CHAPTER 7

Plotting of Detail, Mosaics

If we have been following the chapters through in order, then at this stage we have a pair of photographs (on one of which the contours have actually been plotted) and a base grid on which is plotted the principal point traverses and copious points of minor control. Before sending the finished map for reproduction it is still necessary to plot the photographic detail and the contours on to the points of control. Generally speaking the base grid will be too large and too encumbered with construction lines to be used for plotting detail. A trace of the completed slotted templet plot is therefore made on to a suitable stable transparency. This is known as a compilation sheet. Each map sheet area is represented by a separate compilation sheet.

The profusion of detail on the face of the print makes the draughtsman's task difficult, and it is usual to prepare a separate photograph on which topographic and other required features are picked out in appropriately coloured inks or poster colours. This is known as interpreting a print and is the work of an expert. The fully interpreted photograph, together with a full specification of colours, conventional signs, names and other requirements, is delivered to the draughtsman or instrument operator.

Interpretation as a subject is dealt with in a later chapter.

THE PLOTTING OF DETAIL AND MAP REVISION

The most obvious advantage of making maps from vertical air photographs is in the plotting of detail. In chain surveying and traversing, the chain-lines form the control, and the offset and tie points are minor control points. The only guide to the shape of curved linear objects between such control is found in the sketches and notes in the margin of the field-book. Not only are these relatively crude sketches, but they were themselves made only after imperfect observation of the elevational view of the objects whose plan view we are plotting. Tacheometry provides only single points of detail and minor control. Even plane-tabling, where the detail is drawn up while the objects are in direct view, suffers from the fact that it is still only an elevational view on which the accuracy of the detail depends.

The vertical air photograph provides a detailed plan view which is accurate over short distances. For the same plan accuracy then, far fewer minor control points are needed than would be required for ground methods.

Maps from Obliques

In oblique photographs the shapes of objects depart from those of the true plan view. Plotting detail from such photographs does not therefore offer the same advantages as does plotting from verticals. Nevertheless, if the ground is fairly flat, there are useful geometrical relationships between the oblique view and the plan view, and plotting by graphical methods may be undertaken from single obliques.

We have seen how the four-point method of transferring points from photo to map can tolerate any degree of tilt. The method may therefore be used for plotting single points of detail, or for increasing control from an oblique photograph, though the strict limitations due to variations in ground heights must be remembered.

If only a small amount of linear detail needs to be added to a map, this can be done by choosing minor control points at close intervals on these lines, transferring them by the paper-strip method, and then sketching in the lines by eye using the m.c.ps. as guides. More m.c.ps. would, of course, be needed than for use with vertical photography.

If a new map is required, or a large amount of revision is necessary, then a more systematic approach is needed. This will normally call for the construction of some sort of grid, and the relationship between the grid drawn on the map and that drawn on the photograph will reflect the geometric properties of both. If the ground is sufficiently flat to enable use to be made of the four-point method of point transfer, then there will be very little height distortion and we may assume that distortions are approximately radial from the isocentre. Additionally, if on the map we draw a square grid, such that the lines in one direction are all parallel with the homologue of the principal line, then the corresponding lines on the photograph will all meet in the vanishing point (see Fig. 2.23 and the associated text).

The principal point of an oblique may be found from the calibrating marks in the same way as for a vertical. If there are enough buildings on the photograph, then there should be enough pairs of lines, representing pairs of parallel horizontal lines on the ground, for us to determine the position of the vanishing line or true horizon on the photograph. This would enable the principal line to be drawn in by dropping a perpendicular from the principal point on to the true horizon. The method would be similar to that described for the graphical determination of tilt.

Alternatively, on fairly high obliques, vertical lines may be very much in evidence, and a good approximation to the position of the plumb point may be found relatively easily. The corners of buildings, telegraph poles, and the trunks of most tall trees are often sufficiently nearly vertical for this purpose. A transparency is securely mounted over the photograph. As many vertical lines as possible are chosen, and the construction shown in Fig. 7.1(i) is carried out. In practice all the lines will not normally meet in one point, but if the meeting points are reasonably consistent an approximate position of the plumb point may be found.

To continue the construction of Fig. 7.1(i), join the plumb point to the principal point, and extend this line beyond the principal point. This is the principal line.

The construction of Fig. 7.1(ii) could be superimposed on Fig. 7.1(i); but it is shown separately for clarity. In fact Fig. 7.1(i) is in the plane of the photograph, whereas Fig. 7.1(ii) lies in the principal plane. On 7.1(ii) pS is constructed perpendicular to the principal line, and of a length equal to the principal distance of the camera. Sn is the plumb line of the perspective diagram, so that the angle $pSn = \theta$, the angle of tilt. Determine the position of the isocentre, i, by bisecting the angle pSn, and find the position of the vanishing point, v, by making vS perpendicular to Sn. Check the position of the vanishing point by finding the vanishing line by the method indicated under the graphical determination of tilt.

If the plumb point lies too far off the photograph, or there are few prominent vertical lines in the photograph, it may be better to find the vanishing line first, and use the plumb point determination to check the figure.

Fig. 7.1(iii) is also drawn in the plane of the photograph, but the detail of Fig. 7.1(i) has been omitted, and only the principal line and the points v and i are retained. In the map plane (Fig. 7.1(iv)) the isocentre, I, would need to be resected from three, or preferably more, control points.

On Fig. 7.1(iii) the isometric parallel, ia, is drawn perpendicular to the principal line. a is any identifiable point of detail on the isometric parallel, and is transferred to A in the map plane by the paper-strip method. In Fig. 7.1(iv) AI is now the map representation of the isometric parallel, thus IN, perpendicular to AI, is the map representation of the principal line. Set up a square (say 10 mm) grid on these two lines.

The scale along ai is ai/AI of the map scale. Subdivide ia so that the length of the subdivisions $ji = JI \times ai/AI$. On Fig. 7.1(iii) join each of these points to v. The lines j_1v, j_2v, etc. then represent those map grid lines which are parallel with the line NI.

In the map plane draw a diagonal, *IL*, to the square grid. This line passes through successive grid intersections and with the principal line *IN* it subtends an angle of 45° at *I*. Since angles subtended at the isocentre are correct, the corresponding line on the photo plane will be at 45° in *in*, and will pass through those photo grid intersections corresponding to the map grid intersections, L_1L_2 etc.

Those map grid lines parallel with *AI* will all be represented on the photograph by plate parallels and can be drawn in on Fig. 7.1(iii) by dropping perpendiculars on to *nv* from l_1l_2, etc.

Detail can now be transferred from the photo to the map, square by square, as is done when a map is reduced in scale by the method of squares.

It will be appreciated that the scope of this method of making a map is limited not only by the terrain, but also by the fact that the greater the obliquity the less will be the amount of plottable detail, because the foreground detail will tend to obscure the background. In addition the angle of tilt must be such that the vanishing point and the isocentre do not fall too far outside the format of the photograph. In any case, the scale of photography on the horizon side of the principal point will be so small as to limit the plotting possibilities.

For low obliques it would be possible to find the principal line of the photograph and its angle of tilt by, say, the Anderson method of analysing tilt. The constructions of Fig. 7.1(ii) (iii) and (iv) could follow as above.

The Sketchmaster, described later, may be used to plot the detail from relatively low obliques; but a large amount of control would be needed.

Plotting and Map Revision from Verticals

Rectification is the technical term often used to describe the action of plotting correct planographic detail from an air photograph. The term is an unfortunate one, because photographic rectification is a method of producing a print free from tilt and having no distortions due to the lens. Height distortions remain, however, and can only be removed in a 3-dimensional model. In fact the only true rectifiers are the expensive plotting instruments such as the multiplex and the stereoscopic viewing type of instrument.

The simpler plotting instruments are not rectifiers in the true sense of the term, because in the words of Brigadier Hotine, " The use of an unlimited amount of control on vertical photographs enables the theoretical conditions of true rectification to be given up in favour of mechanical simplicity and more rapid setting." In an extreme illustration of this principle, we may imagine that we have an existing map with a vertical air photograph of the same area. We require to revise the map, and find that only one block of houses is missing. All we need to draw are four straight lines in the form of a rectangle. This could be done with complete satisfaction by plotting the four corners in relation to other nearby features. Over such a small area the tilt would not normally cause any appreciable inaccuracy. In fact, if the map and photograph were to the same scale it would be possible to trace in the detail over an ordinary draughtsman's light table. Provided that the amount of revision is small, any of the normal methods of transferring detail from one map to another could be used, e.g. method of squares, transfer of lines parallel to them-

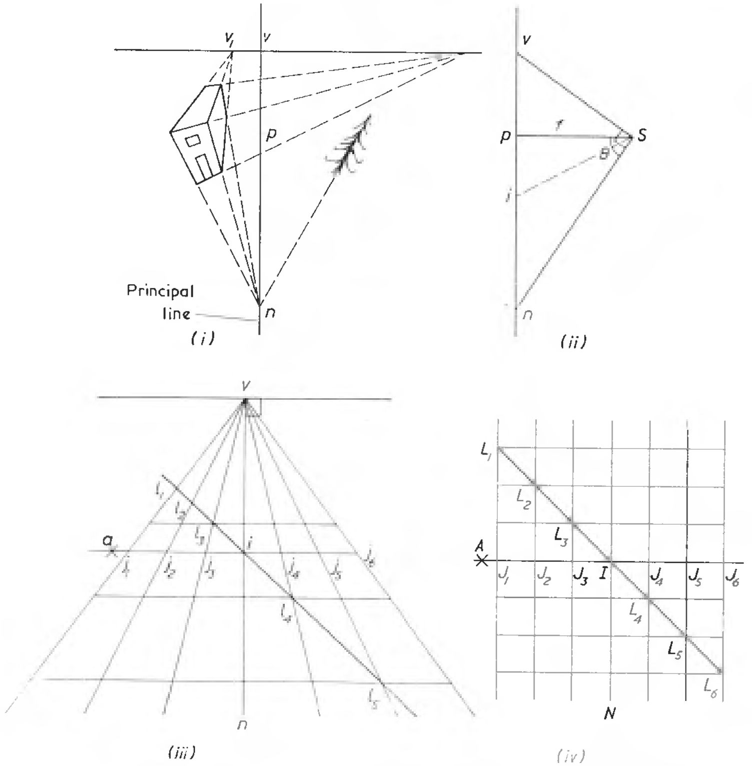

FIG. 7.1. PLOTTING FROM OBLIQUES—THE POLAR GRID
(i) In plane of photo
(ii) In principal plane of photo
(iii) Polar grid on photo
(iv) Square grid on map

selves, the use of a pantograph or proportional dividers. With all such methods, only small areas, up to about ten millimetres square of the photographic detail, should be transferred at one setting.

If there is a lot of revision required it would normally be advisable to trace the extant detail from the map on to a stable transparency, and then to locate the homologues of the principal points on this transparency. This would be done by the paper-strip method or by simple resection. Since the latter requires equality of angles, it must depend on the radial line assumption and can therefore be applied only for transferring the principal point. In order to allow for local height distortions the resection should be made from say five or six points by drawing radials through all these points instead of the usual three; in such a case only a mean fit of the rays to the map control will be possible.

If pairs of photographs are available, a principal point traverse can be drawn, minor control can be intersected and the detail may be plotted as described later for a new map. When only one photograph is available, radials are drawn at regular intervals through the principal points of both map and print. Each ray on the print should be checked to ensure that it passes through points homologous to those on the corresponding map ray. Curves can be drawn in the tangential direction by interpolation between close minor control. Pick a series of minor control points (m.c.p.s) each at about the same map distance from the map principal point. On the map and with its centre at the principal point, draw in an arc of radius equal to the mean distance of these m.c.p's. from the principal point. By interpolation between m.c.p's. on the print, mark points on the homologue of this arc and join these points with a smooth curve—this represents the arc as drawn on the map. (see Fig. 7.2). Repeat this process for a number of such arcs, until a fairly close curved grid is established. Detail may now be transferred in the same way as for the other grids.

Perhaps the most successful method is that of treating each detail line as a separate problem. Thus to plot a boundary line, m.c.p.'s would be plotted (by radial line or paper-strip methods) at all obvious changes in direction, and at regular intervals along the rest of the line. The boundary line would then be drawn in by eye, or by tracing short lengths at a time (cf. plotting a chain survey).

Where the area to be revised is large and little control remains, we approach conditions similar to those involved in making a new map, i.e. where we have traced the principal point traverse on to the compilation sheet and built up minor control to about 20 mm spacing. For this amount of revision and for plotting a new map, some elementary plotting instrument is usually considered necessary, though 1/50,000 mapping is still carried out sometimes by purely graphical methods.

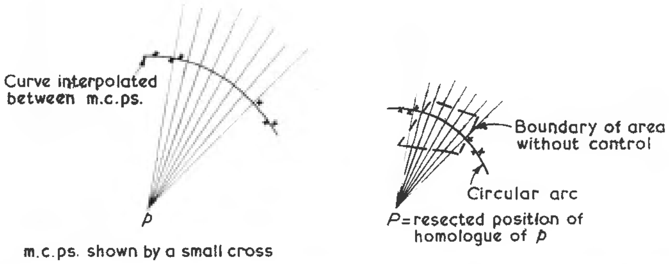

Fig. 7.2. Interpolating one of the Curved Grid Lines in the "Radial Grid" Method
Left-hand side : print.
Right-hand side : map.

Simple Plotting Instruments

Most of this grade of instrument are based on the *camera lucida* principle. An ordinary camera used for taking photographs is a *camera obscura* or dark room—a compartment from which light is excluded. A camera lucida or *chambre claire* is a room or compartment into which light is flooded.

There are two main types of simple plotting instrument in photogrammetry: those which project the image, and those which reflect it. Perhaps the simplest instrument is one which can project the image of the photograph on to the map being revised. An epidiascope or an episcope could, with an adjustment to the lens, be used for this purpose. In such a case the map being revised would be secured to the screen and the photograph would be placed on the projecting table within the instrument. The image of the photograph is projected on to the map screen (see Fig. 7.3) and the object is to arrange matters so that four neighbouring image points appear exactly superimposed upon the four appropriate control points. The detail required within the figure formed by these four points can then be traced off on to the map. The setting is changed to four more points, and the procedure is repeated until all the required detail has been transferred. The adjustment to scale would be by altering the distance of the screen from the instrument and then refocusing. By altering the position of the photograph on the table, rotating it and tilting the screen about the ball and socket, the image of the photograph can be made to coincide with the relevant map detail over a very small area. New detail can be traced in directly on to the screen. The procedure, though simple, is a great strain on the eyes and it is not advisable to work with the instrument for more than about half an hour at a stretch.

The reflecting type of instrument is that most used in simple plotting operations. Perhaps the best known representative is the Sketchmaster. Fig. 7.4 shows the Zeiss Aero-sketchmaster, the

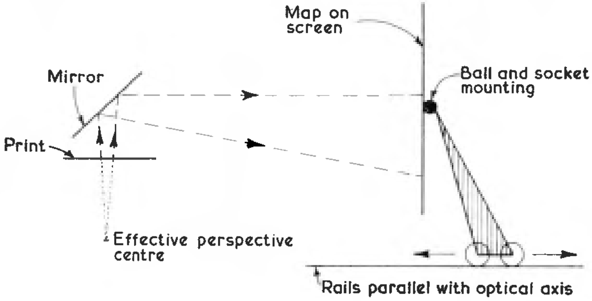

FIG. 7.3. EPIDIASCOPE ADAPTED FOR PLOTTING
(Lens and projective systems omitted)

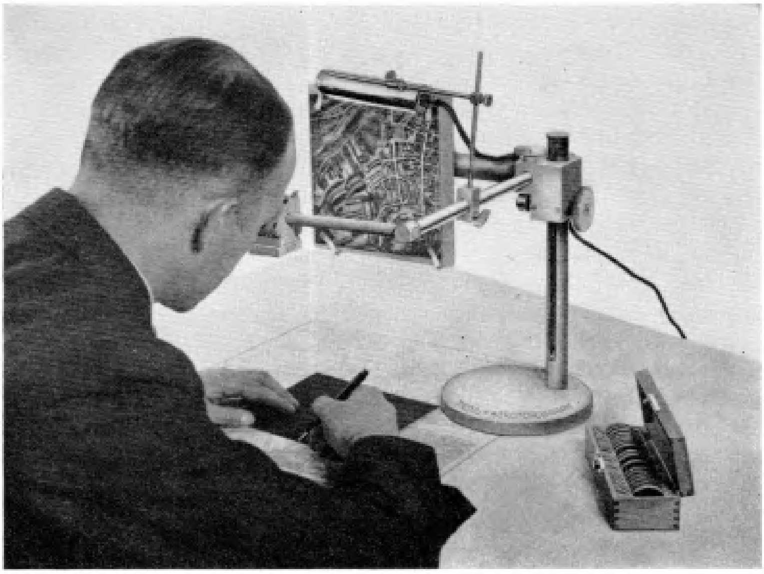

FIG. 7.4. ZEISS AERO-SKETCHMASTER
(*Zeiss Aerotopo*)

principle of which is illustrated in Fig. 7. 5. The eye-piece of this instrument contains a semi-transparent mirror, in which the photo image is reflected and through which the map image passes. The eyes therefore see the doubly reflected image of the photograph superimposed on the doubly reflected image of the map. The photo-holder is ball and socket mounted.

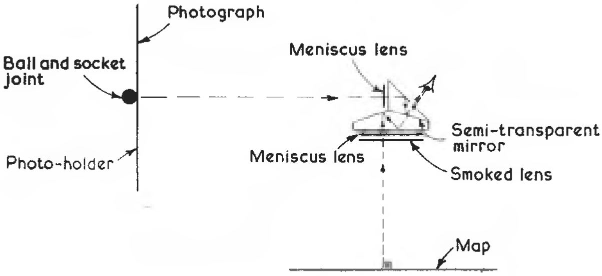

FIG. 7.5. PRINCIPLE OF THE SKETCHMASTER

If the ground covered is sufficiently flat, and the photo-plane and map plane are both correctly oriented with respect to the eye-piece, then the geometrical relationships of Chapter 2 are again set up between the photograph and map. It is therefore sometimes said that the instruments depend on anharmonic principles.

In fact, in order to maintain correct angular relationships between rays, the photo-plane should be fixed relative to the eye-piece (compare inner orientation of Chapter 11), and both tilt and scale should be corrected by movements only of the map plane; but the inconvenience of a moving map plane causes many manufacturers to ignore the theoretical niceties.

The drill for using the Zeiss Aero-sketchmaster is as follows—

1. Calculate the ratio between the photo scale and the map scale. Using the tables provided by the maker look up the appropriate lens-photo and lens-map distances and set these on the instrument. These distances could be approximately calculated by using the relationship—

$$\frac{\text{lens-photo distance}}{\text{lens-map distance}} = \frac{\text{photo scale}}{\text{map scale}}$$

In order to bring the two images into the same plane, and thus remove the effects of parallax, meniscus lenses are introduced in front of the eye-piece; the makers specify the correct lenses for the particular lens-photo and lens-map distances.

2. Mount the photograph with its principal point at the centre of the photo-holder, and by eye make the photo-holder vertical.

3. Secure the compilation sheet or map to the table so that the principal point traverse is more or less parallel with the operator's eyebase, and the homologue of the principal point is in the most convenient viewing position—probably about eight inches from the edge of the table.

4. Switch on the lamp to illuminate the photograph, and balance the strengths of the two images by inserting one of the range of smoked glasses in front of the stronger image.

5. Choose two points on the photograph in positions such as *a* and *b* in Fig. 7.6 so that the line *ab* is approximately horizontal and passes near to the principal point. Let *A* and *B* be the respective map positions of these points. Move the instrument stand until the photo line *ab* is superimposed on the map line *AB*. Now adjust the lens-map distance until *ab* is the same length as *AB*. Move the instrument again until *a* coincides with *A*, and *b* with *B*. This gives a correct mean scale for the line *ab*.

6. If *P* is the map position of *p*, and *P* is closer to *A* than *p* is to *a*, then the scale along *pa* is greater than along *PA*, i.e. the scale near *a* must be greater than that near *b*. Tilt the photo-holder about a vertical axis through *p*, bringing *b* closer to the eye-piece, until *a*, *p* and *b* coincide with *A*, *P* and *B* respectively.

7. Now choose two more minor control points on the photograph, in positions such as *c* and *d*, so that *cd* is approximately perpendicular to *ab* and passes near *p*. Repeat 6 above but using points *c* and *d* instead of *a* and *b*, and tilting about a roughly horizontal axis.

8. Repeat 6 and 7 above until the best mean fitting is obtained. Provided that *A*, *B*, *C* and *D* are points having similar ground heights, then the instrument will now be set for the approximate elimination of tilt. We say that we have completed the general setting, but it is rare that all or even many of the remaining m.c.p.s will be accurately superimposed on their map positions, and further detailed settings will be necessary.

9. Plot all detail nearer to the principal point than such points as *e*, *f*, *j* and *l*.

10. Check the setting of m.c.p.s *e*, *f*, *g* and *h* in Fig. 7.6. If necessary, and using movements similar to those of 6, 7 and 8 above, adjust the photo-holder to achieve coincidence of these points with their homologues. Plot all detail within this quadrilateral.

11. Repeat 10 for *fgkj*, then for *ghqr*, *grtk*, and *kjlm*, etc. until the whole quadrant has been plotted.

12. Repeat 6, 7, 8, 9, 10, and 11 for each of the other three quadrants in turn.

Note that if in any minor control quadrilateral coincidence of all four points is not possible, it means that the minor control is insufficient and further points should be added by intersections from the principal points.

Only a minimum area should be plotted from each photograph. For 20 per cent lateral overlap and 230 mm × 230 mm format this will average a little more than a rectangle 90 mm × 180 mm with the principal point at the centre.

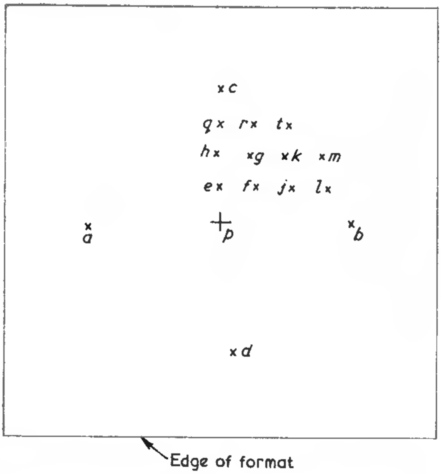

FIG. 7.6. CHOICE OF M.C.P.'S FOR SKETCHMASTER CONTROL

Optical Rectifiers

A typical rectifier (see Fig. 7.7) consists of a projecting lamp and condenser which directs the rays of light through a negative or diapositive. These rays then pass through a lens which brings them to focus in the map plane. There are then three planes: the negative plane, the lens plane, and the map or image plane, and it is the relationships between these planes which particularly concern us.

The basic principles governing the design of an optical rectifier involve—

1. Correction for lens distortion.
2. Maintenance of a sharp image
   (*a*) at centre of projection.
   (*b*) over the whole projected image.
3. Correction for tilt distortion.

One method of correcting lens distortion is by projecting the negative image back through the lens which was actually used in the taking camera. Thus, in theory, each ray of light is made to travel backwards along the path which it took at the time of exposure. In practice it would be very inconvenient to use the same lens in the camera and in the rectifier, and the rectifier lens is usually a paired lens specially manufactured as nearly as possible the same as the camera lens. This is what is known as the Porro–Koppe principle. At one time rectification always involved recourse to the Porro

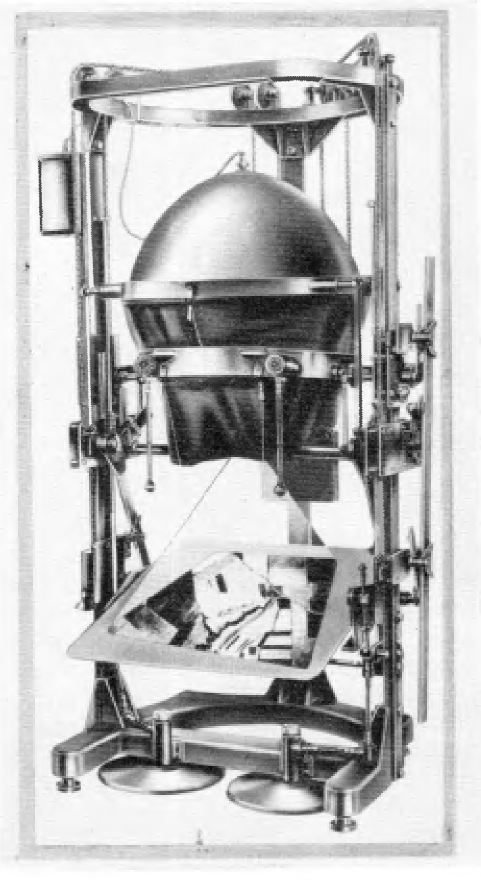

FIG. 7.7. AN OPTICAL RECTIFIER
(*Zeiss, Jena*)

principle, but nowadays many instruments use a glass correction plate instead. Some plotting instruments correct for lens distortion by mounting the viewing telescope on a specially made cam.

In the rectifier, the object is no longer at an infinite distance from the lens, as in Fig. 1.5; but the satisfaction of the lens condition

$$\frac{1}{U}+\frac{1}{V}=\frac{1}{f}$$

(see Fig. 7.8) ensures sharp focus of the image whatever the object distance (V).

Since the negative plane is not necessarily parallel with the lens plane, satisfaction of the lens condition along the optical axis does not ensure its satisfaction over the whole image area. For this reason we must also satisfy the Scheimpflug condition which requires that the negative plane, the lens plane, and the image plane must all meet in one line. Proof that this satisfies the lens condition for every point is as follows: in Fig. 7.9, a is the image of point A, which lies at infinity. Drop aQ perpendicular to the lens plane; then $aQ = f$, the focal length of the rectifier lens.

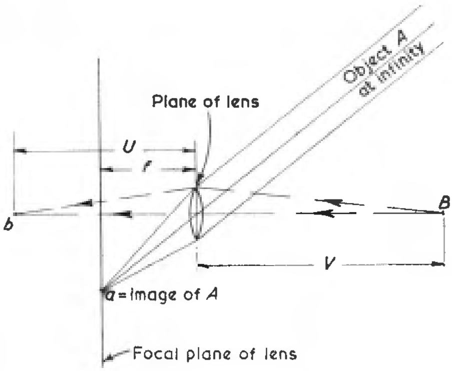

FIG. 7.8. FOCUSING A NEAR OBJECT
b is the image of B, an object at a finite distance V from the lens.
U is the image distance and f is the focal length of the lens.
Then the lens condition requires that $\frac{1}{U}+\frac{1}{V}=\frac{1}{f}$.

Take any point b in the negative plane, with B its image in the map plane.

The ray aA passes through the optical centre O, and is parallel with RB; thus $aOQ = \beta$.

From similar triangles baO and bRB $\frac{aO}{RB} = \frac{ab}{Rb}$

Drop perpendiculars bC and BD on to the lens plane, and let their lengths be U_b and V_B respectively; then

$$\frac{1}{U_b} + \frac{1}{V_B} = \frac{1}{Rb \sin \alpha} + \frac{1}{RB \sin \beta} = \frac{Ra}{f \times Rb} + \frac{aO}{f \times RB}$$

$$= \frac{1}{f} \times \frac{Ra + ab}{Rb} = \frac{1}{f}$$

i.e. the lens condition is satisfied for any image point.

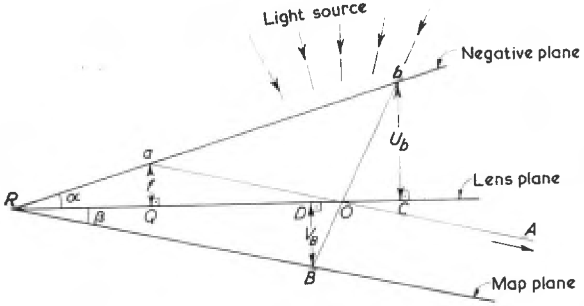

FIG. 7.9. THE OPTICAL RECTIFIER—PERSPECTIVE LINE DIAGRAM ILLUSTRATING PROOF OF THE SCHEIMPFLUG CONDITION

O = optical centre of projecting lens,
a = the homologue of a point at infinity,
∴ aQ is focal length of lens

Theoretically the Scheimpflug condition must be satisfied in all cameras. In the air camera, the condition is only truly satisfied if the exposure is truly vertical, but the flying height is always sufficiently great to give " infinite focus " conditions over the whole of the format so that the whole picture will automatically be in focus.

An automatic rectifier is so constructed that, as the map plane is tilted, so one of the other planes tilts to maintain both the lens condition and the Scheimpflug condition.

The setting of the tilts in an automatic rectifier is achieved by making the projected images of four points of detail coincide with the plan positions of those points as plotted on the image plane. That is we require four points of control for each photograph in order to obtain rectification by this means. If the ground covered by the photograph were absolutely planar, three control points would do; the fourth is required since a tetrahedron is the rigid threedimensional figure in the same way that the triangle is the rigid two-dimensional figure.

Just as we need five facts to fix a quadrilateral, so the rectifier must be capable of five independent movements in order to be set to the control quadrilateral. We say that the instrument has five freedoms of movement, or just five freedoms. For example suppose that the lens plane is fixed; then the first freedom might comprise an adjustment of the lens to image plane distance; the lens to map plane distance would now be determined by the lens condition and is therefore not independent. The second freedom would entail rotation of the negative about a line in its plane, causing a change in the angle α; the angle β is now fully controlled by the Scheimpflug condition. The remaining three freedoms might involve one rotational movement of the negative in its plane, and two lateral movements of the negative in its plane and in directions at right angles to one another; these would cause corresponding and dependent movements of the map. The foregoing is intended merely as a simple illustration of the idea of Five Freedoms—practical solutions of the problem may be found elsewhere.

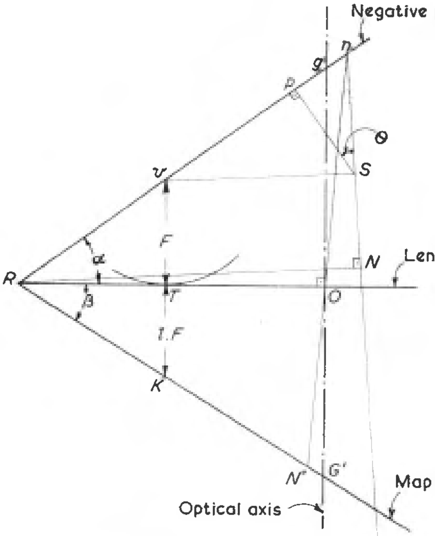

FIG. 7.10. OPTICAL RECTIFIER—CONSTRUCTION OF LINE DIAGRAM

The following method of construction of Fig. 7.10 is given as further explanation of the theory of optical rectifiers—

Draw pn to represent the negative plane, and produce. Set off $pS = f$ (the principal distance of the taking camera) and perpendicular to pn.

Join nS so that $\angle nSp = \theta$.

Draw vS perpendicular to nS and cutting pn in v.

Produce nS to N, so that $SN = H$, where

$$\frac{H}{f} = \frac{\text{map scale}}{\text{negative scale}} = l$$

Draw NR perpendicular to nN, cutting np in R.

With centre v describe an arc of radius F (the focal length of the rectifier lens).

Draw RT tangent to this arc and produce.

Join vT and produce to K so that $\frac{TK}{vT} = \frac{H}{f} = l$. . (7i)

Join RK and produce; mark N' in RK so that $RN' = RN$.

Join nN'. O, the optical centre, is the point in which nN' cuts RT.

When using a non-automatic rectifier the direction and amount of tilt are first calculated by methods similar to those suggested in Chapter 2. Further calculations might then be as follows.

In Fig. 7.10, α and β are the angles which the negative plane and the map plane respectively make with the lens plane. Sometimes it is the complements of these angles which are required.

By similar triangles ($vO || RN'$, since v is point projected to infinity)

$$\frac{vO}{RN'} = \frac{nv}{nR} = \frac{vS}{RN} = \frac{vS}{RN'} \qquad \therefore \quad vO = vS$$

But $$Rv = H \operatorname{cosec} \theta = lf \operatorname{cosec} \theta$$

$$\therefore \qquad \sin \alpha = \frac{F}{lf \operatorname{cosec} \theta} \quad \text{and} \quad \sin \beta = \frac{F}{vO} = \frac{F}{vS} = \frac{F}{f \operatorname{cosec} \theta}$$

i.e. $$\sin \alpha = \frac{F \sin \theta}{lf} \quad \text{and} \quad \sin \beta = \frac{F \sin \theta}{f} \qquad . \quad . \qquad (7\text{ii})$$

Let $gO = a$ and $OG' = b$; then applying the lens condition to the central ray—

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{F}$$

but $$\frac{b}{a} = l \quad \text{i.e.} \quad b = al$$

$$\therefore \qquad \frac{1}{a}+\frac{1}{al}=\frac{1}{F}$$

$$\text{i.e.} \qquad a=F+\frac{F}{l} \quad \text{and} \quad b=Fl+\mathrm{F} \qquad (7\text{iii})$$

The length *pg* can also be calculated, and it can be shown that when $l=1$ the isocentre falls at *g*.

Automatic rectifiers incorporate a variety of link mechanisms for controlling the dependent movements. Fig. 7.11 is a line diagram illustrating a simple Pythagorean inverser, whose function is to maintain the lens condition along the lens axis.

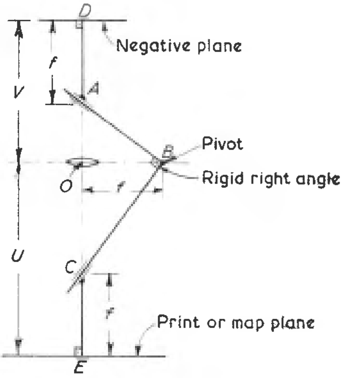

FIG. 7.11. PYTHAGOREAN INVERSER FOR MAINTAINING THE LENS CONDITION

DA, *O* and *CE* are constrained to move only along the optical axis.

B is a rigid right-angle constrained in the plane of the lens.

Focus is varied by moving the lens up and down, thus causing rods *AB* and *CB* to pivot about *B* and slide in sleeves *A* and *C* respectively. So that if the map plane is fixed, then as the lens rises so the negative plane falls.

Triangles *ABO* and *BCO* are always similar;

$$\therefore \quad \frac{f}{OC}=\frac{AO}{f}, \qquad \text{i.e.} \quad \frac{f}{U-f}=\frac{V-f}{f}$$

$$\text{or} \qquad f^2=VU-fV-fU+f^2$$

$$\therefore \quad \frac{1}{f} = \frac{1}{V} + \frac{1}{U}$$

i.e. the lens condition is always satisfied.

Fig. 7.12 shows a Carpentier inverser for maintaining the Scheimpflug condition. In this case—

DE is rigid and pivoted about a fixed point *A*.
Both *D* and *E* are couplings hinged to *DE*.
D can move only along *DB* and in the plane *GD*.
E can move only along *EC* and in the plane *EH*.
BG, *OA* and *CH* are rigid and equal and constrained to move only along the optical axis.

Triangles *BGD* and K_1OB are similar;

$$\therefore \quad \frac{K_1O}{BO} = \frac{BG}{GD} \quad \text{i.e.} \quad K_1O = \frac{Vk}{V \tan \alpha} = \frac{k}{\tan \alpha}$$

Similarly $$K_2O = \frac{U.k}{U.\tan \alpha} = \frac{k}{\tan \alpha}$$

$\therefore$ K_1 and K_2 coincide, and planes *BK*, *OK* and *CK* meet in one line, i.e. the Scheimpflug condition is satisfied.

An optical rectifier could be used for plotting detail by tracing the projected image with a pencil, directly on to the map plane. Since

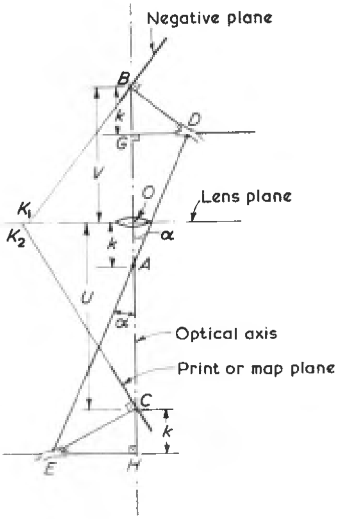

FIG. 7.12. CARPENTIER INVERSER FOR MAINTAINING THE SCHEIMPFLUG CONDITION

height distortion remains in the projected image, the plotting would require copious control and separate settings for each small area of the photograph, in much the same way as when using a simple reflecting plotter. An optical rectifier is usually large and expensive and is rarely preferred to the sketchmaster for this purpose.

When a rectified photograph is being prepared, the instrument is first set to the four points of control. The control plan is then removed, sensitized paper is put in its place, and the exposure is made.

Rectified prints are nominally free from tilt and lens distortions and are required in some plotting machines. They facilitate heighting by parallax bar and are necessary for making controlled mosaics. In very flat areas such a print would be so nearly equivalent to an orthogonal projection that it might be possible to produce a small scale map by actual tracing of detail.

Some Simple Stereoscopic Plotters

The slotted templet assembly incorporates corrections for tilt and height distortions within the limits of accuracy of the radial line assumption, but the sketchmaster and optical rectifier make no allowance for height distortion, except in so far as the area plotted at each setting of the instrument is strictly limited in extent. The radial-line plotter enables detail plotting to be carried out by radial line methods.

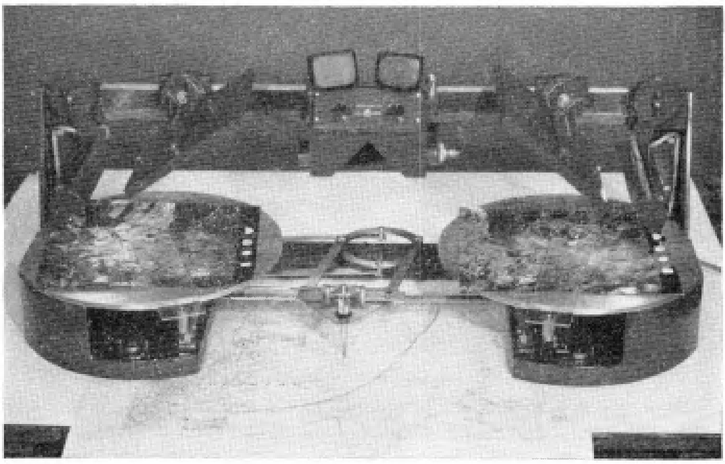

FIG. 7.13. RADIAL-LINE PLOTTER
(*Rank Precision Industries Ltd.* (*Hilger & Watts*))

The radial-line plotter consists essentially of a stereoscope, similar to the normal mirror stereoscope (see Fig. 7.13). Plotting is therefore from a stereoscopic pair of photographs, which are first carefully base-lined and then mounted on the photo-tables with a weighted pin through the principal points. The pin for each photo also passes through a hole in the radial line engraved in the Perspex cursor and through a hole in the centre of the photo-table. Each photograph is now aligned so that the two base-lines are collinear, and then fixed to the table with masking tape. If the prints are viewed through the stereoscope the two radial lines can be rotated until each passes through the point of detail corresponding to the preselected ground point which it is required to plot. The linkage mechanism connects the two cursors together and to the pencil in such a way that the pencil point represents the map position of the point being plotted. The instrument rests on the map table itself, and any point may be plotted directly on to the map (see Fig. 7.14). By moving the pencil so that the point of intersection of the two radial lines moves along the line of detail being plotted, we can draw in

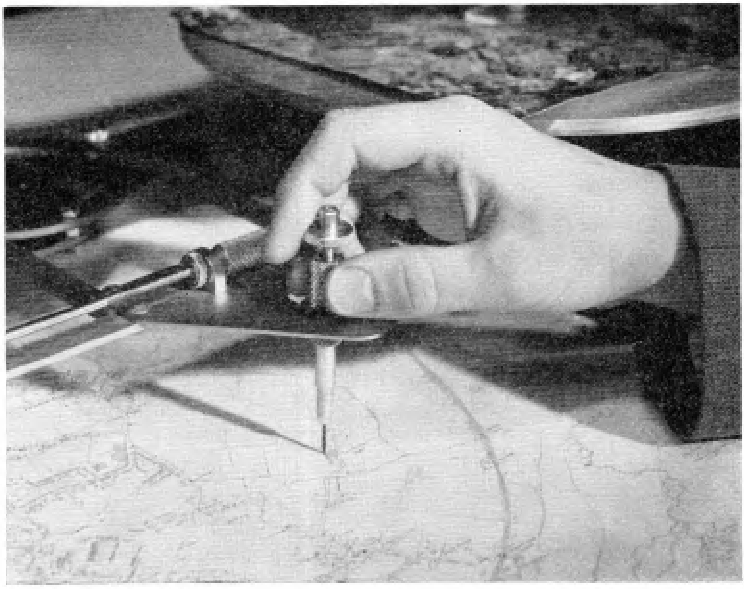

FIG. 7.14. PLOTTING A POINT WITH A RADIAL-LINE PLOTTER
(*Rank Precision Industries Ltd.* (*Hilger & Watts*))

any, or all, detail. The plotting scale can be altered by adjusting the linkage mechanism, and the range of plotting scales is from half to twice photo-scale. The instrument is used for plotting detail between slotted templet control, and each model is oriented relative to the plotted positions of only the two principal points and the four pass points.

One drawback to the radial-line plotter is that, in common with all plotting by intersections based on the radial line assumption, the intersections near the base line will be very acute and consequently weak; this is overcome by the device of displacing the photographs by a fixed distance in the y-direction.

FIG. 7.15. THE STEREOPRET
(*Zeiss Aerotopo*)

The stereoscope and parallax bar with parallel guidance mechanism (mentioned in Chapter 6) can have a drawing attachment fitted;

but this will only plot the detail direct from the left-hand photograph. It is therefore useful only for making small-scale sketch-maps, though accuracy can be increased by increasing the control, and it should give better results than say the pantograph because of the stereoscopic scanning. By fixing the stereometer reading and scanning lines of equal parallax, the instrument can be used to sketch in form-lines.

The Stereopret (see Fig. 7.15) is a handier version of the parallel guidance mechanism and drawing attachment. In this instrument the photographs are mounted on a carriage which is free to move only linearly in the x- and y-directions. The parallax bar is rigidly attached to the stereoscope. Movement of the photo carriage operates a pantograph type of plotting arm and sketching can be done at scales between 0·2 and 2·0 times the mean photo-scale.

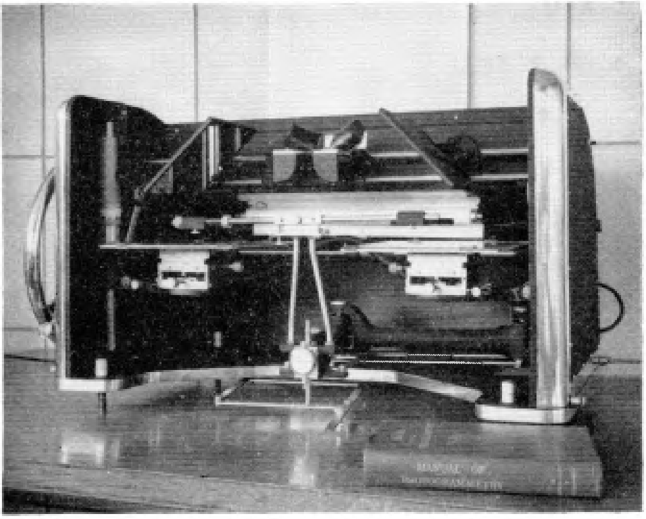

FIG. 7.16. THE K. E. K. PLOTTER
(Philip B. Kail Associates)

The K.E.K. instrument (Fig. 7.16) has been a well-known simple plotter for many years. This instrument allows a limited amount of tilt to be imparted to the photographs, thus increasing the accuracy. The British-made Stereosketch is a similar type of instrument.

MOSAICS

Another type of map can be prepared from air photographs by.

piecing together parts of the prints themselves in the form of a photographic mosaic. Such a composite picture is sometimes known as a photo-map or photo-plan, but these terms are not considered so suitable as the name mosaic.

There are two main sub-divisions of mosaics: controlled and uncontrolled. The construction of a fully controlled mosaic is described in the following paragraphs.

First of all a base grid is prepared and a slotted templet control is plotted on to the grid. Then each of the photographs is rectified photographically thus producing a print equivalent to that which might have been produced directly had the air camera been truly vertical at the time of exposure.

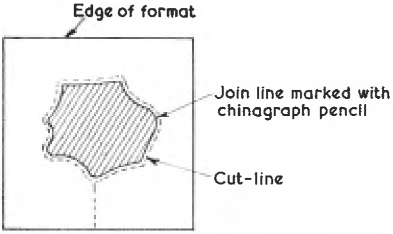

FIG. 7.17. CUTTING THE PRINT FOR A MOSAIC—FIRST PRINT

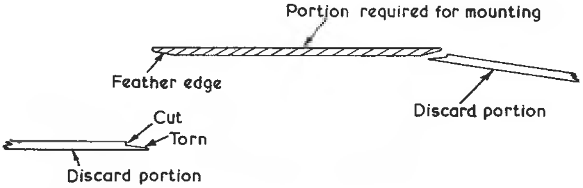

FIG. 7.18. SECTION THROUGH CUT PRINT

When mosaics are being made the lateral overlap of the photographs must be increased to at least 30 per cent whilst fore and aft overlap can still be 60 per cent.

The central print for the area is taken first and the part required to be used on the mosaic is chosen. An area near the middle of the photograph will be preferred as this is the part having the least height displacement. The boundary of this area will be marked precisely using a chinagraph pencil (see Fig. 7.17). A cut-line is made with a sharp razor blade 3 mm outside the chinagraph line and in such a way that the blade penetrates to only about one-third of the thickness of the print. Now hold the centre portion of the print on the palm of the left hand and tear down the discard portion with the right hand, leaving a feather edge as in Fig. 7.18.

Use a flour and water paste, and apply it thinly to the back of the photograph and to the face of the base grid. Stick fine needles through the photo control points and so orient the print on the base grid. The print can be stretched a little to fit the control merely by pulling it to shape. The print is now stuck down (see Fig. 7.19(i)) using a rubber roller to squeegee the paste from the centre outwards. Remove the surplus paste with a clean soft cloth.

The next print is now marked and trimmed in the same way as the first, except that the edge which will join with the already mounted print is cut to the exact join line, instead of 3 mm outside it. This is now pasted and oriented as before, taking care to match up the detail along the common features where they join. Squeegee into position as in Fig. 7.19(ii).

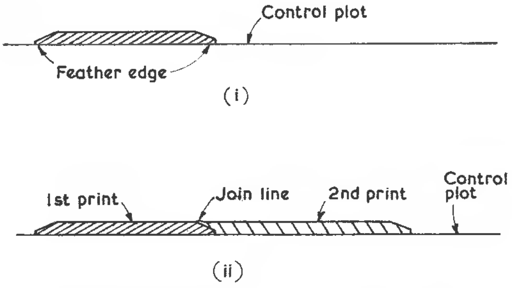

FIG. 7.19. MOUNTING THE CUT PRINTS
(i) FIRST PRINT MOUNTED
(ii) SECOND PRINT MOUNTED

The remaining prints are cut and mounted in succession until the mosaic extends beyond the required limits of the whole map (see Fig. 7.20). The surplus part of the mosaic is then cut away leaving the edges sharp and clean. Borders are now stuck on and the map is annotated as desired. Place names will be printed on paper strips and stuck on the face of the photo-map. If cleverly used, these name-strips can blot out some of the unwanted photographic detail. One of the drawbacks of a map of this description is that so much detail is shown that it becomes difficult to pick out the more important features. Figure 7.20 shows a mosaic under construction.

The map now contains ridges at the join lines, and after touching-up where necessary, it must be rephotographed to obtain the finished product. At this stage it is permissible to increase the scale of the map by up to $4\frac{1}{2}$ times the original photo scale, but in modern practice it is more usual to maintain approximate mean photo scale throughout.

Cut-lines should be chosen so that the joins between successive pieces of photograph fall along irregular lines of dark detail—the shadow of the line of a hedge would be ideal. Straight lines would be more obvious in the finished map, and the darkness of the detail tends to conceal the shadow thrown by the overlapping edge of photo.

FIG. 7.20. A CONTROLLED MOSAIC UNDER CONSTRUCTION
Note the registration with underlying map at left-hand edge.
(*Hunting Surveys Ltd.*)

Even with rectified prints it will be difficult to make every small part of detail match exactly along the cut-line (see Fig. 7.21). A stretchable paper base for the print is therefore used, and the photos are pulled into shape as far as possible. Expansion of one print relative to its neighbour may be encouraged by adding more or less water to the paste according to the amount of expansion required. Differential stretching of a print is easier after it has been soaked in water but this softens the emulsion and makes it even more hazardous to handle.

An uncontrolled mosaic is one plotted without reference to any control points. Such a map would certainly not entail the use of rectified prints, but in other respects it would be similar to the controlled mosaic.

Mosaics can be compiled much more rapidly and more cheaply than any other type of map for large areas of land, particularly the uncontrolled variety. They are therefore very useful for reconnaissance. They show much more variety of detail than other types of map, but they are not so simple to understand, and some important features might be hidden by overhanging trees. Contours may be added as for other maps, but this will partly offset the rapidity of of production. Inking in the streams and rivers in blue would help to convey a rapid impression of the configuration of the ground. It must be remembered, however, that distances cannot be accurately scaled from such a map because, however successful the rectification may be in removing tilt and lens distortions, it cannot remove the displacements due to the varying height of the ground.

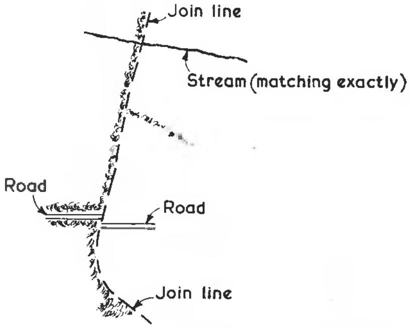

FIG. 7.21. LACK OF REGISTRATION AT MOSAIC JOIN-LINE
The right-hand print is to a slightly larger scale than the left-hand one, causing lack of registration of the two images of the road.

A rough form of mosaic is sometimes made as a navigation map for flying for more accurate cover. In such a case skeleton cover would be flown first—probably only every third or fourth strip would be flown, and cross strips at 20 to 35 kilometre intervals. A rough mosaic could be made from these photos and navigational points could be chosen on this skeleton map. This procedure is sometimes necessary where an area is being mapped for the first time.

FURTHER READING

RECTIFICATION AND PLOTTING
(i) Schwidefsky, pages 56–9, 144–67, 174–95.
(ii) *Manual of Photogrammetry*, Vol. II, Chapter 16.
(iii) Hart, pages 236–74.
(iv) Moffitt, Chapter 10.
(v) Hallert, pages 103–19.
(vi) Lyon, Chapters 10 and 12 (cartography).
(vii) Zeller, pages 228–49.
H.M.S.O., *Manual of Map Reading, Air Photo Reading and Field Sketching*, Part II, pages 11–17 on COPYING AND ENLARGING.

DETERMINATION OF TILT
(i) *Manual of Photogrammetry*, Vol. I, pages 33–45.
(ii) Hallert, pages 9–28.

PLOTTING FROM OBLIQUES
(i) *Manual of Photogrammetry*, Vol. II, Chapter 18.
(ii) Hart, pages 336–50.
(iii) Moffitt, Chapter 13.
(iv) Trorey, pages 7–36, especially 23–36 on perspective grid.

MOSAICS
(i) *Manual of Photogrammetry*, Vol. II, Chapter 17.
(ii) Moffitt, Chapter 11.

(See Bibliography (page 346) for the full titles.)