THE USE OF STANDARD CAMERAS IN TERRESTRIAL PHOTOGRAMMETRY

by

RAYMOND NEWELL SHAW

B. S., University of Arkansas, 1955

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1959

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INTRODUCTION

The definition of the term "photogrammetry," as stated by the Committee on Nomenclature of the American Society of Photogrammetry, is "the science or art of obtaining reliable measurements by means of photography" (1). The common usage of the term by engineers and lay persons in recent years has tended to artificially restrict its definition to "the science or art of constructing maps by use of aerial photographs." While map preparation utilizing aerial photographs is probably the major field of endeavor within the science, both in terms of volume of work and monetary expenditure, there exists no valid reason or justification for the artificial narrowing of the definition of the term. One major result of this common error of definition of the term "photogrammetry" is the immediate supposition by the layman or engineer not trained in the science, that since aerial photographs are used and complex and expensive stereoscopic plotters are necessary for map compilation in the standard techniques, the use of the art or science is automatically limited to large firms which may justify large financial expenditures because of the relatively high volume of work anticipated. While individuals or small firms may wish to utilize the science because of the large savings in time which result, they feel that the financial expenditures for the necessary equipment will be so great as to more than offset any savings that would result due to the reduction of the time necessary for map compilation.

It is often the desire of firms, both large and small, to obtain large scale maps of areas of limited extent such as building sites, both industrial and dwelling; bridge sites; small sewer districts; farms; and many other such items. Due to the small area involved and the relatively high cost of obtaining aerial photographs of these areas, particularly if they lie at any distance from an airfield which may be used as a base of operations, or are located in locals where weather conditions tend to make the process of obtaining aerial photographs difficult, the standard mapping techniques such as the transit-tape or plane table method are usually indicated in preference to photogrammetric surveys. Various mapping agencies, particularly European agencies, make use of a system or procedure whereby photographs of the desired agencies are obtained from the ground using special instruments called "phototheodelites," and by the use of specialized plotting machines, maps are then compiled, using these photographs. This process is usually referred to as "terrestrial photogrammetry" in order to differentiate between it and "aerial photogrammetry." The author has felt that this method of approach should lend itself admirably to the problem of mapping areas of limited extent, particularly if planimetric maps with spot elevations at critical points are desired, and if some means could be found whereby a phototheodelite and terrestrial photogrammetric plotter would not be necessary.

In June of 1958, research was begun to determine if standard cameras might be used in place of more elaborate instruments for mapping purposes. The term "standard camera" is meant to imply a camera which is readily obtainable at a fairly nominal cost and which may be used by the average person with a minimum of training. It should be further stated that modification of the camera, particularly the internal characteristics, was considered to be undesirable if these modifications were of a permanent nature.

HISTORY

The art or science of photogrammetry is almost as old as photography itself. The first known photographs, the daguerreotypes, were produced in 1839. In 1840, a French geodesist by the name of Arago advocated the use of photography by topographers, architects, and archeologists (2). Aime Laussedat, an engineer officer of the French army, initiated extensive research in the field of mapping by use of photography in 1849. His prolonged studies in the field have caused some modern writers to refer to him as "the father of photogrammetry" (1). He experimented with glass plate cameras suspended from balloons and kites, and he constructed a few maps by means of the aerial photographs obtained in this manner (1). The inability of this type of support to maintain the camera in a previously determined position and the movement of the camera with respect to the ground at the instant of exposure which resulted in blurred images caused him to turn to the use of terrestrial photographs or photographs taken from the ground. Another source of difficulty was the problem of obtaining enough photographs from one air station to cover all the area that the outlook commanded. In 1849, he announced to the Academy of Science in Paris the successful use of photographs taken with a phototheodelite, a combination of theodelite and camera, in the preparation of maps (3). The first conception of the use of terrestrial photographs for the construction of maps envisaged a process whereby the plane table was replaced with phototheodelites and in this manner obtaining photographs of the terrain which was being mapped. Then the photographic coordinates of all desired points were determined by measurements on the photographs and this information transferred to the map compilation sheets.

In 1894, Colonel von Hubl, Chief of the Topographic Section of the Geographic Institute of Austria, adopted the methods of Laussedat to work in high mountains, and through his efforts the stereocomparator became a recognized instrument in the science or art of mapping. Lieutenant von Orel, while attached to the Geographic Institute of Vienna, transformed the stereocomparator into a drawing instrument and developed the stereoautograph. The stereoautograph permitted tracing the map not only point by point, as was necessary with the stereocomparator, but automatically in more or less the same manner as present day plotting machines (2). From these small beginnings the science developed very rapidly.

The outbreak of hostilities in 1914 gave the science an added importance, for up-to-date maps of terrain whose cultural features were undergoing constant and rapid change became an item of major importance to the armies engaged in the conflict. It was during this same period that the airplane became an instrument of warfare, not only from the standpoint of a weapons system, but also as a highly mobile and fairly reliable camera platform. Since map compilation by terrestrial photogrammetric means required the precise measurement of baselines, a virtually impossible task with the instruments at hand and under enemy fire, the use of aerial photographs almost superseded other photogrammetric mapping procedures. At the conclusion of hostilities, the techniques of aerial photography were fairly well-established. Aerial photographs have numerous advantages over terrestrial photographs, including the ease with which an area may be photographed and the fact that there are generally no objects between the lens of the camera and the area being mapped which would obscure important details. These factors led to the extremely rapid commercial development of aerial photogrammetry for mapping purposes in this country. Terrestrial photogrammetric methods, which require a higher density of control per unit area and hence more time spent in the field by conventional survey parties, did not enjoy the rapid development and exploitation that was experienced by the aerial photography methods.

MATERIAL AND METHODS

Two cameras were selected for study, a Leica IIIc and a Kodak "Pony." These cameras are 35 mm. "candid" type cameras using a standard 35 mm. film cartridge. They represent, to a rough degree, the range of this type of camera as far as cost and precision. The Leica camera is, according to some authorities, one of the best 35 mm. cameras available on the open market, while the Kodak "Pony" represents the other end of the scale, a camera produced for the average amateur photographer in this country. The former is manufactured with all the care of a precise instrument, while the latter is manufactured under semi-mass production conditions.

The study of 35 mm. cameras was undertaken for two main reasons: (1) This type of camera enjoys a widespread popularity in the United States at the present time. (2) Pictures taken with this type of camera have a relatively small negative size, and they must be enlarged to approximately five diameters prior to their use in map compilation work. Thus any distortions or errors introduced by the lens or technique would also undergo considerable magnification. From the standpoint of the cartographer this is undesirable, but it was felt that the investigation should include rather than ignore this problem.

Since no suitable plotting instruments were available, the actual work of map compilation was carried out by measuring the "x" and "y" coordinates of a particular point on the photographs, and by operating on these measurements, this same point was then transferred to the map compilation sheet. In the discussion which follows, reference should be made to Figs. 1, 2, and 3[1] in order to clarify the explanation of the method used.

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1 All figures in the Appendix

A photograph is, in all actuality, a precise graphical presentation of a mathematical equation. It can readily be seen by referal to Fig. 1 that all light rays emanating from an object or objects which impinge upon the photographic film pass through the perspective centers O_1 and O_2. Any plane which is perpendicular to the optical axis of the system, O_1p_1 or O_2p_2, represents a conic projection of the area which is being photographed. Since the negative material is placed in such a position, that is, normal to the optical axis of the camera lens, the resulting negative photograph is a conic projection. By referal to Fig. 3, it may be seen that any enlargement or print is also a conic projection. In order to prepare a map or plan view of the object or objects photographed, the distance from the perspective center, "O", to the principal point, "p", where the optical axis pierces the photograph must be known. For the negative, this distance is equal to the focal length of the camera lens or the distance from the nodal point of emergence to the focal point of the lens, providing the negative material does not undergo any physical changes between the time of exposure and the time that the negative is used in the mapping problem. It should be noted that this is true only when the lens is set at infinity. This distance is designated by the symbol "f" in this paper. For the photographic positive or print, this distance designated by the symbol "f" is equal to the focal length of the camera lens multiplied by the magnification factor, "m". Since the magnification factor of a contact print is equal to unity, the theoretical focal length of the photographic print is the same as the focal length of the lens. However, the dimensions of the contact print undergo changes in the developing process, and the theoretical focal length may not agree with the actual focal length. Once the focal length of the photographic print has been determined, the positions of all points which appear on two or more photographs taken from different positions may be determined with respect to the perspective centers of the photographs.

Consider point "A" in Fig. 1. The rays of light which emanate from this point pierce Photograph #1 at a point, a_1, and Photograph #2 at point a_2; thence they pass through the perspective centers O_1 and O_2. If the camera lens and camera were level at the instant of exposure, then lines $O_1p_1P_1$ and $O_2p_2P_2$ are level lines as are the "x" axes of the two photographs. The "y" axes, being normal to the "x" axes and to the optical axes, are both vertical lines. The photographic coordinates of point "A" in Photograph #1 are x_{a1} and y_{a1} and in Photograph #2 are x_{a2} and y_{a2}. By inspection it can be seen that $f_1' : x_{a1} :: O_1P_1 : X_{A1}$ and $f_2' : x_{a2} :: O_2P_2 : X_{A2}$. Similarly $f_1' : y_{a1} :: O_1P_1 : Y_{A1}$ and $f_2' : y_{a2} :: O_2P_2 :: Y_{A2}$. Therefore, if it is possible to orient the photographs on the map sheet, it is possible to locate all points which appear in both photographs.

If the points O_1, O_2, and A are known in position and elevation, they may be plotted to any suitable scale on the map compilations sheet, point A serving as a picture control point. Using O_1 and O_2 as centers, arcs are drawn whose actual radii equal f_1' and f_2' respectively. The lines O_1A_1 and O_2A are drawn as has been done in Fig. 2. Tangents are then drawn at the intersection of the focal length arcs and the previously mentioned lines. These points are labeled a_1' and a_2' respectively. The distances $a_1'p_1''$ and $a_2'P_2''$, corresponding to the distances a_1p_1 and a_2p_2 on the photograph, are then laid off in the proper direction along tangents to the focal length arcs. From the points p_1'' and p_2'', lines are drawn through the optical centers O_1 and O_2. By inspection it can be seen that these lines, O_1p_1'' and O_2p_2'', correspond to and are collinear with the optical axes of the respective photographs. Also, it will be seen that the intersection of these lines and their respective focal length arcs correspond to the points p_1 and p_2 in the photographs and are labeled p_1' and p_2'. Tangents to the focal length arcs at these points will then describe the properly oriented positions of photographs 1 and 2.

The plan positions of all other points may then be located by measuring the x coordinated of the points in question, transferring these distances to the photographic planes on the map compilation sheet, and then extending the rays through the points from O_1 and O_2 respectively to their points of intersection. For example, point B may be located in position by laying off the distance $p_1'b_1'$, as measured on the photograph, along photographic plane 1 and extending ray O_1b_1'. In the same manner, point b_2' is located on photographic plane 2 and the ray O_2b_2' extended till it intersects ray O_1b_1'. This point of intersection is B or the proper location of B on the map compilation sheet.

The elevation of all points appearing in both photographs may then be determined in the following manner. The distances O_1b_1 and O_1B are measured on the map compilation sheet. O_1b_1 is measured in the same units as the photographic coordinates and O_1B is measured to the map scale. The y coordinate of point b on Photograph #1, y_{1b}, is then determined. Since $O_1b_1' : y_{b1} :: O_1B : Y_B$, the height of B, Y_B, above or below point O_1 may be calculated, and if the elevation of O_1 is known, then the elevation of point B may be determined. This same procedure may be followed utilizing Photograph #2 as a check on the previous calculations.

In order to ascertain the focal length of the photographs used in mapping, the actual magnification of the enlargements must be known. The magnification of the photographic enlargements was found by the simple expedient of inserting a focusing aid such as is available in most camera stores in the enlarger after the enlarger has been adjusted to yield the desired size of photograph. An enlarged print of the focusing aid was then made, using the same processes as were utilized in the preparation of the photographs used for mapping purposes. If the distance between any two selected points on the focusing is known and the distance between these same two points on the enlarged print is measured, the magnification factor can then be readily ascertained. It should be emphasized that care must be taken to insure that the print of the focusing aid and all other prints whose magnification will be determined by this print must be handled and developed under the same conditions. The time spent in the various chemical baths, the time spent in the wash bath, and the drying process should agree as closely as possible. It is of extreme importance that the prints be dried in such a manner as to prevent any abnormal stretching or shrinking of the prints. This requirement precludes the use of ferrotype plates or similar devices used to obtain a glossy surfaced print, for such devices normally stretch the wet paper and emulsion of the print in at least one dimension.

FIELD PROCEDURE

Three sites were selected for mapping purposes. The first two are relatively small sites with areas of less than one acre, while the third or final site has an area of approximately twelve acres. The first site is the area immediately south and east of Southeast Hall between Southeast Hall and Petticoat Lane on the Kansas State College Campus. The second site is the northwest corner of the Athletic Field of Kansas State College. The third and final site is a cultivated field immediately west of the Riley County Hospital and whose main borders are delineated by Tecumseh Road, the service road of Riley County Hospital, and Claflin Road in Manhattan, Kansas.

The Southeast Hall site was selected originally because of the gently sloping ground within the area, the fairly large number of small trees, the building with its readily defined architectural details, and its ready accessibility. The most feasible location of the camera stations was on the opposite side of Petticoat Lane. Photographs of the area were taken with the Leica and the Pony cameras. Difficulties were encountered due to parked cars in Petticoat Lane, and quite a bit of time was lost due to the fact that the investigators had to stop work on numerous occasions and ask the drivers of automobiles to remove their vehicles from the area under study. For this and other reasons the second site was selected, the northwest portion of the Athletic Field.

The Athletic Field site offered numerous advantages over the Southeast Hall site. There were no interruptions due to traffic, the foreground is relatively flat, there is a pedestrian bridge within the area, and there are radical changes in terrain within the mapped area. This site was photographed with both cameras.

The final site was chosen because of its gently rolling terrain, high incidence of telephone and power poles along its borders which would serve as secondary control stations for checking map accuracy and bridging purposes, and its proximity to the campus of Kansas State College.

The first two sites, Southeast Hall and the Athletic Field, were purposely kept small in order that various techniques and cameras might be readily checked with a minimum of time spent in the field and the actual map compilation. It should be pointed out, however, that the areas involved are equal to or greater than the average size dwelling lot and hence, the results and difficulties encountered in the course of the investigation may be of interest to architects and landscape architects. The final site might be considered as a typical site for a school or industrial building, a small subdivision, or a park. The use of the term "final site" with respect to this area may be misleading. It is not the intention of the author to convey the idea that the area encompassed is the largest that could be mapped by terrestrial photogrammetric methods; the term simply implies that this was the last site selected and mapped by this method in the course of the investigation.

No attempt was made to orient the maps with respect to true north or any other reference. Admittedly, this information should appear on any complete map, but it was felt that the investigation should be restricted strictly to the matters pertaining to camera investigation and map compilation techniques. A north arrow appears on the map sheets, but its purpose is for rough or approximate map orientation, and it indicates only the approximate direction of north.

The first set of photographs was taken with the Leica and a map compiled from these photographs. Results proved to be promising with the use of this camera, and in order to expedite the work, it was decided to prepare fairly complete maps from photographs taken with this camera and only partial maps or maps showing only a few important details with photographs taken with the "Pony."

In all cases, a baseline or baselines was measured along one border of the area to be mapped with the ends of the baselines serving as both control stations and camera stations. The baselines were measured by conventional taping methods, using a 100 foot steel engineer's tape for measuring distances and maintaining line with an optical transit. The distances were measured both forward and back, and the mean of the two values obtained was accepted as the correct length of the base.

Prominent features within the areas were selected for secondary control stations and their positions determined by intersection. The transit was set up at the end of each baseline and the angular distances to these secondary control points measured with respect to the other end of the baseline. The baselines and these secondary control points were then plotted on a sheet of tracing linen for the purpose of checking the finished maps by simply placing the control sheet over the map sheet and checking for discrepancies in position.

The above-mentioned procedure was deviated from in the map of the final site. It was decided to complete the map of the area prior to running any secondary control survey for the purpose of checking the map itself, then print the map on Ozalid paper and check it by conventional plane table methods in the field. This was done because of the high incidence of secondary control points such as telephone and power poles. It was felt that the relatively high number of these objects would lead to confusion in the actual plotting of a control sheet.

Since a third point is needed in the area of photography to orient the photographs, a point was chosen that would fall within the pictures and at the same time be divorced from any other prominent features which would also appear in the photographs. This point was located by the same method used for locating the secondary control points. In order to differentiate between this point or points in this paper, these points will be called "picture control points."

Vertical control was established by spirit leveling to "third order" specifications. In practically all instances, with the exception of the final area, the elevations of all points were determined by standard leveling procedures; however, in a few cases, spur shots were used in order to expedite the work. In the case of the final area, a system of bench marks was established; and practically all elevations, with the exception of the picture control point elevations, were determined by spur shots. Leveling was carried out, using a standard "Philadelphia" rod and either a "tilting-head" or "automatic" level.

The camera support was the tripod and baseplate of a Wild T-1 theodolite or optical transit. They not only served as a rigid support but furnished a means of leveling the camera so as to insure that the optical axis of the camera lens was a level line, provided that it was parallel to the base of the camera. During the course of the investigation, a plastic plate was inserted between the baseplate and the camera base in order to facilitate the centering and pointing of the camera. Prior to the adoption of this method, considerable difficulty was encountered in these operations, due to the interference of the baseplate leveling screws. As a check on the possibility of inclination of the optical axis of the lens, targets were set within the photographed area at the same elevation as the center of the camera lens. The first targets used were standard level rod targets, which were placed on 1 inch by 2 inches wooden stakes. Since these were rather small and at times practically invisible due to the scale of the photography and the resolution of the film and paper, larger targets were constructed. These consisted of 2 feet by 2 feet plywood ½ inch thick with a bracket attached to the rear of the target, which enabled them to be mounted on 2 inches by 2 inches by 5 feet wooden stakes. These targets proved to be very satisfactory for the smaller areas, but somewhat bulky and tedious to place in the final area, since this area was much larger and a much greater number of pictures was required to give complete photographic coverage of the desired area. For this reason, targets which lent themselves to more rapid adjustment were used, and the 2 feet by 2 feet targets were used to identify camera control stations. This third set of targets was improvised from materials which were readily available and consisted of such items as paper triangles tacked to telephone poles, two stakes held together with clamps and rope, and a telescopic fishing rod case tied to a stake. In these instances, the top of the rod case or stakes and the upper apex of the paper triangles indicated the elevation of the camera lens.

A target consisting of a cylindrical wire frame with cloth panels stitched to the framework at right angles to each other was used to identify the picture control point in the two smaller areas. As mentioned previously, the 2 feet by 2 feet plywood targets which were larger and more easily identified in the photographs were used in the final areas.

The conventional instruments used in terrestrial photogrammetric processes for obtaining photographs are the phototheodelite or surveying camera. These instruments have a method of determining the principal point and the x and y axes incorporated in their design. The common method utilized is the system whereby the film frame blocks out portions of the light falling on the negative. When the negative is printed, these portions show up as black images resembling arrowheads. When lines are drawn from point to point of these marks, they correspond to the x and y axes of the photograph, and their intersection indicates the position of the principal point. Since major modifications would be necessary to adopt this system to the cameras used and this modification would not only be difficult, but from the point of view of the author, undesirable, another method was used. This method was found to be reasonably satisfactory. It was assumed that the optical axis of the lens would pierce the center of the photograph as delineated by the film frame, and that therefore the principal point could be located by drawing diagonal lines from the corners of the rectangular area formed by the film frame itself. A line was then drawn through the principal point so found and parallel to the top and bottom of the rectangle formed by the film frame. This line would delineate the x axis. A, perpendicular to this line and passing through the principal point, would then serve as the y axis. A check on this method was furnished by the presence of the images of the targets used to locate the height of the camera lens in the photographs themselves. As will be seen by referal to the examples of photographs used in the map compilation, all photographs were printed in such a way as to insure that edges of the negative mask would appear in them.

Perhaps the greatest source of difficulty encountered in compiling maps by this method is the determination of the focal length of the camera lens. This is particularly true in the case of cameras using film sizes in the neighborhood of 35 mm. The negatives obtained with cameras utilizing these film sizes must be enlarged to four or five diameters in order to yield a photograph of usable size in the map compilation procedures. Since the focal length of the lens is multiplied by the magnification factor in order to obtain the focal length of the photograph, any error in determining the focal length of the lens will undergo a corresponding magnification. Thus, if an error of only 0.1 mm. is made in the determination of the focal length of the lens, the error in the focal length of the photograph will be of the magnitude of 0.4 - 0.5 mm., a definitely measurable quantity. Errors arising from this source are readily detectible. If the calculated focal length of the photograph is too short, all points will be displaced toward the optical axis; if too long, the points will be displaced in the opposite direction or away from the optical axis.

Most cameras on the market today have a focal length marked on them, but this value may be misleading. The focal length reported on the lens is usually the nominal focal length and is reported to only the nearest millimeter. Thus a lens having a reported focal length of 49 mm. may have an actual focal length anywhere between 48.5 to 49.5 millimeters. In some cases, the tolerance is even greater, as with the lens manufactured for the "Pony" camera by Eastman Kodak. Upon inquiry, they reported that all their lenses of this type were manufactured with a tolerence of plus or minus 2 per cent. Therefore, the reported focal length of the lens would fall somewhere between 49.98 and 52.02 millimeters, while the reported focal length was 51.0 millimeters. Secondly, all lens manufacturers do not use the same definition of focal length. They may, for example, choose to call the distance from the optical center of the lens to the focal plane or the distance from the back surface of the lens to the film plane the focal point. Since there exist many definitions of the term focal length and only one is correct insofar as the topographer using this method is concerned, some means for determining the distance from the nodal point of emergence to the focal point must be available. The obvious choice is the use of an optical bench and auxiliary equipment as described in most texts on physical optics. These instruments are not usually readily available, and some other means which would be suitable without using additional expensive equipment was deemed desirable. It should be noted that some manufacturers code their lenses in such a manner that upon request they can furnish the owner of a particular lens with a closer value of the focal length of the lens in question than is reported on the lens barrel. Such is the case with lenses manufactured by E. Leitz for Leica cameras.

Perhaps the simplest method of determining the focal length of the photographs used in the mapping process as far as the average user is concerned is a "trial and error" method which does not entail the determination of the lens focal length directly. A control system is set in the field, using either a triangular or quadrilateral configuration. The control points are selected in such a manner as to insure that at least two of the control points will appear in one picture. The control system is then surveyed by conventional methods, using extreme care and as much precision as is available with the instruments on hand. Pictures are then taken of the control area with suitable targets erected over the control points so that they may be readily identified in the photographs. The photographs are processed by the usual methods and the magnification factor determined. Then the control system is plotted to a convenient scale. Using one of the pair of control points which appear in any particular photograph as a picture control point, the photograph is oriented on the plot by the usual method. After orientation, a ray is drawn from the optical center through the image point of the second control point. If the ray passes through the plotted position of the control point in question, then the focal length determined by multiplying the nominal lens focal length by the magnification factor is correct as far as mapping requirements by this method are concerned. If it does not pass through the plotted position of the point, then the focal length as determined by computation is too short or too long, and a new try is necessary. The orientation procedure is run through once again with the newly estimated focal length, and again the check is made. This process is continued until the ray or rays used for checking fall through the plotted positions. The photograph's actual focal length is then measured on the plot. For future computational purposes, the focal length so determined is divided by the magnification factor of the photograph to determine the distance from the nodal point of emergence to the focal point or the focal length of the camera lens. This method of focal length determination is referred to as the "two control point" method in later pages of this paper.

SUMMARY

Partial maps were compiled for the S. E. Hall, Athletic Field, and the Riley County Hospital sites with the photographs taken with the Leica. Partial maps of the Athletic Field and Riley County Hospital sites were compiled with photographs taken with the Kodak "Pony." The maps compiled with photographs taken with the Kodak "Pony" were not as detailed as those compiled with photographs taken with the Leica, because it was felt that a relatively small number of points would suffice for checking purposes.

The focal length of the Leica lens was determined with the aid of an optical bench and found to be 51.28 mm. This value was subsequently found to be in error, and E. Leitz, Inc., the manufacturers of the lens, reported it to be 51.6 mm. When this latter value was checked, using the "two control point" method as set forth in the body of this paper, it was found to be correct within the required tolerance.

The partial maps of the S.E. Hall and Athletic Field sites had already been prepared with the erroneous value for the focal length. The largest error in position was found to be 0.055", and it was felt that nothing would be gained by recompiling the maps using the corrected focal length value. The Leica map of the Riley County Hospital site was compiled, using the 51.6 mm. value for the focal length. Such items as telephone poles and building corners were plotted on a sheet of tracing linen, a print of this plot was made, and the print was taken into the field for the purpose of checking the plot. The standard plane table method of intersection was used in the field for locating the horizontal positions, and spirit leveling was used to determine elevations.

Thirteen points were checked for horizontal position on the "Leica" map of the Riley County Hospital site. The maximum discrepancy between the plotted position and the position as determined in the field was found to be 0.110 inch, the average discrepancy was 0.055 inch, the median discrepancy was 0.039 inch, and the minimum discrepancy was 0.024 inch. The map was plotted to a scale of 1 inch equals 40 feet, therefore these discrepancies correspond to 4.4 feet, 2.2 feet, 1.6 feet, and 1.0 foot respectively.

Eleven points were checked for vertical position on the "Leica" map of the Riley County Hospital site. The maximum discrepancy between the plotted elevation and the elevation as determined in the field was 1.0 foot, the average discrepancy was 0.5 foot, the median discrepancy was 0.4 foot, and the minimum discrepancy was 0.0 foot.

The "Pony" map of the Riley County Hospital site was compiled, using a focal length of 51.7 mm. This value differed from the value of focal length reported on the lens barrel (51 mm.) and was determined by the "two control point" method. The map was compiled on a sheet of tracing linen and checked by placing it over the print used for checking the "Leica" map of the same area.

A total of six points were checked for horizontal position, on the "Pony" map of the Riley County Hospital site. The maximum discrepancy between the plotted position and the position as determined in the field was found to be 0.098 inch, the average discrepancy was 0.045 inch, and the minimum was 0.0 inch. This map was also plotted to a scale of 1 inch equals 40 feet, and these discrepancies correspond to 3.9 feet, 1.8 feet, and 0.0 feet.

Twelve points were checked for vertical position on the "Pony" map of the Riley County Hospital site. The maximum discrepancy between the plotted elevation and the elevation as determined in the field was 1.1 feet, the average discrepancy was 0.6 foot, the median discrepancy was 0.6 foot, and the minimum discrepancy was 0.2 foot.

There is an apparent inequality in the above-mentioned figures in that the horizontal position discrepancies noted for the "Pony" camera tend to indicate a higher degree of precision than those noted for the "Leica" camera, while the converse is true for the vertical position or elevation discrepancies. If one examines the maps prepared with both cameras, this lack of agreement between the two sets of figures becomes less disquieting. The points checked for horizontal position for the "Pony" map lie between and to the north of the line joining camera stations A and B. Since these points were checked by intersection from camera stations B and C, they also lie in a region where the intersecting rays form very acute angles, and therefore the actual positions of the points in question may vary with the accepted positions. It should be noted that rays were drawn on the "Pony" map, utilizing photographs taken from camera station C, which pass through the photographic images of the power and telephone poles along Claflin Road. The correct position of these poles has also been indicated, and by inspection it may be seen that, in actuality, the "Leica" and "Pony" cameras approach the same order of precision.

CONCLUSIONS

The most universally accepted specifications for maps compiled by aerial photogrammetric means are as follows:

> 90% of all identifiable horizontal features shall be within 0.025 inches, their correct position as determined from the nearest grid lines, and the remaining 10% shall not be more than 0.05 inches in error.

> 90% of all contours shall be within ½ contour interval of their correct position. The remaining 10% shall not be in error by more than one contour interval (4).

Obviously neither of the two maps which were compiled will satisfy these specifications. While the specifications refer to topographic maps showing contour lines and prepared from aerial photographs, they may be utilized as one criteria by which the cameras and techniques employed may be checked. The author has had considerable difficulty in finding any specifications other than the one quoted above. Indirect specifications referring to the thickness of an average pencil line or one minute of arc when using an alidade and plane table have been located, but none which refer directly to allowable discrepancies in position have been located. The scarcity of information on this subject may be explained by the fact that the maximum allowable discrepancy in position of a point is a function of both the field surveying and compilation techniques employed and the purpose for which the completed map will be used. If only a fair degree of precision is necessary in the completed map, it is obvious that the additional expense and time necessary to attain a higher degree of precision will not be justified. Many times, maps are required which represent information in a quantitative rather than a qualitative form. When such a map is desired, the exact position of a point shown on the map sheet is of secondary importance to the fact that the point actually appears in its approximate position. As an example, a map may be desired of various areas which are being considered for the location of a school or factory building. The approximate location of power lines, access roads, trees, and buildings, correct within four or five feet, is important in the initial or preliminary planning stage. After the final site is selected and the approximate location of the building is laid down on the map sheet compiled by the means set forth in this paper, the area needing more detailed study may then be mapped by conventional methods; or if the exact location of only a few objects is needed, these points may be measured and the appropriate corrections made on the original map sheets.

It is axiomatic that distances should never be scaled off a map if these required distances need be obtained with any degree of precision. The paper on which the map is printed, unless of very high dimensional stability, undergoes considerable dimensional change with changes in humidity, temperature, and storing or carrying conditions. Therefore, regardless of the degree of precision obtained in the actual compilation and manufacture of the map sheets, one cannot be absolutely sure of a particular point's location with respect to other points on the map by simply scaling the required distances.

The process used for map compilation required the marking of two points on a line delineating the photographic planes and then extending rays through these points until they intersected at the theoretical position of the required point. Inasmuch as the original marks and the lines delineating the photographic planes have finite dimensions, it is not only possible but probable that a certain amount of human error would be present when the intersecting rays were drawn. Since these rays are actually a graphical representation of an angular measurement, any error introduced at this point would increase rapidly with and in direct proportion to the distance from the optical center or camera station.

The author is of the opinion that the plotting or compilation method employed contains the source of many of the discrepancies in position noted in this paper. If a more refined method of measuring the x and y photographic coordinates could be employed rather than simply measuring these coordinates with a scale, it is felt that more precise results could be obtained. If these photographs were enlarged more than approximately five diameters, the degree of error could perhaps be reduced, somewhat, but a point is soon reached where the resolving power of the lens, film, and paper is exceeded, and excessive graininess of the enlargements precludes accurate measurement.

It is felt that this method of map compilation should be very satisfactory wherever extreme accuracy is not necessary or in locations where only a few points need be precisely located and the remaining points or objects may be located with a lesser degree of precision. This is particularly true of areas which need be mapped during times when the weather is very inclement and prevents the carrying out of the standard field operations used in mapping at the present time. The photographs may be taken in the field in a very short period of time and the compilation work done in the office in relative comfort. Even though map compilation time is not greatly reduced by this method, the total time needed for the completion of a given map may be greatly reduced.

ACKNOWLEDGMENT

The author wishes to express his appreciation for the help and guidance which Professor John G. McEntyre has so willingly given in the preparation of this thesis.

LITERATURE CITED

(1) American Society of Photogrammetry
Manual of Photogrammetry, 2nd Ed.

(2) Talley, B. B.
Engineering Applications of Aerial and Terrestrial Photogrammetry, New York, Pitman.

(3) Church, E. and Quinn, A. O.
Elements of Photogrammetry, Syracuse, Syracuse University Press.

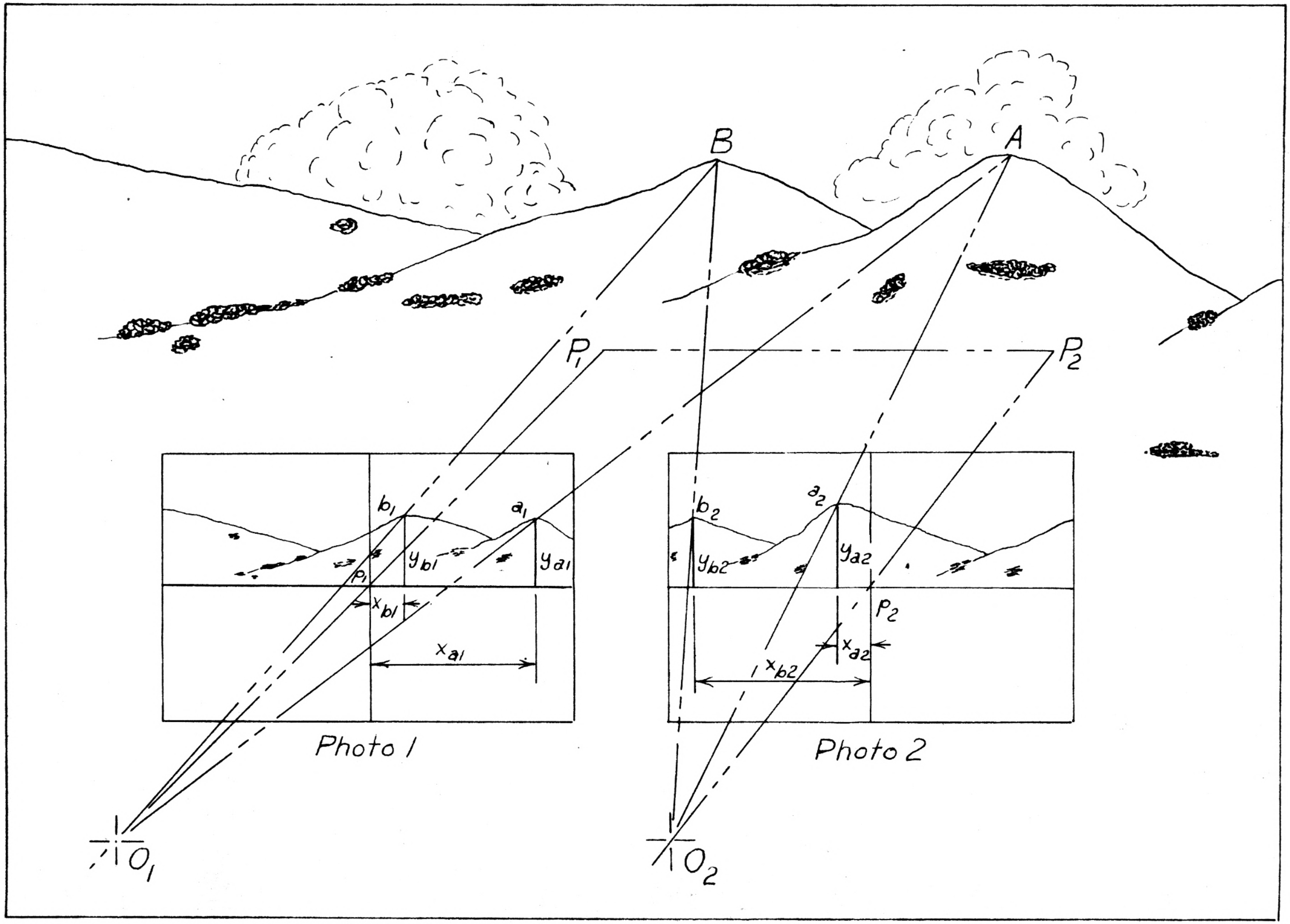
(4) Breed, C. B. and Hosmer, G. L.
The Principles and Practise of Surveying, Vol. II, Higher Surveying, New York, Wiley.

APPENDIX

EXPLANATION OF PLATE I

Sketch showing relationship between terrain and photographs of terrain.

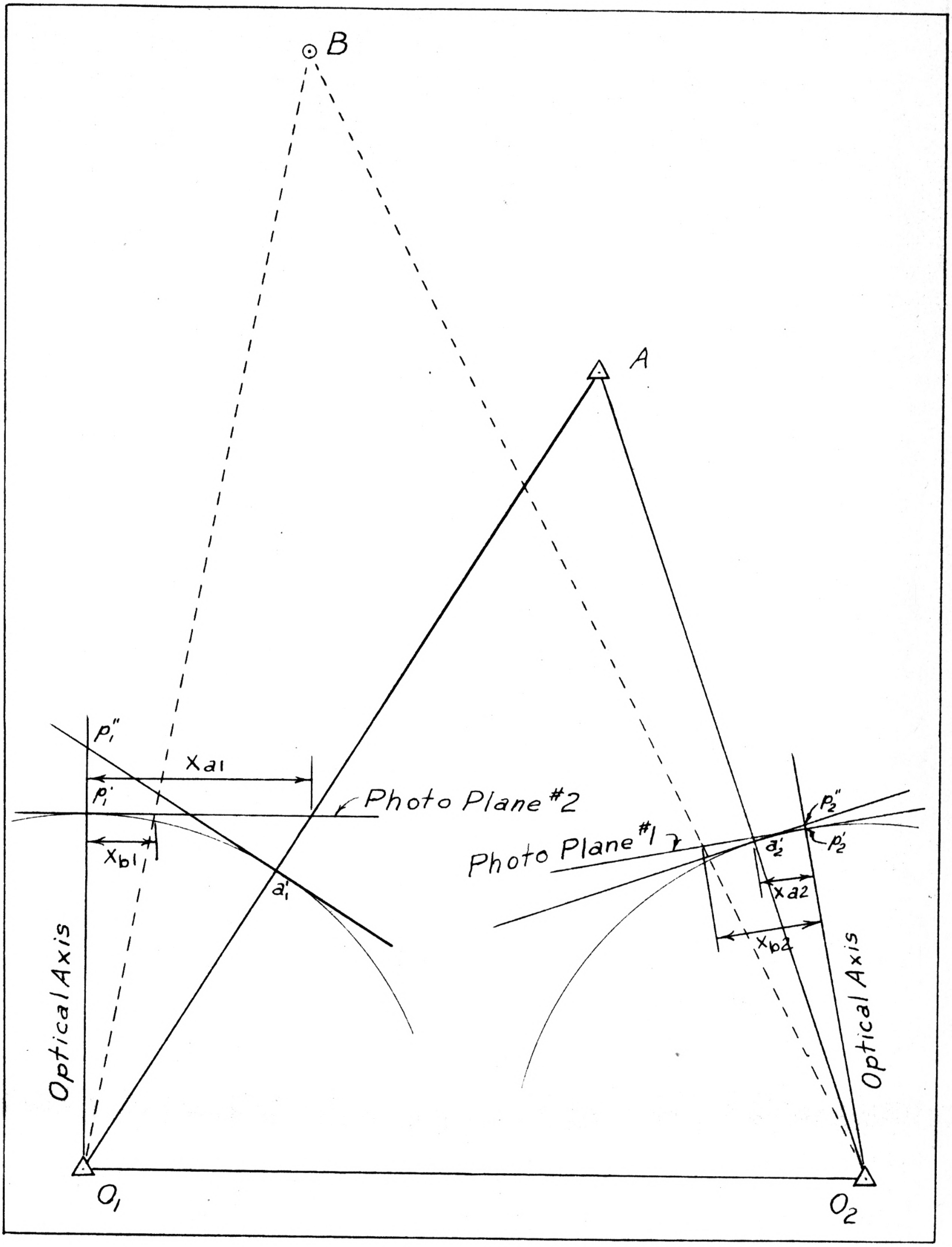
PLATE I


B
A
P1
P2
b1
a1
yb1
ya1
p1
xb1
xa1
Photo 1
b2
a2
yb2
ya2
p2
xa2
xb2
Photo 2
O1
O2

EXPLANATION OF PLATE II

Sketch showing method of orienting terrestrial photographs for map compilation.

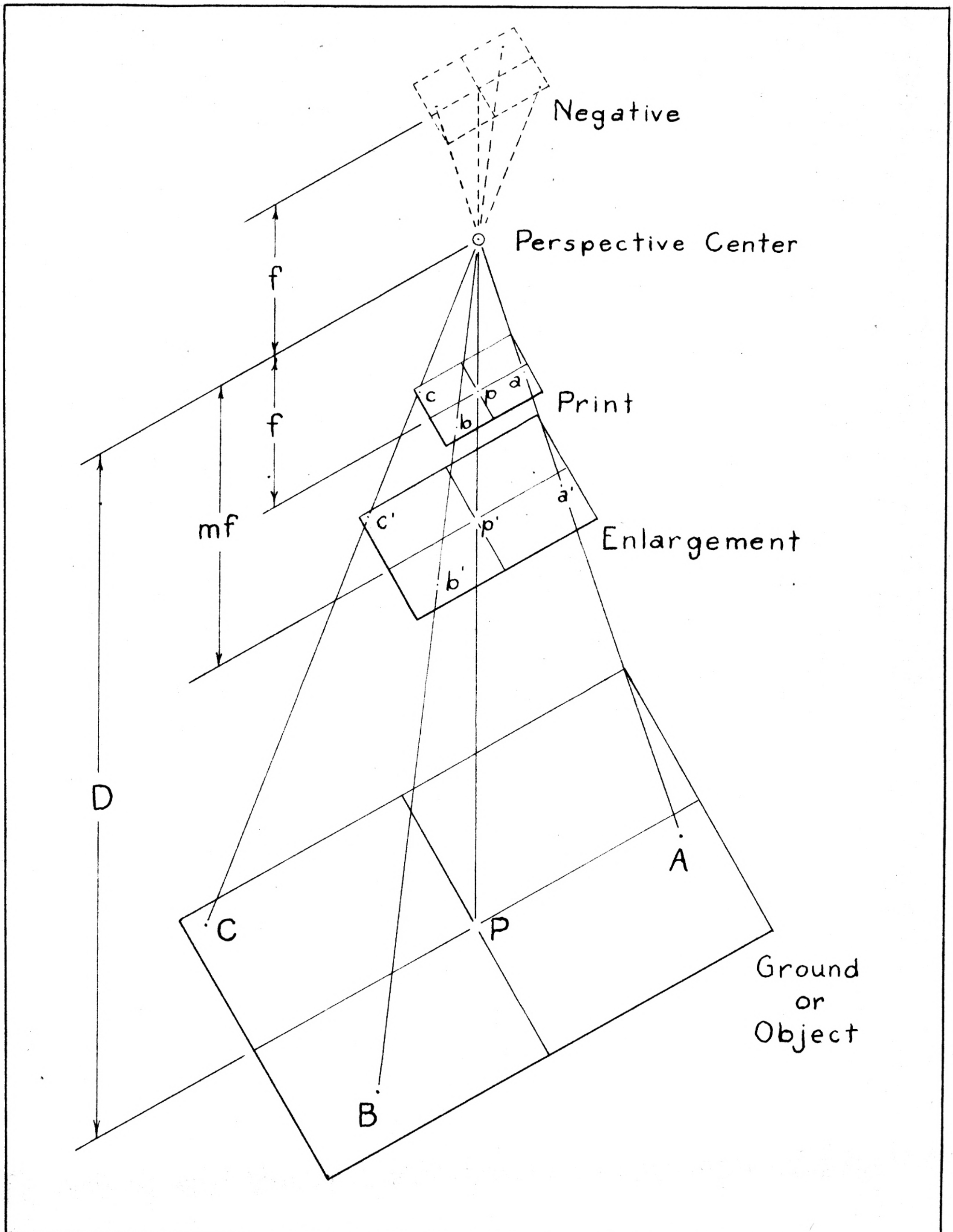
PLATE II


B
A
p_1''
X_{a1}
p_1'
Photo Plane #2
X_{b1}
a_1'
Optical Axis
O_1
p_2''
Photo Plane #1
a_2'
p_2'
X_{a2}
X_{b2}
Optical Axis
O_2

EXPLANATION OF PLATE III

Sketch showing relationship between ground, negative, print, and enlargement.

PLATE III


Negative
Perspective Center
f
f
mf
D
Print
c
p
a
b
Enlargement
c'
p'
a'
b'
A
C
P
B
Ground
or
Object

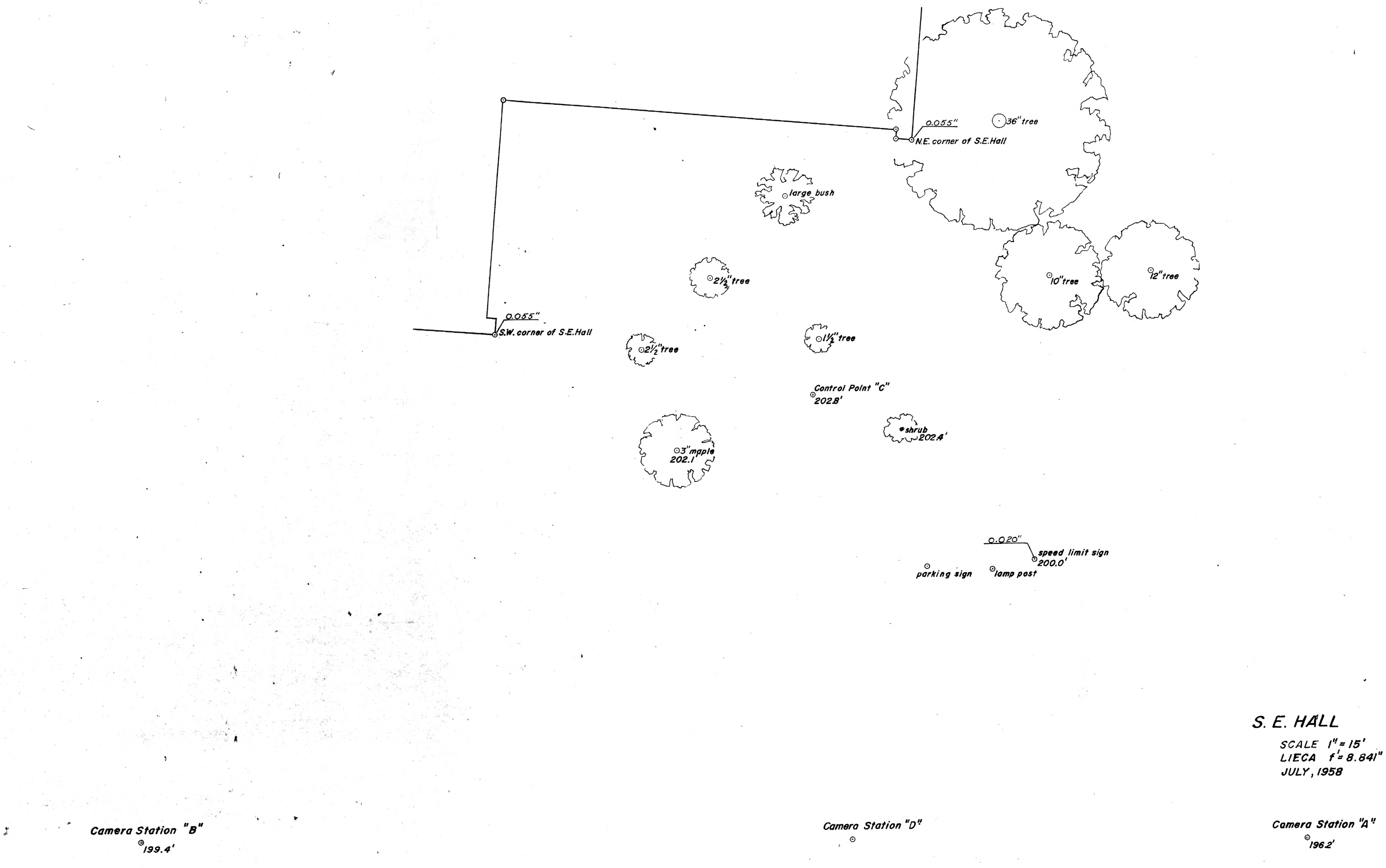


FIGURE NUMBER 1

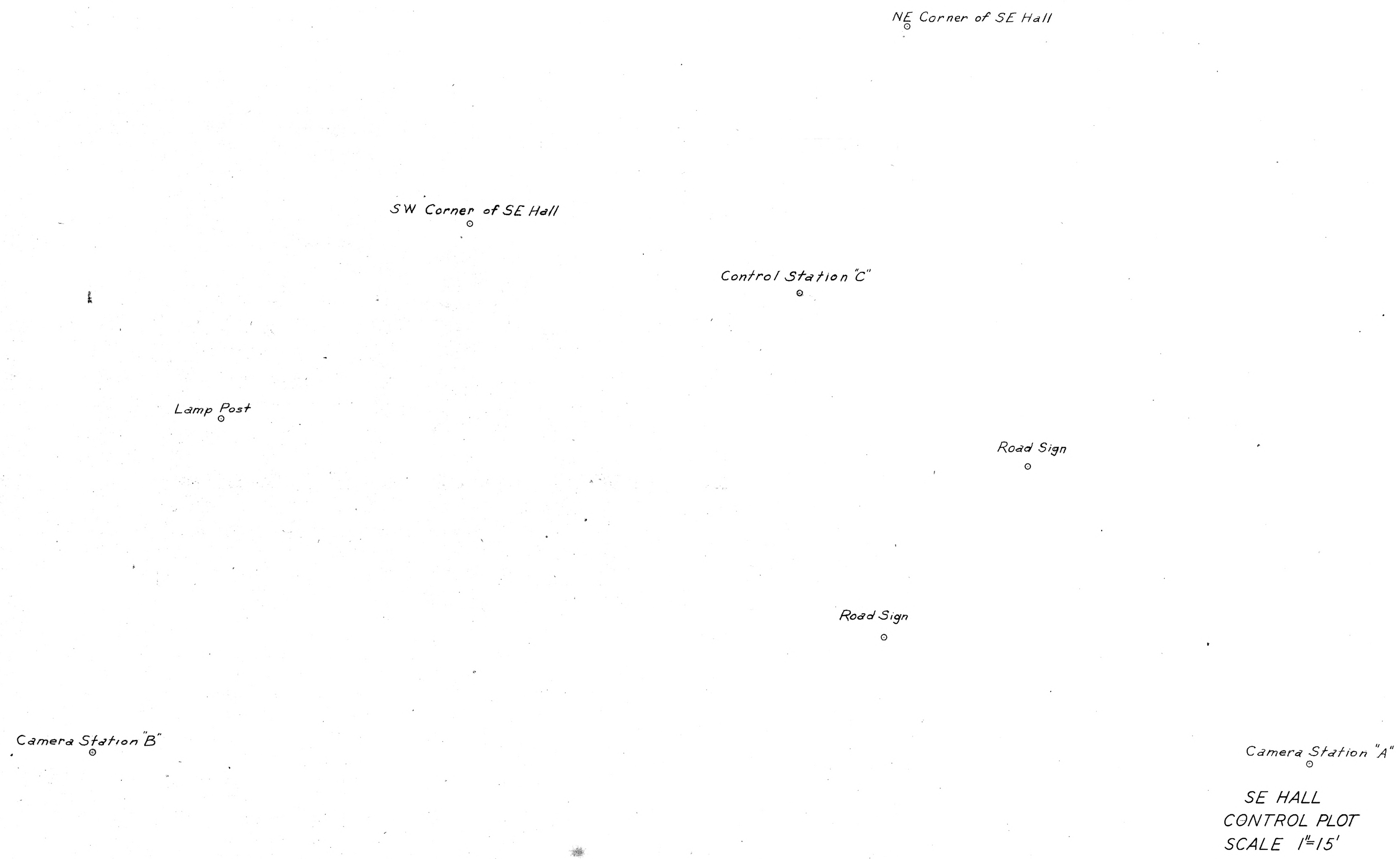


FIGURE NUMBER 2

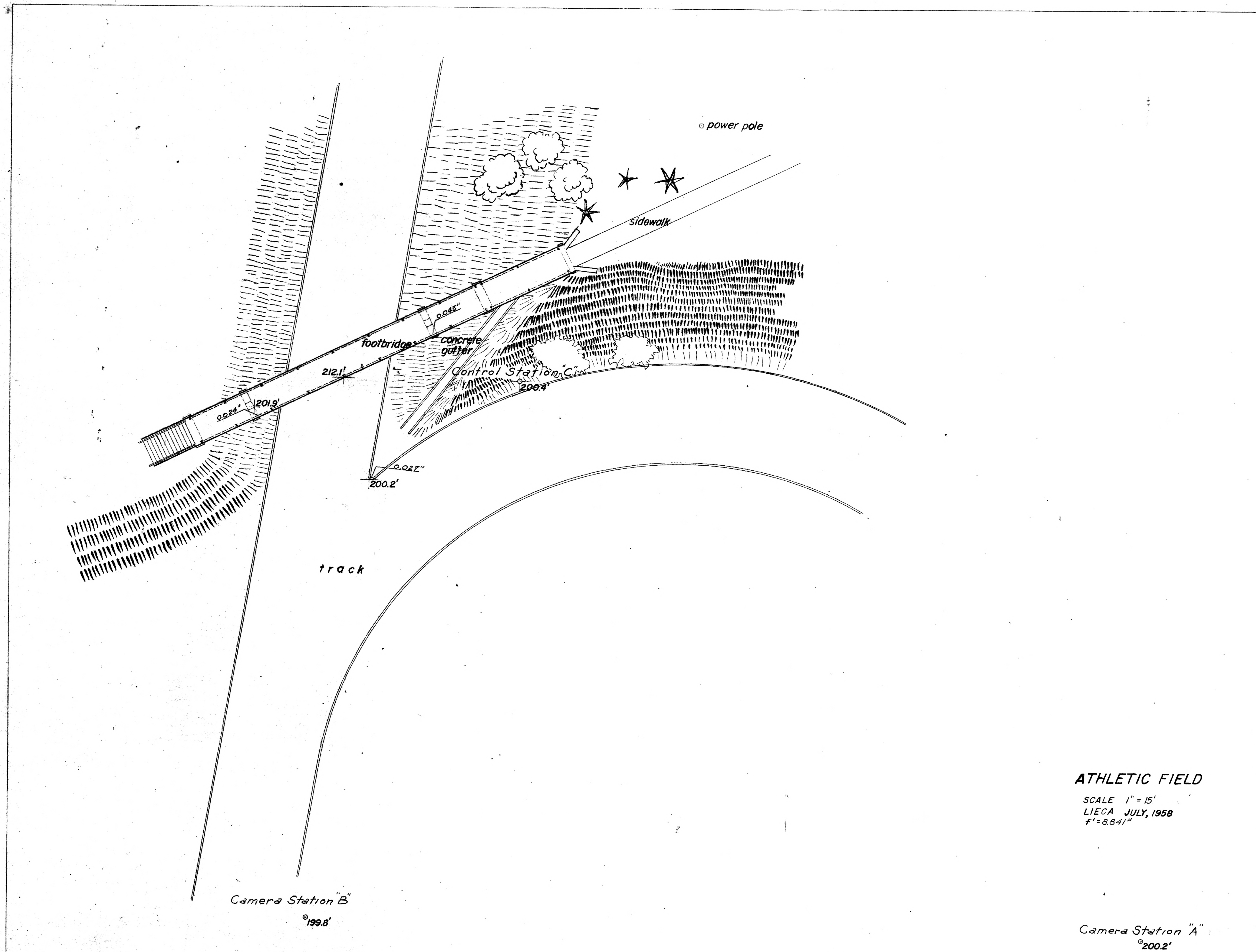


FIGURE NUMBER 3

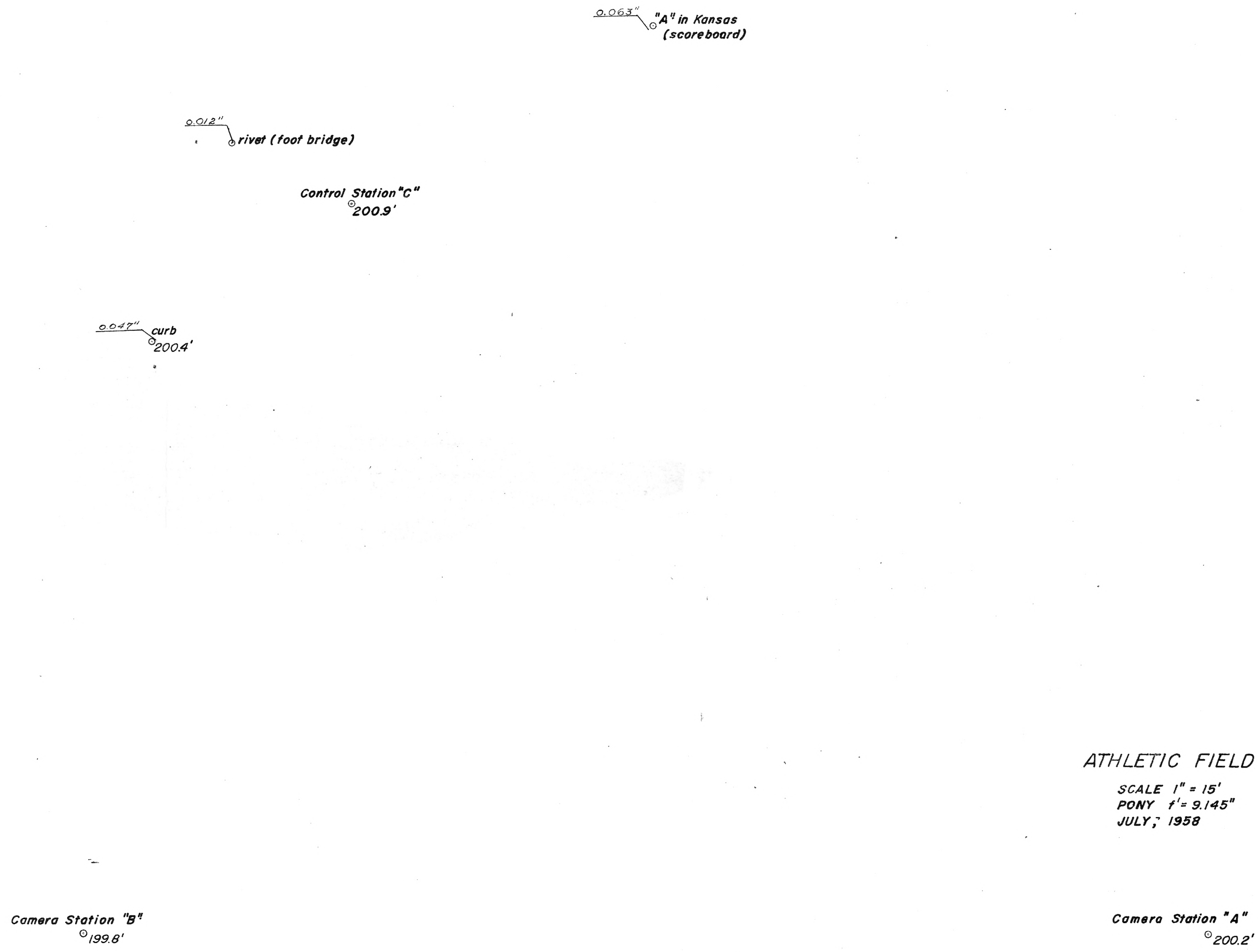


FIGURE NUMBER 4

FIGURE NUMBER 5

Figure Number 6

Figure Number 7

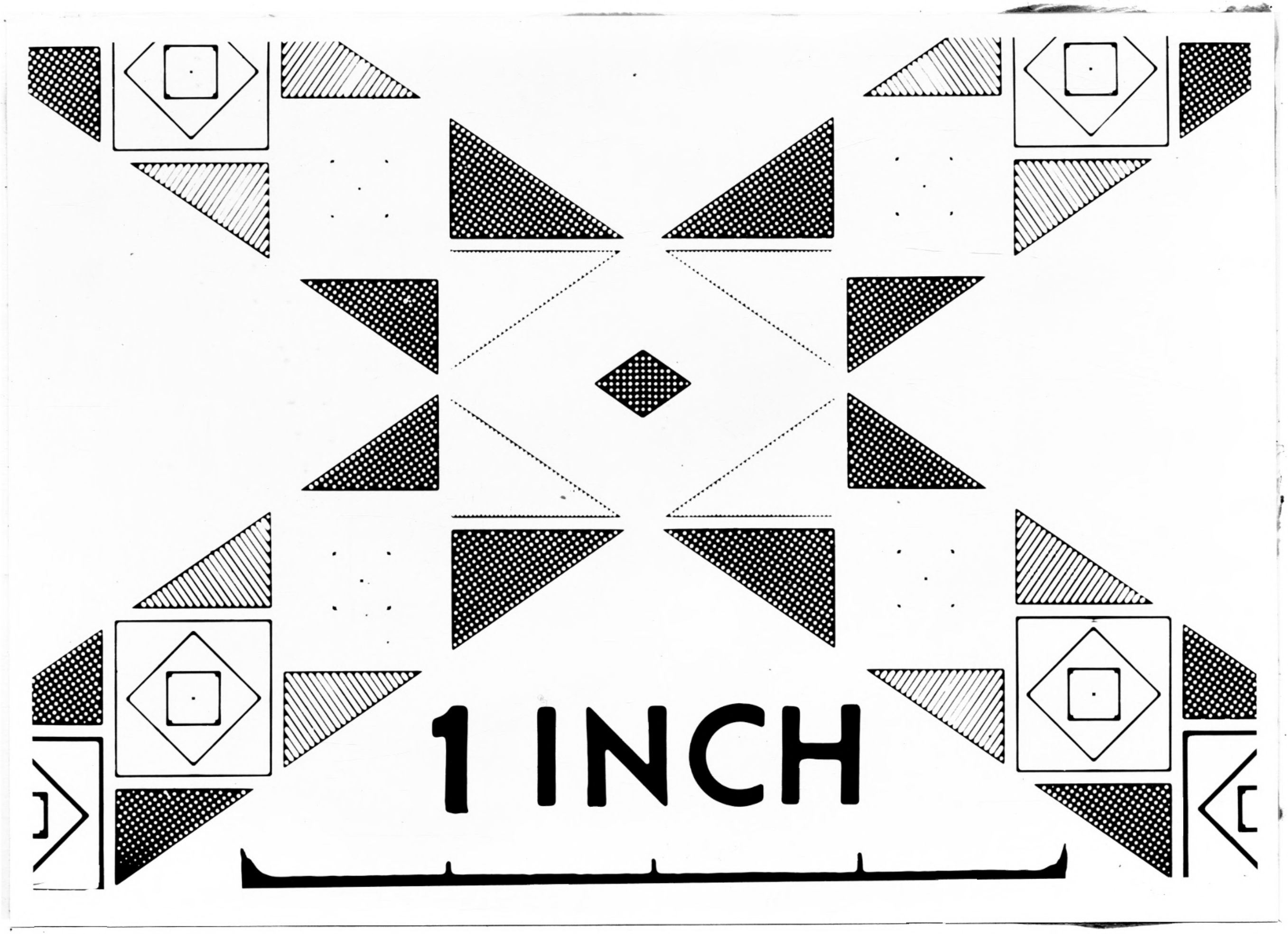


Fig. 8. Enlargement of focusing aid used for determining magnification factor.

Fig. 9. Typical photograph of the Riley County Hospital Site. Taken with the "Lieca" and used for map compilation.

Fig. 10. Typical photograph of the Riley County Hospital Site. Taken with the "Lieca" and used for map compilation.

Fig. 11. Typical photograph of the Riley County Hospital Site. Taken with the Kodak "Pony" and used for map compilation.

Fig. 12. Typical photograph of the Riley County Hospital Site. Taken with the Kodak "Pony" and used for map compilation.

THE USE OF STANDARD CAMERAS IN TERRESTRIAL PHOTOGRAMMETRY

by

RAYMOND NEWELL SHAW

B. S., University of Arkansas, 1955

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1959

It is often the desire of firms and individuals to obtain large scale maps of small areas quickly and cheaply. The use of aerial photographs is precluded due to the high cost of the auxiliary plotting equipment necessary and the relatively high cost of obtaining suitable aerial photographs. Terrestrial photographs or photographs taken from the ground may be used, but again the cost of the photo-theodolite ordinarily used for this sort of work may be excessively high.

In June of 1958, research was begun to determine if standard cameras might be used for mapping purposes. The term "standard camera" is meant to imply a camera which is readily obtainable at a fairly nominal cost and which may be used by the average person with a minimum of training.

Terrestrial photogrammetry was first employed by Laussedat in 1849 to prepare a map of Paris, France. Aerial photogrammetry superceded the terrestrial photogrammetry after World War I except in a few instances where terrestrial photogrammetry is still used for special problems.

The method used for compiling maps in this research was as follows: Photographs were taken in the field using two "35 mm." cameras, a Leice, and a Kodak "Pony." These photographs were then enlarged to four or five diameters for use in the map compilation work. Measurements were made on the photographs to determine the photographic coordinates of various points and these measurements transferred to the map compilation sheet in such a way as to enable the compiler to determine the horizontal position and elevation of the points with respect to other points whose positions were known.

Partial maps of three areas were prepared. The first areas selected were on the campus of Kansas State College near S. E. Hall and the Athletic Field. The third and final site was the area immediately west of Riley County Hospital. No attempt was made to plot all identifiable points or objects within these areas, but certain objects were selected as representative points which would indicate the degree of accuracy obtained. The maps prepared with the photographs taken with the "Leica" are more detailed than those taken with the "Pony" because it was felt that if results were satisfactory with one camera, a lesser number of points would be needed to check the second camera.

In all cases it was found that the cameras and methods utilized were satisfactory as long as extreme precision was not required. The maximum discrepancy in horizontal position on either of the final maps was 0.110 inch, corresponding to a ground distance of 4.4 feet. The maximum discrepancy in elevation on either of the final maps was 1.1 feet. While these discrepancies exceed those allowed by some mapping specifications, it is felt that they are within allowable limits for many purposes for which maps are prepared. It is also felt that the compilation procedure rather than the cameras was the source of some of the errors encountered.