflecting projectors are used, although the former are the more popular. The *sketchmaster* employs the principle of the *camera lucida*, in which the photographic image is seen superimposed on the map base through a semi-transparent mirror surface of a prism. The semi-transparent surface is provided by coating one surface of the prism with a very thin layer of silver. Probably the two most popular are the vertical sketchmaster manufactured by Aero Service Corporation (U.S.A.) and the Aero-Sketchmaster by Zeiss (West Germany). The Zeiss Sketchmaster reduces to ½ and enlarges to 2·5/1.

A substitute for an instrument using the principle of the camera lucida is the *reflecting projector*, resembling a photographic enlarger. As the name suggests, a light source of adequate brightness is used to reflect an image of the photograph from the back of the projector through the lens on to the map base. Reflecting projectors have the disadvantages of being bulky, and of requiring the use of a semidarkened room. These instruments cost £400 upwards; but a home-made type, described by Meyer (1961) can be assembled for £50, being suitable for transferring photographic details on to existing maps. Recently Kail has marketed a convenient compact table type of reflecting projector, not requiring a semi-darkened room for use. Transparency slides, taken with a standard 35 mm camera and projected on to a suitable copying screen, provide a cheap and frequently satisfactory method (Howard & Kosmer, 1967).

Stereoscopic mapping instruments. The vertical sketchmaster and the reflecting projector have two disadvantages. Firstly the photographic detail is transferred to the map base by means of a monocular instrument, so that within any one of the triangles formed by the principal points and the six wing points, errors caused by radial displacement will not be corrected. . Secondly it is often necessary to examine each photograph separately with a stereoscope before monocularly transferring the detail to the map or map base, in order to ensure that the details seen monocularly are interpreted correctly. These disadvantages can be overcome by using an instrument in which a stereo-model is seen as the details are transferred to the map base.

Instruments for the preparation of planimetric maps from a three-dimensional model may conveniently be grouped into three classes. The first type of instrument uses a *mirror stereoscope combined with a camera lucida.* The operator sees with both eyes the stereoscopic model formed from the two photographs; and views the map base as he did when using a sketchmaster. In so doing, he is able to transfer the details of the three-dimensional model on to the map base. An instrument employing this principle is the *Stereosketch* (Hilger and Watts). Viewing is at photographic scale or in the range 1/0·45 to 1/1·25.

The Stereosketch gives satisfactory results under most conditions, provided tip and tilt is not high and relief displacement is not excessive. Some operators complain of eye-strain and unskilled operators may find that the model moves in relation to its position on the map base. This latter disadvantage occurs also with other types of instruments and is due to optical parallax between observer, stereoscopic model and map base. The drawing table below the stereoscope has a vertical movement of 12 in. and a tilt of ±5°.

A second group of instruments uses the principle of *radial line plotting* introduced via the overlay method, hand templates and slotted templates. A large number of objects on the photographs could be located in their true position by drawing radial lines as described earlier; but the method would be cumbersome and slow. It has, however, been successfully used by Desjardins (1943a), who employed black thread to provide the direction of the ray from each principal point.

Improvement, however, can be made by using two straight edges pivoted at the principal points of a stereo-pair of photographs. The true location of an object is given by the intersection of lines subtended by placing the straight edges over the image common to the two photographs. The method is slow; but can be again improved by connecting the straight edges, by a suitable linkage mechanism, to a recording pencil or other drafting device. This technique, coupled with a mirror stereoscope, is used in several radial line plotting machines, including the *Kail Plotter* (fig. *12.3*) and the *Hilger and Watts Plotter*. In the Kail Plotter, two radial arms of

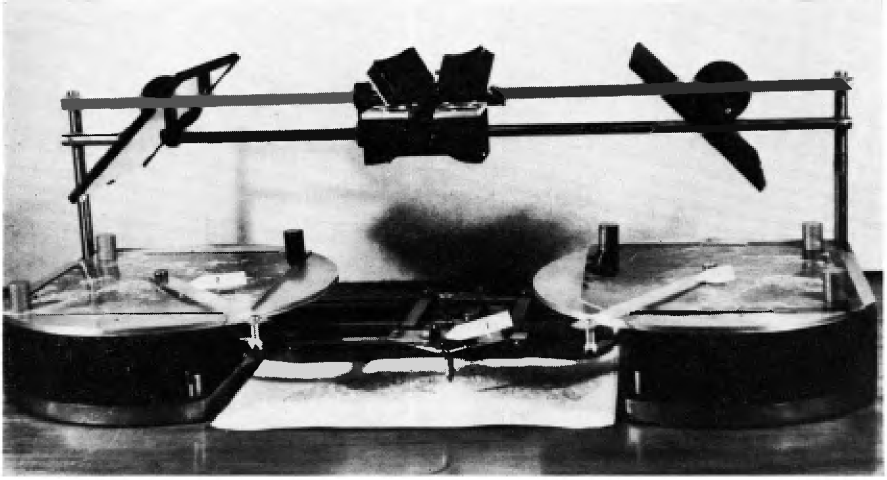
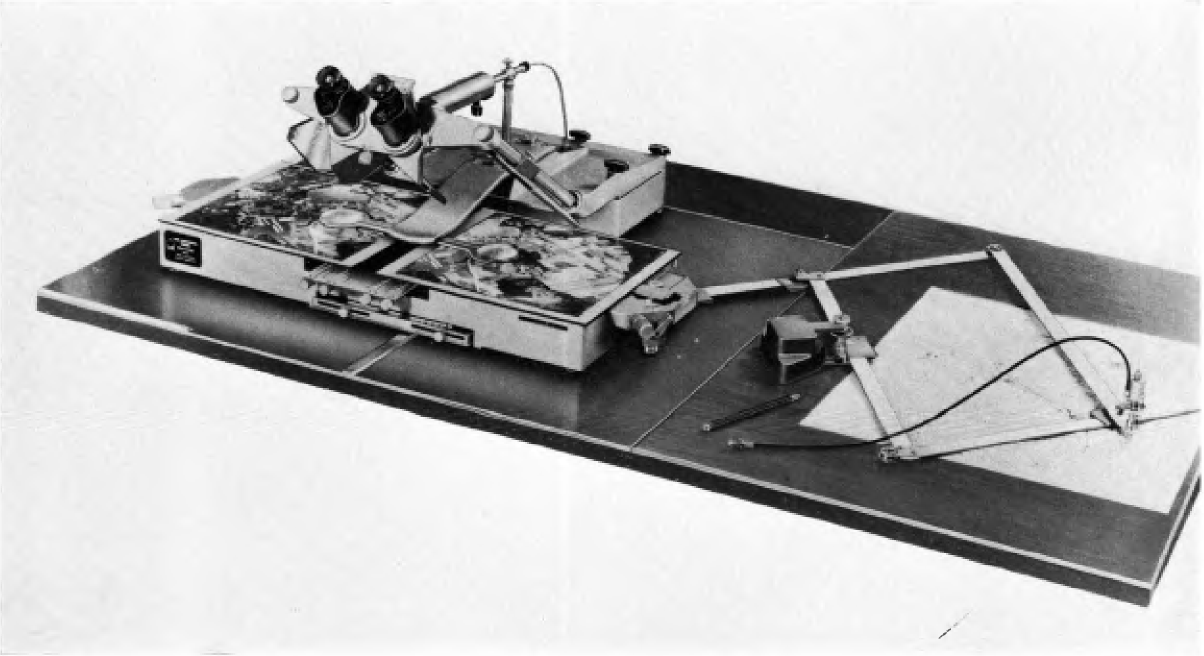


FIG. 12. 3c. Kail Radial Line Plotter. This comprises a mirror stereoscope, two tables on which the photographs are mounted and two radial arms which rotate at the principal points of the photographs and are connected to the drafting mechanism (1).

FIG. 12. 3d. The Zeiss Stereotope, a third-order instrument, provides a mechanical solution of errors due to radial displacement.



perspex operate from the centre of two metal tables on which are mounted a stereo-pair of photographs. A scale adjuster permits the drafting pencil to record between 1/3 and a little larger than 1/1 ratio. During viewing of the stereo-model the radial arms can be seen but not the drafting pencil. Difficulty is encountered, and resetting is necessary, when sketching close to the flight lines. Also, as in surveying, the accuracy is reduced when the rays intersect at oblique angles. The machine does not correct for tip and tilt. Some operators have difficulty in keeping the intersection of the radial lines fixed in relation to a selected point in the stereo-model. However, an operator using photographs of fairly level terrain is reasonably efficient within one to two days' training. When preparing a map, using a radial line plotter, the base map can be prepared as outlined earlier by means of slotted templates.

Finally, there are machines in which the principle of the fused floating dots (i.e. floating mark) is introduced. A stereo-pair of photographs are viewed under a mirror stereoscope as described above; but at the same time a floating mark is introduced in place of the radial lines. The mark is made to float on the apparent surface of the stereo-model; and is used in conjunction with a suitable drafting mechanism to trace the outline of the images on to the map base.

In its simplest or earliest form, the 'floating dot cum tracer' comprised a parallax bar having a centrally mounted pencil, e.g. *Tracing Stereometer* (Zeiss). The scale of the tracing is obviously the same as the scale of the photographs. With slight modification, *Fairchild's Stereocomparagraph* and *Abrams' Contour Finder* operate on this principle. These have the stereoscope, parallax bar and tracer as a single unit, and can be attached to a parallel drafting arm. In the *Stereopret* (fig. *12.2*), the parallax bar is fixed to the stereoscopic viewing head and is stationary. Movement of the floating mark and coverage of the stereo-model is achieved by a moving table on which the photographs are mounted. Some new operators, when tracing, experience difficulty in keeping the floating dot in contact with the stereo-model. Transfer of the photographic detail to the map base is carried out by a pantograph arm attached to the table. The scale of the pantograph can be adjusted from 1/5 up to 3·0/1. Errors resulting from radial displacement cannot be eliminated but adjustment can readily be made to correct for y-parallax. In the *K.E.K. Plotter* the floating mark is used to establish a datum plane and the stereo-model is introduced into this plane. The *Stereoflex* and *Stereotope* (fig. *12.2*), to be described later, may also be used for planimetric mapping.

Topographic mapping instruments. The simplest topographic plotting instruments incorporate a parallax bar and mirror stereoscope under which the three-dimensional model is viewed. Plotting, as outlined previously, and form-line tracing is by a floating dot and pantograph attachment. There is no provision for correction of the y-parallax in the *Abrams' Contour Finder* and the *Stereocomparagraph.* The *Stereopret* has an adjusting arm to correct for y-parallax only and provides perspective contours. The *Stereotope* uses built-in mechanical analogue computers (rectiputers) to correct for topographic displacement and tilt. The interpreter views the model formed from

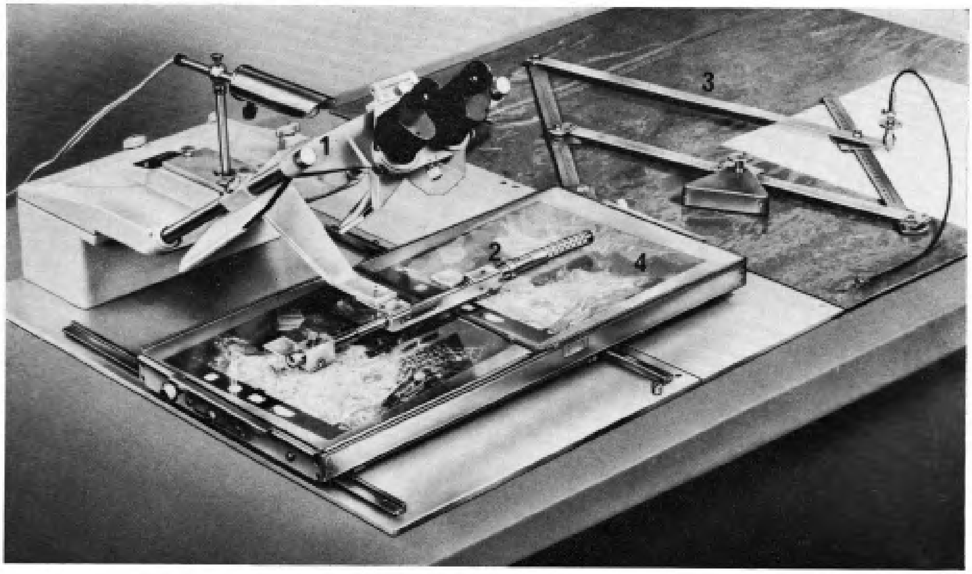
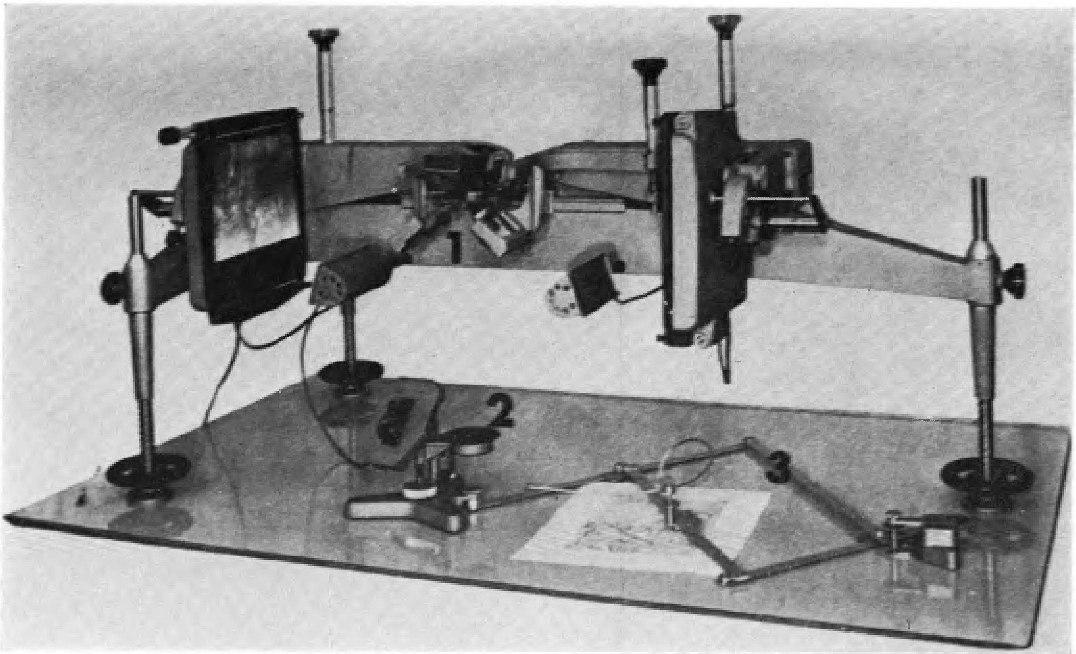


FIG. 12. 3a. The Zeiss Stereopret, which incorporates a mirror stereoscope (1), a parallax bar (2) and a pantograph (3). The stereo-pair of photographs are mounted on the sliding table (4) to which the pantograph arm is attached.

FIG. 12. 3b. The S.O.M. Stereoflex, which is a third-order optical-mechanical instrument. The operator views the stereo-model through semi-transparent mirrors (1) and the point-source of light in the small plotting table (2). The latter is attached to a pantograph for mapping.



the stereo-pair of photographs as in the Stereopret; but the parallax bar is replaced by a fixed distance floating mark. The floating mark is raised or lowered by the x-parallax thimble, which alters the distance between the horizontal photo-holders. A y-parallax thimble controls the y-movement of the right-hand photo-holder. The two photo-holders and rectiputers are mounted on a carriage which can be moved freely; and are connected to the pantograph (scale range: 1/5 to 2·5/1). A relatively new instrument of increasing popularity and also using a mechanical system for rectifying errors due to tilt and relief displacement is the Cartographic Stereomicrometer (Galileo-Santoni).

In a second group of instruments, an attempt is made to completely eliminate combined tilt by tipping and tilting the photographs out of the common plane. Instruments include the *K.E.K. Plotter* and recently the *S.O.M. Stereoflex*. The delineation of contours is subsequent to the preparation of the planimetric map. In the Stereoflex, the three-dimensional model is viewed at a little less than photographic scale through semi-transparent mirrors. As the model is always subject to exaggeration of the vertical scale with respect to its horizontal scale, a small plotting table (the height of which can be adjusted), is operated above the map base to remove the optical parallax. This is an important innovation so far not commented on. The floating mark is provided by a point-source of light in the plotting table.

With all the instruments so far mentioned, bridging between photographs of the same flight line is impracticable or tedious; but the instruments are considerably less expensive and relatively portable compared with first-order machines. It is, however, sometimes convenient to have a basic map provided by a first-order machine and then to add detail by a third-order machine such as the Stereotope. For example, one first-order machine can supply map bases for up to ten Stereotopes.

In the *Manual of Photogrammetry*, the first-order instruments are classed as automatic stereoscopic plotting instruments and subdivided by projection systems. The most popular first-order machines used in mapping include the *Balplex ER-55*, *Kelsh Plotter* (C-factor: 1,000), *Multiplex* (C-factor: 750), *Kern PGI Plotter*, *Nistri Photocartograph*, *Stereomat*, *Stereoplanigraph* (C-factor: 1,200), *Stereotopograph*, *Wild Autograph* (C-factor: 1,200) and *Thompson-Watts Plotter*. The most widely used instruments vary considerably between countries, depending probably more on government policy, marketing and 'after-service' than on the instrument being the most suitable for the local conditions. All first- and second-order instruments are expensive, costing £3,000 to £10,000. Some require bedding on concrete or on a similar base and cannot be considered as even semi-portable. For photogrammetric mapping, they have the advantage of providing accurate maps with small scale photographs, e.g. 1/30,000 to 1/100,000, so that the number of ground control points is reduced per unit area of ground. Further bridging between photographs is possible and is frequently used for providing additional control points. Tilt, lens distortion and model deformation can be eliminated. The optical system of the instrument may, however, limit the choice of focal lengths to be used with the aerial camera.

The *Multiplex* and the *Kelsh* employ a principle not so far described. This is *double image projection.* Diapositives of a stereo-pair of photographs are placed in the instruments and projected downwards on to the drafting table to form a double image. The double image (or anaglyphic image), when viewed through one blue and one red lens, forms a normal three-dimensional model. A light-source floating dot and a pantograph are used to plot each model on the map base at the correct scale. Other instruments involve the application of optical mechanical principles by the creation of a virtual image by the stereoscope and the human mind. A light-source floating dot is used for plotting and for contouring. Print-size diapositives are most commonly used.

There is little doubt that, as colour aerial photographs come to be more widely used, the light systems will require modifying/improving. For example, using the well-known *Stereoplanigraph E-8* and a *Stereo-plotter A-8*, Maruyasu & Nashio (1962) found that colour photographs provided no positive advantage over monochromatic, particularly due to the small bulbs providing reddish light through a refracting optical system.

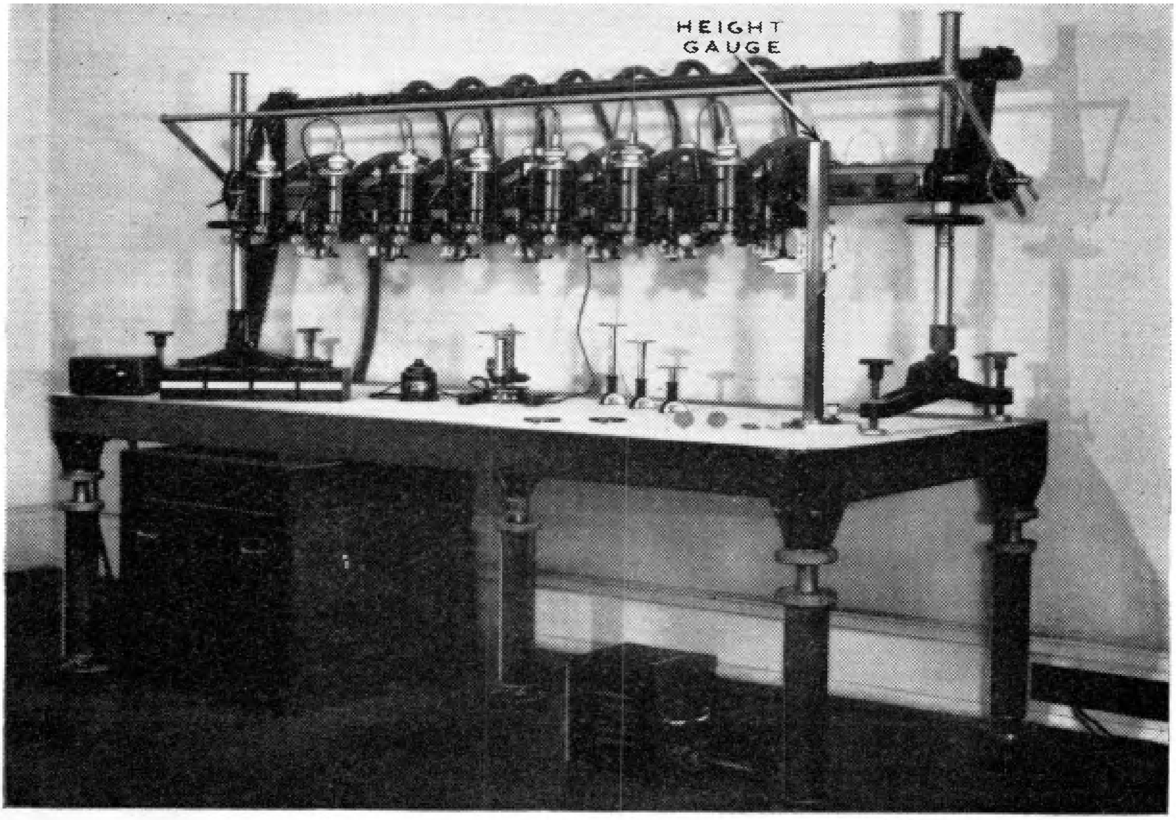
C-factor. The reader will observe that the term 'C-factor' has been introduced after the names of a few instruments to describe the relative accuracy of the machine. The C-factor is commonly used in the U.S.A. to indicate a relationship between the least contour interval and photographic scale, being found a simple but practical method of comparing instrumental qualities, i.e.

$$\text{C-factor} = \frac{\text{Flying height above ground}}{\text{Least contour interval}}.$$

The least contour interval is defined as double the range in elevation within which 90% of the points of the measured height fall about the mean. Thus if the range for 90% of the points is 3·5 ft, the least contour interval is 7 ft.

The application of C-factor is appropriate when standards are uniform and similar aerial photographic equipment is being used, but may be unreliable when there are great variations in the quality of the photographs, type of equipment and skill of the operators. Skilled photogrammetrists may differ in assessing the C-factor according to local conditions. Colner (1962) quoted the Kelsh Plotter as having a C-factor of 512 and Tewinkel (1962) appraised the instrument with a C-factor of 1,200 to 1,700. Recently Lyon (1964) has suggested a modification of C-factor; and used the term coverage-contour factor, which takes into consideration the area of the stereo-model as a function of flying height. In continental Europe, *map error* is used instead of C-factor, being the error expressed in terms of one standard deviation under the conditions provided by the film, camera-lens, photographs, plotting machine, etc.

Bridging. A photograph mounted in a suitable stereo-plotting machine and correctly orientated in space in relation to known ground control points can be used stereoscopically to transfer selected photographic control points on to the next photograph. The second photograph can then be held in the machine, whilst the first photograph is



THE MULTIPLEX 7-PROJECTOR ASSEMBLY WITH ILLUMINATION CONTROL UNIT
(Williamson Manufacturing Co. Ltd.)

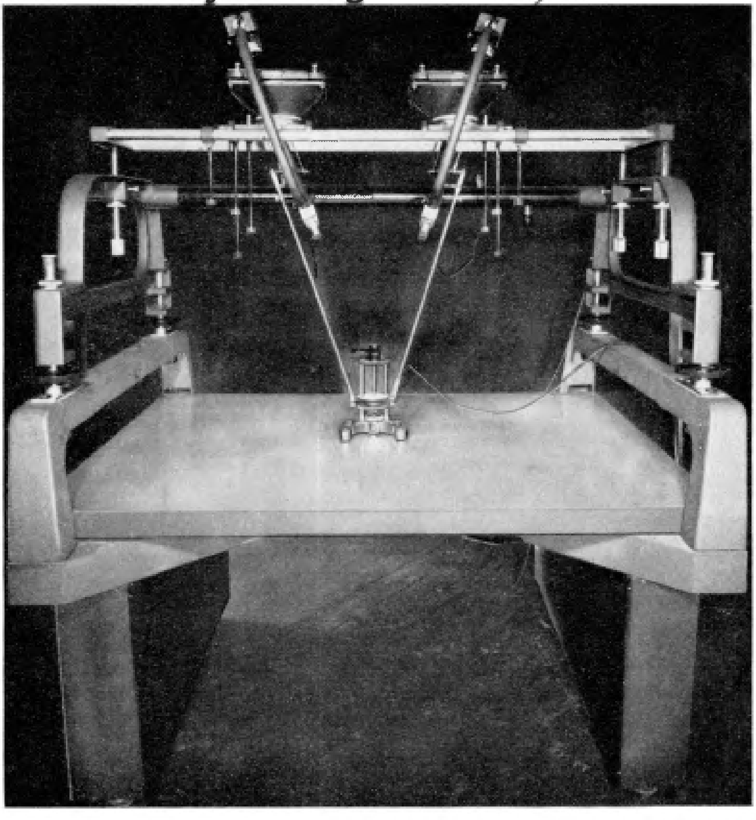


FIG. 11.8. THE KELSH PLOTTER
(The Kelsh Instrument Co. Inc.)

removed and the next photograph is introduced. The process may be continued until the end of the flight strip, when a 'tie-in' is made with similar ground control points on the last photograph. This process is termed *bridging*. If ground control points are only available on the first photographs, then the term '*extension*' would be applied in lieu of bridging. Once the photographic control points have been established on each photograph by means of a first-order machine, e.g. Wild A5, details from each stereoscopic pair of photographs can be transferred to the map base by a simpler and less expensive instrument, e.g. Stereotope. This procedure was used by the Snowy Mountain Authority, as slotted templates were found to be unsuitable due to the rugged nature of the terrain.

(b) Topographic maps

As a part of photogrammetry, topographic mapping is a complex subject about which a great amount has been written by the photogrammetrist, trained in mathematics and surveying. The *Manual of Photogrammetry* is considered about the best lucid reference on the subject.

When showing relief the easiest method is to prepare a planimetric map and then to use shading to show changes in the topography. This technique has been used effectively by the Division of National Mapping in Australia. A second method is provided by sketching *form lines*. These lines are similar to contour lines but are sketched by visual examination of the stereo-model. A true topographic map, however, provides contours. The Directorate of Overseas Surveys, London, has obtained satisfactory results by establishing stereoscopically 20 to 25 photographic control points per photograph and then sketching in form lines at 50 ft contour intervals. The map so produced is prepared in about one-third the time of a contour map. The 'styling' of form lines and contours can sometimes be improved if the photogrammetrist has a knowledge of geomorphology, e.g. valley forms (Verstappen, 1964).

The simplest method of preparing a 'topographic' map is as follows. Firstly, a planimetric map is provided by one of the methods outlined previously. Then, combined with additional ground survey to determine the elevation of the ground control points or the determination of the heights from existing maps, height control points are established on the photographs. Next, using a suitable floating dot machine, incorporating a parallax bar and pantograph, lines are traced off on to the planimetric map. The Fairchild *Stereocomparagraph* and the Zeiss *Stereopret* are both suitable instruments provided tilt is negligible and the ratio $\frac{\text{elevation change}}{\text{flying height}}$ remains small. Unless the contour intervals are fairly widely spaced, the inexperienced operator tends to run contours into each other. As a check, it is also advisable to establish additional height control points on the photographs by parallax bar before starting. Frequently an additional form line can be inserted free-hand between two contours.

Mott (1956) gave an interesting account of contouring in dense jungle in Ceylon based on ability of the photogrammetrist to recognize the height of prominent trees above the ground on photographs at a contact scale of 1/20,000. A similar technique has been tried when mapping from photographs of New Guinea. Mott observed that the canopy had a flattening effect on the formation of the terrain, but it was obvious from the photographs that the main ridges stood out reasonably well and that the general shape of the terrain could be deduced from an appreciation of the height of the canopy in association with spot heights obtained in forest clearings. Lack of moisture on the top of hills and ridges was considered likely to give rise to stunted growth compared with that in the valleys where the moisture content was known to be greater. As part of the area had been contoured by ground control previously, it was possible to compare the results. In general the shape of the contours showed a remarkable consistency. The maximum discrepancy was about 20 ft and the mean deviation was ±10 ft.

(c) Photographs as planimetric maps

As a photograph is a perspective view and a map is an orthographic projection, errors will occur in using photographs directly as a map, due principally to radial displacement and sometimes to misinterpretation of shadows. However, armed with knowledge of the errors that are likely to occur, it is often convenient to use individual photographs or assemblies of photographs as a temporary 'map'. Obviously the enormous advantage of the stereoscopic view is lost, but a person who has been accustomed to viewing photographs non-stereoscopically can develop a skill in interpreting local features particularly if the shadows are favourable to viewing. Frequently, this type of skill is not acknowledged or is sometimes treated as a heresy! Photographs or photograph-assemblies used as maps have frequently an advantage over maps in that they may contain information not shown on maps made from the photographs by normal photogrammetric methods. This is particularly the case in ecological, forest and land-form studies.

If angles are required to be determined from photographs, a transparent 360° protractor is suitable. It is convenient to drill or punch a pin-hole through the protractor at its centre of rotation; so that it can be pinned in position on the photograph or mosaic and rotated as required. North may be determined from flight line data and sun shadows and should be shown. A bearing and distance towards the edge of the photograph may need adjusting due to radial displacement. This particularly applies to mountainous areas; and is difficult to check in areas of closed forest, e.g. tropical rain forest, due to lack of prominent features. If a bearing on a photograph is checked on the ground by magnetic compass, both bearings must be expressed in degrees true or degrees magnetic. Both the flight line and other radial straight lines from the principal point will also provide straight lines on the ground.

Aerial photographs, to be used as maps, may be conveniently classified under the following headings:

(i) *Rectified prints.* These have been considered previously. They are single prints made from tilted photographs and corrected for the tilt by re-creating an opposite tilt at the time the print is made.

(ii) *Ratioed prints.* When prints are enlarged or reduced in scale compared with the original negative they are said to be ratioed .

(iii) *Enlargements.* As mentioned above these are ratioed prints. Spurr (1952) recorded that modern aerial photographs can be enlarged at least two to four times and yet produce images of high pictorial quality. Studies in Japan (Maruyasu & Nishio, 1962) to compare black-and-white photographs and colour prints indicated that the sharpness was similar at about the same scales; but delicate tonal differences became noticeable in the colour enlargements (which were not observed before) and these differences were helpful in the interpretation.

An enlargement at the same scale as a contact print will not have identical qualities for stereo-interpretation and photogrammetry. Enlargements are bulky to handle and difficult to study under a stereoscope. For study of tropical forests, which often have a great complexity of pattern, enlargements have been found useful both in the office and field in New Guinea and by the Directorate of Overseas Surveys, London.

(iv) *Photo-maps.* This term has been applied loosely to enlargements of small scale photographs and to mosaics of two or more rectified prints; but is here restricted to enlargements of the effective area of a photograph. In New Zealand, by enlarging two to four times the effective areas only of photographs taken at a scale of about 1/60,000 a print is obtained which can be used satisfactorily as a 'map' for many purposes. Possibly in the near future, due to the introduction of small scale photogrammetrical photography, this type of enlargement will have a much wider appeal. In the U.S.A., photographs at 1/56,000 were enlarged 3½ times, gridded and then copied by Ozalid printer to provide field 'maps' for timber assessment in Washington state (Kummer, 1964).

(v) *Index mosaics.* The aerial photographs are assembled so that common images on contiguous photographs overlap and the indices at the bottom of each can be seen. The assembly is then photographed and printed at whatever scale is required. This is then used as an index for easy reference to the photographs. In areas not yet mapped, an index mosaic can be helpful to field work until the photographs, map mosaics or maps are available.

(vi) *Uncontrolled map mosaics.* A map mosaic comprises the assembled effective areas of the aerial photographs. These are fitted together, similar to pieces of a jig-saw, so that the edges of each effective area are carefully matched with the adjoining edges. Normally, the edges are 'feathered' into each other to give the appearance of a single photograph. Single-weight photographs are preferred.

Careful inspection of a mosaic will often show that matching cannot be perfectly attained due to topographic displacement and tilt. There is likely to be considerable difference in scale in different parts of the mosaic, especially if the terrain is rugged. Also errors are likely to accumulate in any direction as there is no means of localizing them, as was possible by using slotted templates for planimetric maps. However, as only effective areas are used, the margins of the photograph which are likely to give the greatest errors are excluded.

(vii) *Controlled map mosaics.* These are similar to the previous mosaics, but photogrammetrical control points and ground control points are used to provide overall control of the scale of the mosaic. In preparation of controlled mosaics rectified prints are normally used to remove excess tilt and ratioed prints are used to provide photographs at approximately the same overall scale. The final scale of the mosaic is provided at time of printing as for uncontrolled mosaics; but the assembled effective areas prior to printing may comprise contact prints, ratioed prints and rectified prints. Controlled mosaics are useful in the field for initial planning and for the purpose of providing an overall idea of conditions. Often a clearer understanding of geomorphic structures and general hydrology can be obtained from the mosaics than from individual photographs. Mosaics are probably the most useful photographic aid in regional geographic studies. In Sweden, mosaics are printed with contours.

Orthophotomaps. An orthophotomap is a mosaic of uniform scale formed from an assembly of orthophotographs. It may also be termed an *orthophoto-mosaic. An orthophotograph* is a photographic copy of the area covered by an aerial photograph in which the effects of the lens aberrations and the radial displacement due to tilt and topography have been removed. It contains the same detail as would be recorded in an orthographic aerial photograph, if the latter were possible. An aerial photograph is a perpsective view of the ground.

To obtain orthophotographs from aerial photographs an orthophotoscope is used. Basically, this is a photo-mechanical device, incorporating an anaglyphic projector; a movable slit (or scanning aperture) which replaces the table of a photogrammetrical plotter and a light-sensitive film below the slit, which records the anaglyphic image and is processed into orthophotographs. The slit aperture can be varied according to the topography and can be moved in the x- and y-directions. The film is adjustable in the z-direction.

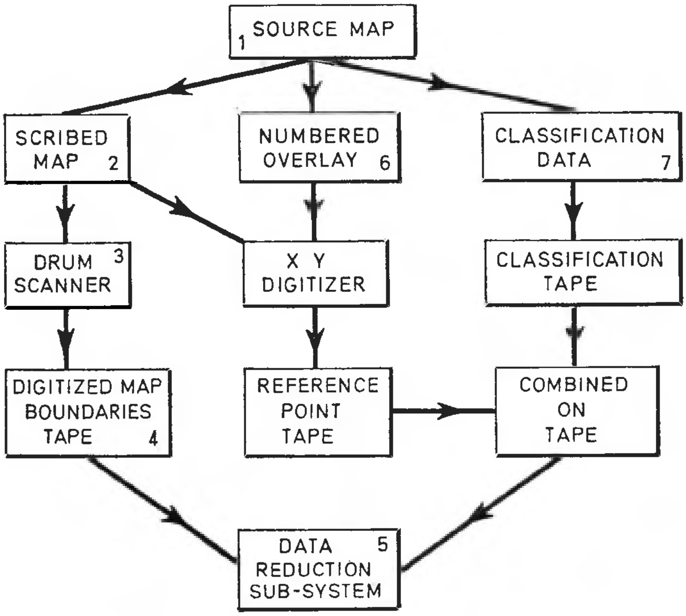
Orthophotographs and orthophotomaps are a new introduction and therefore their importance to the interpreter has not as yet been evaluated. An orthophotomap is a true map and may be contoured by conventional photogrammetrical techniques to provide a 'photo-contour map'. No doubt orthophotographs will have a wide application in natural resource studies not requiring a stereoscopic examination.

Thermal maps. In the last few years, remote sensing by infrared radiation in the range $0{\cdot}72\,\mu$ to $14\,\mu$ has been used to provide 'thermal maps'. The infrared thermal mapping can be provided by either daylight or night flying. Definition of coast lines and other water boundaries are sharp. Highways under suitable conditions are clearly recorded due to differences in surface conditions and temperature. Ploughed and unploughed fields and ploughing patterns are clearly recorded in map form. This results from the compacted and grass-covered nature of one and the reverse conditions of the other (Harris & Woodbridge, 1964). Except for overall similarities the details recorded on thermal maps are different from the details recorded on photographs as the former represent infrared emissivity from the scene and the latter reflected solar radiation in the visible and near infrared spectra. Radar has also been studied and tested in the preparation of maps. Impetus is now being given to the study by side-scanning high-resolution radar.

(d) Digitized mapping of natural resource data

Parallel to the development of orthophotomapping is the development of a computer-based storage system of map information related to natural resources. Information is stored on magnetic tape in a form suited to rapid retrieval, rapid measurement and rapid comparisons of large numbers of maps and data related to areas, lines and points on the maps (i.e. location specific information). Such a system, the Geographic Information System, is now operated in Canada by the Department of Forestry and Rural Development (Tomlinson, 1968). Map boundaries and location-specific information related to land-use and the capability of land for agriculture, forestry, recreation and wild-life are stored in digitized form on magnetic tape. About three hundred conventional map sheets, showing an average of 800 distinct areas (map elements) can be stored on a single tape.

The procedure (Tomlinson, 1968), for digitizing and storing information recorded on a (source) map of land-use classes etc., is illustrated in the flow chart.
The boundaries of each class (map element) are scribed in lines about 0·08 inches



thick on a separate blank sheet. The scribed map is then placed on the surface of a drum, which rotates as it is slowly traversed by an electronic scanninghead. The scanning system is connected to a standard magnetic tape-drive and detects, within areas of 0·032 inches × 0·04 inches of scribed map, the presence or absence of a boundary line. Each time a map line or map point is detected, its X-Y-co-ordinates are recorded in digital form on magnetic tape. Finally the digitized map boundaries are combined with digitized data relating a numbered overlay of the map elements and specific information related to each map element (class).

The S.F.O.M. Orthophotoscope produces orthophotomaps from stereo-pairs of diapositives (1). The stereo-image is recorded on light sensitive paper which is exposed through an adjustable slot (2).