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Contract Nonr-609(02)

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Edwards Street Laboratory  
Yale University  
New Haven, Connecticut

ESL Technical Memorandum No. 18  
(ESL:460:Ser 1)  
15 May 1953

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*J. Biel*  
7/27/54

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Location of Position  
by  
Photographic Triangulation

by Carl W. Miller

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LOCATION OF POSITION  
BY  
PHOTOGRAPHIC TRIANGULATION

When a contact photographic print is examined from a distance equal to the focal length of the taking lens, all objects in the photograph lie in the same direction as the objects which they represent when viewed from the camera location. If an enlarged print is used instead of a contact print, the correct distance at which angles are preserved in this way is the product of the focal length of the camera lens and the degree of enlargement. This is known as the focal length of the print. If a surveyor's transit were set up at this distance and focussed on the print, the angles between various objects in the photograph could be measured exactly as though the transit were set up at the camera location. The photographic alidade used by cartographers for analyzing aerial photographs is, indeed, just such a device for translating angular directions on the photograph into azimuthal bearings on the map. Such analysis is, of course, complicated by camera tilt and topographic relief. If, however, the problem is solely one of determining map location from photographs of an object at sea taken from two shore stations, the task as a whole is greatly simplified.

One fundamentally simple method of accomplishing this purpose is being currently explored <sup>under contract # 60902</sup> by ~~PROJECT HASTINGS~~.

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A photograph made from one of the observation stations in the Beavertail area is to be laid down horizontally on the Beavertail Point map in such a position with reference to the camera location on the map that all objects in the photograph shall lie in the proper direction. If two such photographs have been taken from two different observation points, the intersection of the two lines of sight will yield the map location.

Two pieces of apparatus are necessary for carrying out this procedure: one, a cartographic tool, for relating the photograph to the map, and the other, a specially designed photographic enlarger for making the photographic print.

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### THE CARTOGRAPHIC TOOL

The cartographic tool consists of a brass frame designed to accept an 8x10" film transparency, which, in turn, is accurately located within this frame by the pins A and B (Plate IV). This frame is rigidly attached by the rods F and G to a vertical pin C, which is designed to fit accurately into any one of several ball bearings which are accurately centered in the map about the observation stations. The center of the frame is thus held at a distance from the observation station equal to the focal length of the print. The frame itself is supported by ball bearings in the blocks H and I, thus enabling it to glide smoothly over the map about the observation station C as a center. A thread is attached to a ring E which is mounted by another ball bearing to the pin at C. When the thread is drawn taut, it radiates thus directly from the observation station. In use it is only necessary to hold this thread in coincidence with some known landmark in the photograph and swing the entire frame until the thread is in line with the map location of this object. Then all other objects in the photograph will also be in line with their map locations.

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### THE PHOTOGRAPHIC ENLARGER

When a photographic print is laid horizontally on a map, only one line of the print can be located at the requisite distance from the observation station, i.e. the focal length of the print. Only for points on this line, therefore, will angles be accurately preserved. If this line is chosen as the horizon, the cartographic method described in the preceding paragraph can be applied to points on or near the horizon, but errors will increase as the distance from the horizon increases. It was accordingly decided to construct an enlarger in which the print could be properly distorted to correct for this error.

When an enlarged print is made by projection, it is usually formed in a plane which is perpendicular to the axis of the projection lens and parallel to the negative. The image is then an undistorted reproduction of the negative. If the image plane, however, is tilted with reference to this axis, parallel lines are transformed into converging lines, but they do not remain uniformly in focus. If, however, the negative plane is similarly tilted, it is possible to introduce such convergence and at the same time to retain correct focus throughout the length of the lines. Furthermore if the focal length of the projection lens is less than that of the taking lens, it is possible to tilt these planes by an amount which is just sufficient to overcome the difficulty pointed out in the last paragraph.

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When this has been done, the angles subtended by all points in the photograph at the observation station are identical with the angles subtended by their map locations.

Plates I and II show the enlarger which has been constructed with this end in view. An obsolete model of Leitz enlarger with an excellent condenser and projection lens was fortunately available for this purpose. The mechanical task consisted in fabricating from sheet aluminum a housing to insert between the projection lens and the condenser. A film carrier from a Leitz projector was so mounted in this housing that it could be tilted through any angle up to  $22^{\circ}$  by turning the knob A and tightening the knurled screw B. In order to be able to carry out this tilt either lengthwise or crosswise of the film, the film carrier was attached to a plate C which could be rotated through  $90^{\circ}$  in the frame D and locked by the screw E. This last adjustment was desirable in order to be able to use the projector both for single and double frame negatives. Although the lens cell F of the original projector could be used intact with its diaphragm, a new sleeve G had to be made. The limitations of space for this construction were quite stringent in order to maintain the proper functioning of the condenser, but the work was successfully carried out.

The entire projector (Plate I) had to be very rigidly mounted and capable of very precise rotation about a horizontal axis. This was accomplished by making use of a heavy stand with leveling screws which was fortunately available. Heavy pipe construction with knurled screws was used to determine the

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approximate setting about vertical and horizontal axes. The leveling screws are used for the final precise adjustments.

The 3" focal length of the projector was ideal for use in connection with photographs made with the 4" camera lens, which will probably be the one most frequently used for position location purposes. Further construction will be necessary if the equipment is to be adapted to a shorter focal length lens for use with photographs made with the 2" camera lens.

A 24" print focal length was adopted for the prints to be made by this method. This is long enough for rather high precision in cartographic measurements but is still within the convenient dimensions of the map area to be utilized. Plate III is an example of such a 24" focal length print, made from a 4" camera lens negative with the present equipment.

#### THE PHOTOGRAPHICALLY RECORDING CLOCK

Where the object being located is in motion, means must be available for identifying simultaneous photographs. Extremely heavy and expensive apparatus (such as the Army balloon theodolite) are in existence for recording time on motion picture frames. The usual method is to enclose some form of digital clock within the camera housing, and to provide illumination and the requisite optical system to place the record on the margin of the film. The present effort has been directed at constructing such a device as simply as possible from readily

available parts. Plate V shows the prototype model. A telechron clock movement A has attached, in place of hands, three plastic dials on which hours, minutes, and seconds have been placed photographically. A narrow slot in the plate C exposes the time signature which is shown in the sample print of Plate VI. This slot may be illuminated as desired by artificial light or by skylight, since it is oriented in the same direction as the camera. The vertical brass tube at the top of the photograph contains at its lower end (G) a 20" achromatic lens. The box at the top of the tube contains a beam-splitting mirror, set at an angle of  $45^{\circ}$ . The camera, placed directly behind this box, is exposed through the beam-splitting mirror, thus recording simultaneously the desired operations and the time signature. The image of the clock dials is brought to the collimating lens at G by the three front surface mirrors, D, E, and F. The mirrors are used in the interest of compactness. The long focal length of the collimating lens is a necessity if the time signature is not to occupy too large a proportion of the picture area. No provision is made in the present model for exercising any great measure of control over the location on the frame of the clock signature. The proposed model, which uses a different optical path, makes use of only two mirrors instead of three, but it is hoped to give one of these mirrors two degrees of freedom which will permit locating the signature in the most advantageous part of the frame, usually in a relatively dark foreground position. The definition present in the photograph

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of Plate VI demonstrates the high quality of the beam-splitting mirrors which are currently available at very moderate prices on the surplus market.

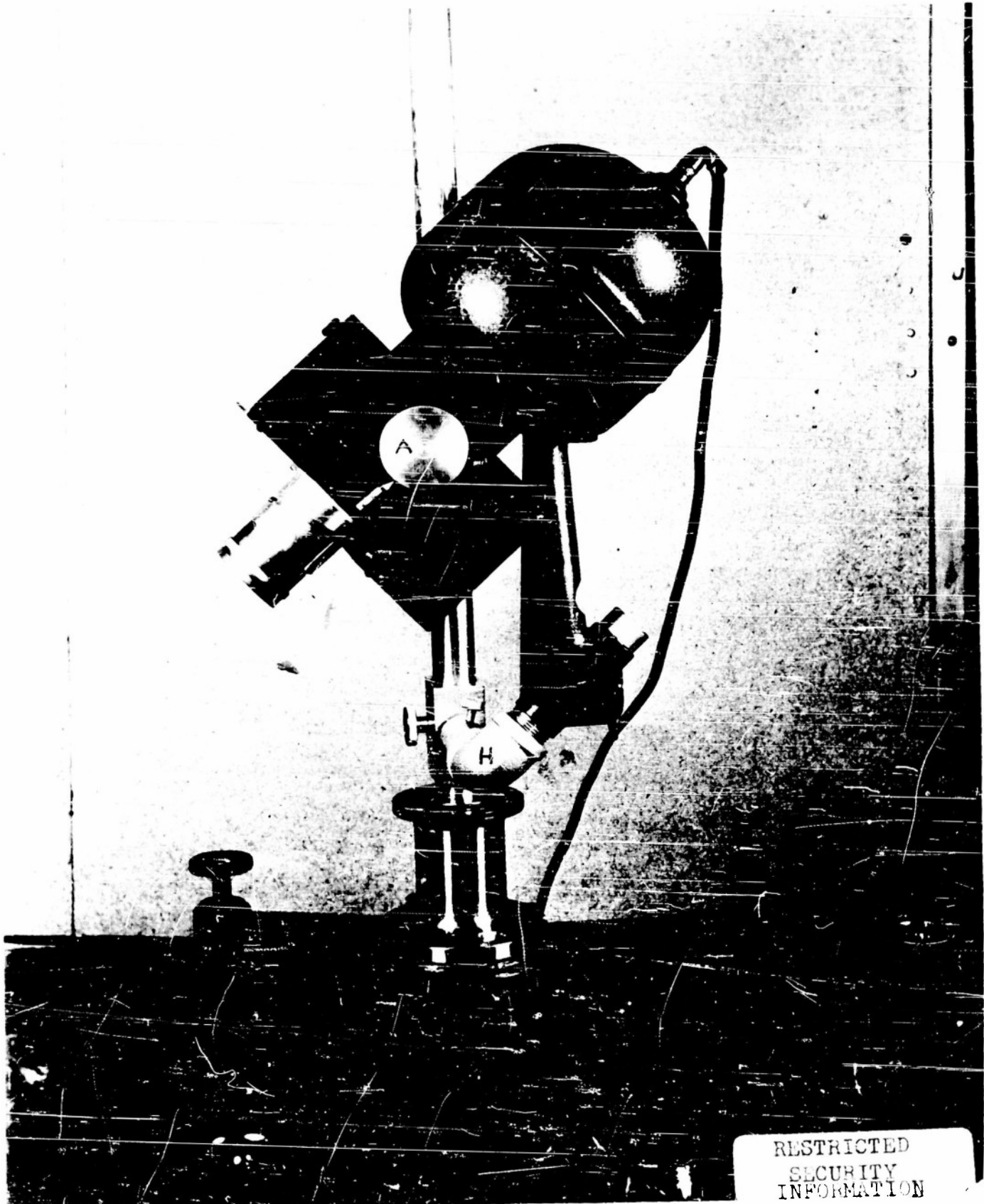
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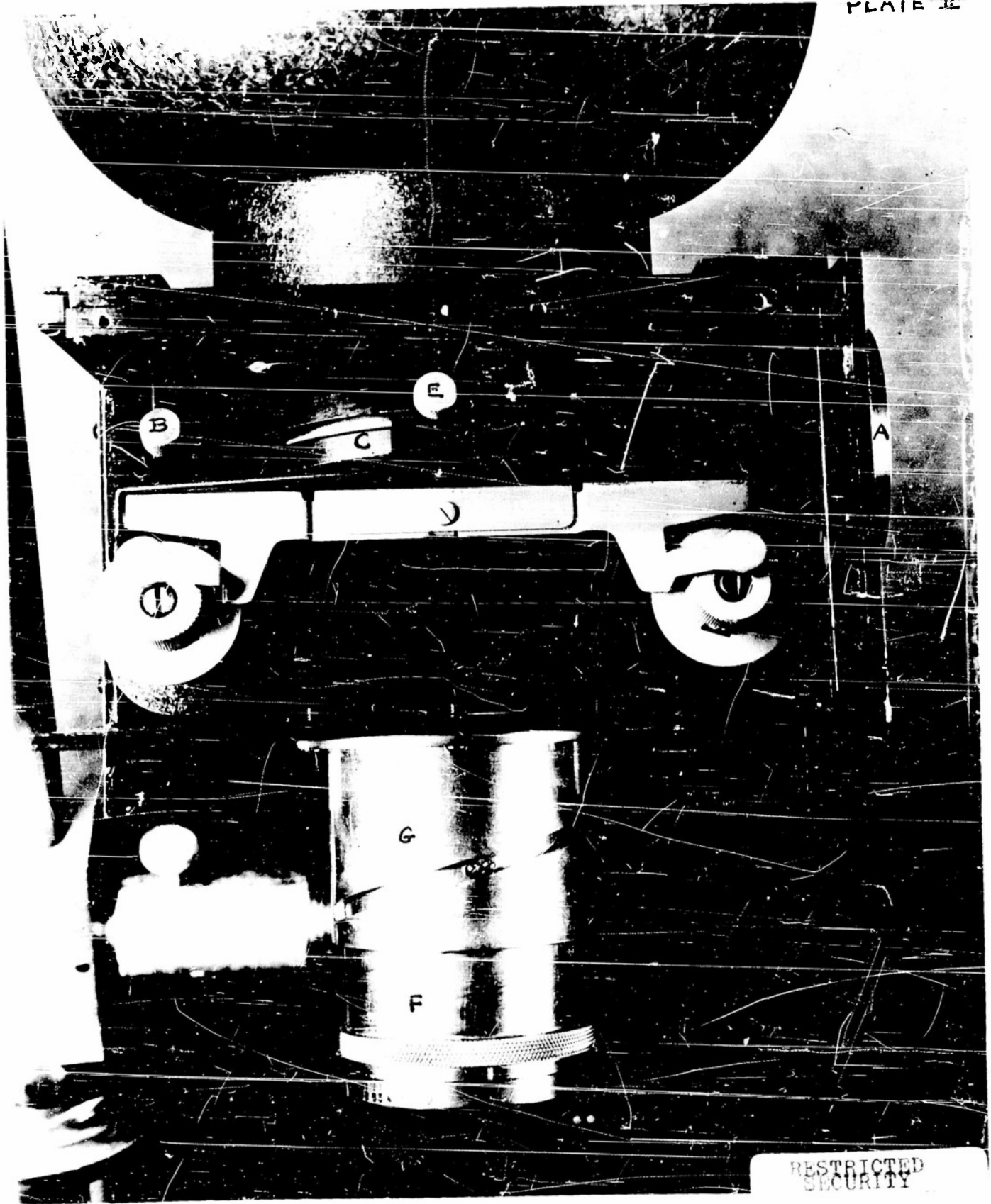
TITLES OF PHOTOGRAPHS

Plate I Photographic Enlarger and Mount  
Plate II Details of Photographic Enlarger Construction  
Plate III Distorted Photograph made with Enlarger  
Plate IV Cartographic Tool  
Plate V Photographically Recording Clock  
Plate VI Photograph Showing Time Signature of Photographically  
Recording Clock

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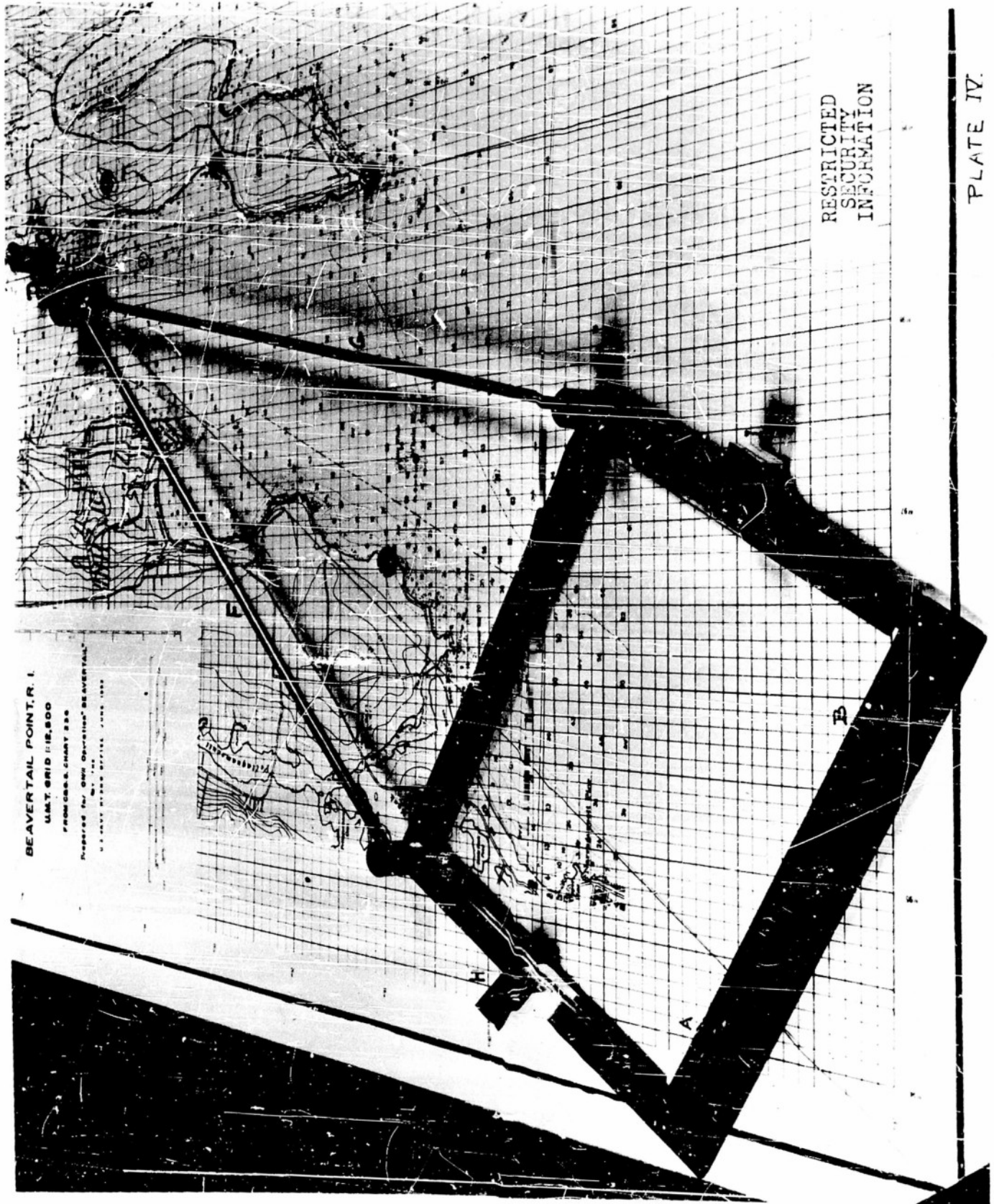
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PLATE III

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BEAVERTAIL POINT, R. I.

U.M.T. GRID 1:12,500

FROM C.S.S. CHART 233

Prepared for G.M.T. Operations BEAVERTAIL

No. 100

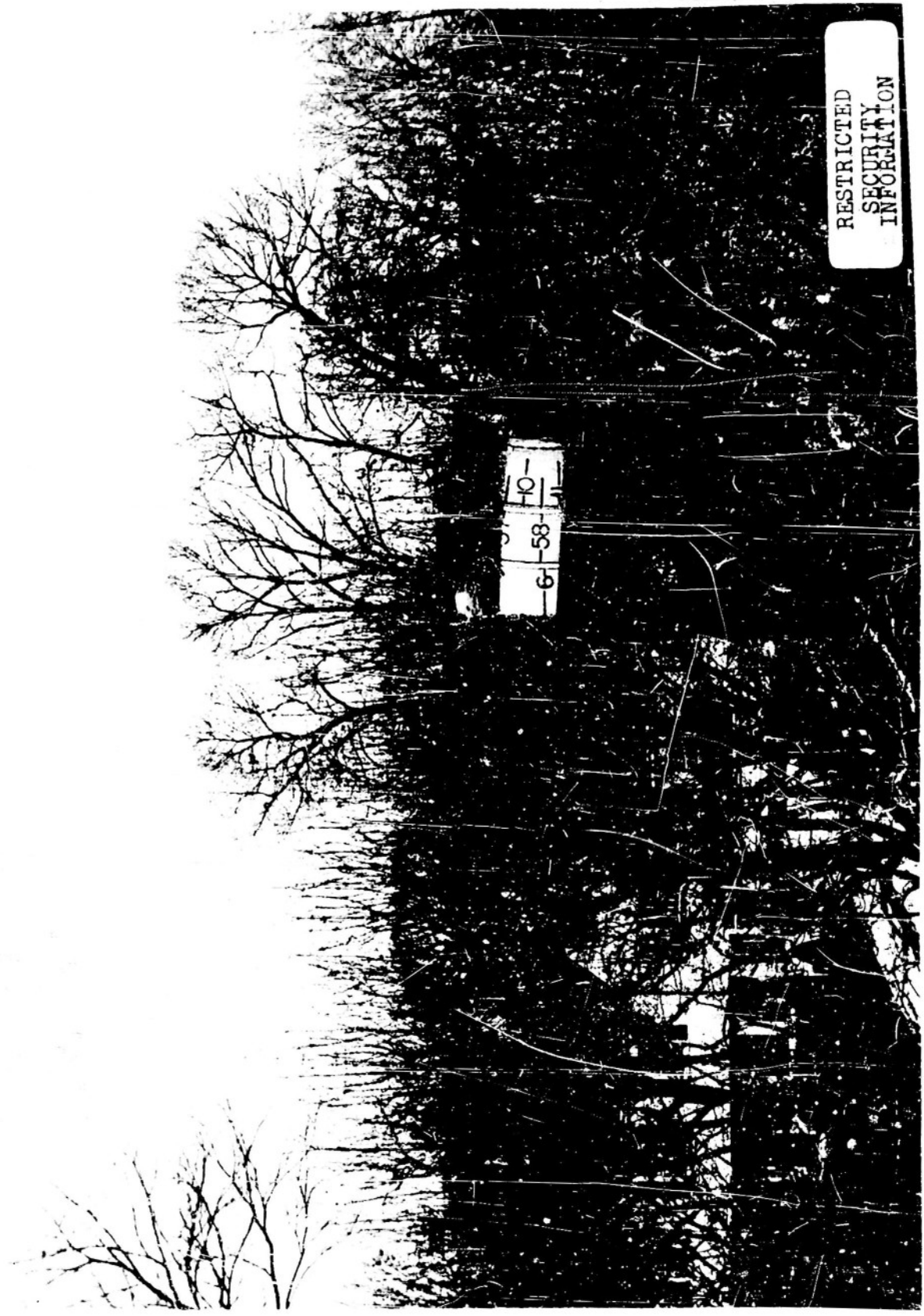
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PLATE IV.



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