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INVESTIGATION OF SELECTED IMAGERY FROM SKYLAB/EREP S190 SYSTEM FOR MEDIUM AND SMALL SCALE MAPPING

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1. INTRODUCTION

Canada's ten million square kilometers of land surface necessitates a continuous large mapping endeavour by the Topographical Survey Directorate, Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa. The utilization of satellite photography, such as that provided by the SKYLAB missions, was considered to be well worth a detailed study. The SKYLAB mission provided the opportunity to investigate satellite imagery with relatively high metric and resolution qualities for future possible applications in planimetric mapping at medium and small scales. The main mapping interests involve the potential usage of SKYLAB imagery for new and revision line mapping, photomapping possibilities and the application of this photography as control for conventional high altitude aerial surveys.

2. TECHNICAL APPROACH AND TASK DESCRIPTION

As a mapping agency responsible for the National Topographic Mapping Program, the Topographical Survey Directorate, Surveys and Mapping Branch, was primarily interested in conducting research studies on the SKYLAB/EREP photography for various mapping applications. The formal agreement between NASA and the Department of Energy, Mines and Resources to undertake this research was presented in the form of Exhibit "A", Statement of Work for the Investigation of SKYLAB/EREP Data, NASA Headquarters Proposal Registration No. 558 (see Appendix A). This proposal outlined the provisions identifying the services, tasks and deliverable products required of the Principal Investigator, the associated Co-investigators and their related organizations for the investigation and analysis of SKYLAB/EREP imagery. Specifically, the Technical Approach of Exhibit "A" proposed to conduct the following studies:

(1) the determination of ground resolution capabilities of the S190A system photography;

(2) the utilization of S190A photography for the production of planimetric line maps and photomaps at scales of 1:50,000, 1:100,000 and 1:250,000;

(3) the formation of photogrammetric models of the terrain using stereoscopic satellite photography;

(4) the establishment of exterior orientation of analytically formed models using satellite photography;

(5) the feasibility and accuracy attainable of using analytical aerial triangulation and numerical adjustments with satellite photography for planimetric mapping in northern Canada where control is sparse.

In performing these studies, glass and/or film diapositives were to be produced from both color and black and white originals. Photogrammetric mensuration and resolution evaluation was to be performed on each type of imagery received, with measurements achieved on comparators and the Analytical Plotter. The maximum number of models available were to be used for aerial triangulation and adjustment. The graphical line maps produced were to be evaluated against available redundant ground control and existing larger scale mapping (1:25,000). Photomaps, particularly of the Canadian hinterlands, were to be produced and evaluated for the purposes of mapping and map revision. Data from the S192 multi-spectral scanner was to be co-investigated by the Canada Centre for Remote Sensing, Department of Energy, Mines and Resources.

The Task Descriptions as outlined by Exhibit "A" required that the Principal Investigator should:

(1) assist NASA in mission planning activities related to the previously mentioned technical studies as well as provide guidance during real time EREP pass planning;

(2) be responsible for establishing scientific requirements and/or objectives for the studies being investigated and participate where required in the views related to the performance operation and data requirements of the investigation;

(3) conduct the supporting studies required to complete the designated investigations and prepare reports for NASA describing results and analysis of studies;

(4) be responsible for the reduction, analysis and interpretation of EREP data as outlined previously.

3. NARRATIVE HISTORY OF THE INVESTIGATION

As the SKYLAB/EREP missions progressed, it became apparent that the items listed in Exhibit "A" as part of the Technical Approach could not fully be realized as originally stated. The main test area selected for planimetric and aerial triangulation tests called for a strip of photography with 60% overlap extending from Windsor, Ontario to Quebec City. Although several earth sensing passes were attempted over the southern extremities of Canada during the SL-3 mission, the net result consisted only of cartographically usable imagery along a short stretch of the Manitoba-North Dakota boundary and several short passes of 2-5 images in Southern Ontario and in the Bay of Fundy area. The scheduled pass from Windsor to Quebec City could not be acquired, initially because of the problems resulting from the loss of solar panel and part of a heat shield and later because of adverse weather conditions. However, the several short passes of imagery mentioned were received in the Spring of 1974 and copies of the more useful passes were forwarded to the three Co-investigators involved in the mapping investigations.

In order to undertake as many as possible of the investigations listed in the Technical Approach of Exhibit "A", the three Co-investigators, were assigned research projects supervised by the Principal Investigator. These Co-investigators, funded by the

Topographical Survey Directorate, were as follows: (1) the Research and Development Section of the Topographical Survey Directorate, Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa; (2) the Department of Surveying Engineering of the University of New Brunswick, Fredericton, New Brunswick; and (3) the Department of Photogrammetry, Universite Laval, Quebec City, Quebec. Agreements in the form of official contracts, which specified that all investigations were to be carried out according to Exhibit "A" (Appendix A), were issued to the two outside research agencies in June 1973. It was not until June 1974, however, that suitable imagery became available to the Co-investigators. Six separate investigations were performed (see Chapter 4: TECHNIQUES AND PROCEDURES USED) by the Co-investigators: three quantitative and three qualitative studies.

The Topographical Survey performed one of the quantitative assessments - the determination of the planimetric accuracy of the S190A photography. This investigation was completed in October 1974. The accuracy attainable for horizontal control points determined by fully analytically aerial triangulation of SKYLAB S190A and S190B photography was ascertained by the Co-investigator at the University of New Brunswick in May 1975. The evaluation of S190A and S190B photography for the provision of supplementary control for mapping procedures and the determination of the accuracy with which this photography could be used to establish control for high altitude photography was undertaken by the Co-investigator at Laval University and the results were submitted in July 1975.

The three qualitative analysis on SKYLAB S190A and S190B imagery were also performed by the Topographical Survey Directorate. These investigations included: (a) the intercomparison of the quality of specific cultural detail between three sets of six-simultaneously taken images from the S190A system; (b) the map revision potential of S190A and S190B imagery for both urban and rural-recreational areas; and (c) the photomapping applications of SKYLAB imagery. The evaluations were completed in April 1975.

Separate Sub-reports were prepared on each of the six independent investigations by the Co-investigators in charge of each study. The contents of these reports form the substance of the overall investigation. Although the quantitative tests were performed by three separate agencies, similarities and consistencies in final results were obtained as will be shown later (Chapter 12: GENERAL CONCLUSIONS). Similarity of characteristics was also apparent in the qualitative tests as will be further shown.

4. TECHNIQUES AND PROCEDURES USED

In order to follow as closely as possible the specifics of the agreement of Exhibit "A", Technical Approach and Task Descriptions, the following six investigations were carried out by the Co-investigators identified in the previous chapter and monitored by the Principal Investigator:

I The planimetric accuracy of points determined from S190A photography was determined from (a) a single model of third generation, 70mm format, black and white diapositives, and (b) the same model but fourth generation, four times enlarged, black and white diapositives. Mensuration for this determination was carried out both on the Analytical Plotter AS11A and the Wild STK-1. Several independent adjustment procedures were applied to the data.

II Aerial triangulation was performed on several strips of four models each, twice on a selected black and white series and once again on a colour series of the S190A system, and also on a colour series of the S190B system. The Zeiss PSK was used for mensuration in all cases. After adjustment, residual errors were determined on redundant ground control.

III Another independent investigation was set up to evaluate S190A and S190B photography for the provision of supplementary ground control for mapping procedures, as well as determine the accuracy with which this photography can be used to establish control for high altitude aircraft photography. Measurements were performed on the Wild STK-1 and the adjustments were computed employing two separate techniques.

IV A qualitative intercomparison was made between three sets of six-simultaneously taken images from the S190A camera system. Image quality for specific cultural detail required for mapping was rated for clarity on a scale devised by the investigator.

V The map revision potential of both S190A and S190B imagery was evaluated for (a) urban areas and (b) rural-recreational areas. Selected models of both black and white and colour imagery were evaluated using the Wild B-8 Stereoplotter and the Bausch and Lomb Zoom Transferscope.

VI The photomapping applications of both SKYLAB S190A and S190B were investigated and compared against photomaps produced from standard aerial photography and ERTS imagery at a scale of 1:250,000. Sample photomaps were produced of all these systems at the scale of 1:250,000.

As can be seen by the preceeding, the investigations eventually undertaken differed somewhat from those originally stipulated in Chapter 2: TECHNICAL APPROACH AND TASK DESCRIPTION. These differences were unavoidable due mainly to the relatively small sample of imagery received. The investigation was extended to include tests on imagery from the earth terrain camera S190B. Another primary difference between the originally designated tasks of the Principal Investigator and those actually carried out was the eventual establishment of another Principal Investigator at the Canada Centre for Remote Sensing to complete the independent study on imagery from the S192 multispectral scanner. A separate report on this investigation will be produced by the Canada Centre for Remote Sensing. Otherwise, the Technical Requirements and Task Description outlined in Exhibit "A" were followed as closely as possible and are described in the detailed chapters on the six separate investigations.

5. GENERAL REMARKS ON SKYLAB DATA ACQUISITION

To conduct the tests originally outlined by Exhibit "A", the SKYLAB coverage requested included a well controlled strip extending from Windsor, Ontario to Quebec City. Unfortunately, this imagery was unattainable. Suitable imagery for the proposed investigations was not made available until Spring 1974. The imagery that eventually reached the respective Co-investigators consisted of several small sets of third and fourth generation photography forming strips of four to five models each. The second generation imagery received by the Principal Investigator was retained and stored in Ottawa at the National Air Photo Library. Thus, third and fourth generation products, generally in the form of film diapositives, were produced and forwarded to the various co-investigators so that individual investigations would not be further delayed. Orbital information associated with the actual imagery was quite complete.

Although pre-flight scientific specifications for the respective cameras were made available to the Principal Investigator, very little actual precise camera calibration data, necessary for analytical photogrammetric work, was available as the experimentations began. A number of assumptions regarding calibration were made in order to get the investigations underway. These various assumptions and their implications to the experimental data acquired are separately reported for each investigation. On the whole, subsequent receipt of Pre-flight Baseline Data of the system proved most of the assumptions to be relatively valid. However, a precise definition of the position of the photogrammetric principal point was one factor which remained quite uncertain.

It must be noted that NASA was very prompt in forwarding available SKYLAB literature and information at all times. Unfortunately, most of these data, although informative and useful in many aspects, were not sufficient to furnish the complete precise camera data essential for analytical photogrammetric studies.

A detailed list of the actual imagery and complementary SKYLAB/ EREP data employed in each separate investigation will be included in the respective summaries of the six individual studies.

6. INVESTIGATION I: DETERMINATION OF PLANIMETRIC ACCURACY OF POINTS ESTABLISHED ON SKYLAB S190A PHOTOGRAPHY

6.1 Technical Approach and Task Description

The objective of this investigation was to determine the planimetric accuracy of supplementary control points on photography from the SKYLAB S190A Camera system. Similarity and projectivity transformations were performed on data derived from observations on the Wild STK-1 of fourth generation enlarged photography as well as on third generation small scale 70mm diapositives. Three dimensional transformations were also applied to both sets of data.

6.2 Photography used for Investigation I

Two sets of photo material were selected for the investigation: (a) third generation, 70mm format, black and white diapositives of photos 314 and 315 of roll #47, Orbit 52 dated 21 September 1973 and (b) fourth generation approximately 4X enlarged black and white diapositives of the above exposures. The photo pair was selected from camera station number 5 because it had the best estimated ground resolution of the 6 stations, with an expected resolution of 30 to 38 meters. The selected photo pair forms a model covering a large area of northeastern Nova Scotia and part of New Brunswick. Approximately one-third of the image area of each photo is water (Bay of Fundy) and the land area is heavily forested, especially on the New Brunswick side. The effects of these features combine to make very dark appearing diapositives but with adequate density and contrast to allow reasonable point identification and mensuration.

The Mapping and Charting Establishment (M.C.E.) of the Canadian Armed Forces aided in the mensuration work in this investigation. Photogrammetric quality tests, performed by M.C.E. (see attached M.C.E. Report Appendix B.4), showed pockets of residual parallex at the completion of relative orientation. M.C.E. was the only agency that performed an optical-empirical relative orientation on the photography.

6.3 History of Investigation I; Discussion of Techniques and Procedures

The preparation for the mensuration was carried out entirely on the enlarged diapositives and paper prints of these diapositives. Thirty-five (35) well distributed photo-identifiable road intersections were selected on each photo, with approximately half of these points being common to both photographs. Attempts to transfer these identities to the 1:50,000 map sheets obtained for the co-ordinate derivation proved impossible in many instances as several road systems were non-existent on the available map sheets. The reverse process was then applied wherein the identities on the map sheets were transferred to the photos and diapositives. This was a time consuming and not entirely successful procedure as, in order to maintain good point distribution, some less than well-defined intersection transfers had to be accepted. A total of forty-seven (47) road intersections were finally chosen with thirty-one (31) of these points appearing on Photo 314, thirty-five (35) on photo 315 and nineteen (19) appearing in the common overlap. (See Appendix B.3 for identification of these points.) Ground control co-ordinates were derived by romer measurements (Appendix B.3-a). Since grid sizes vary according to the date and method of printing the map sheets, no map derived co-ordinates could be assumed to be better than ±20 meters.

Two photogrammetric instruments were used on the project:

a. The Analytical Plotter AS11A (M.C.E.) performed a computer-assisted optical-empirical relative orientation. The output of this instrument was model point co-ordinates of the 4X enlarged, 24" focal length, diapositives.

b. The STK-1 of the Topographical Survey Directorate provided plate co-ordinates of both the 70mm, 6" focal length, and 4X enlarged, 24" focal length materials.

The original assignment was to perform both Similarity and Projectivity transformations to STK-1 data obtained from observations on 4X enlarged diapositives. Nine to twelve peripheral points were chosen on each photo, with the remaining points used as check points. This requirement was later expanded to include a similar procedure using the very small scale 70mm diapositives; and also to include 3-Dimensional transformations on both sets of data.

The data derived from all sources were processed as follows:

a. Data of Analytical Plotter AS11A (see Appendix B.4)

(1) 3-Dimensional transformation of 4X enlarged, 24" focal length material only. The Program used to perform the transformation was the well-known Shut Strip Polynomial Adjustment of the National Research Council of Canada.

b. Data of the STK-1 (the original and enlarged formats were processed separately).

(1) 2-Dimensional Similarity transformations to reliable ground control.

(2) 2-Dimensional Projectivity transformations to reliable ground control.

(3) 2-Dimensional, 9-Point Similarity transformations to peripheral control selected from reliable points.

(4) 2-Dimensional, 9-Point Projectivity transformations to peripheral control.

(5) 3-Dimensional transformations to reliable control.

The data for the Similarity and Projectivity transformations was provided by employing programs developed by the Research and Development Section of the Topographical Survey Directorate, and the 3-Dimensional transformation was computed by using the Stuttgart Adjustment Program PAT-M-43.

A summary of the final results of the above transformations is shown in Appendices B.1-b and B.1-c together with the pre-adjustment corrections applied (Appendix B.1-a).

Each adjustment was performed using the normal procedure at Topographical Surveys of including the apparent reliable ground control points until an optimum solution is found. The criteria for rejection or inclusion is based entirely upon the magnitude of the residuals following each trial adjustment.

6.4 Ground Truth Activities of Investigation I

All ground control coordinates were map-derived from existing topographical maps of scale 1:50,000. These coordinates are known to be no better than ±20 meters.

6.5 Problems Encountered during Investigation I

At the beginning of this project, very little precise calibration data with respect to the S190A camera system was known. Therefore, in order to get the project underway, a number of assumptions were made. These assumptions, together with the available hard data furnished by NASA, were as follows:

a. Focal length, 70mm format - six inches
   Focal length, 4X enlarged format - 24 inches
b. Flying height - 425 kilometers or 264 miles. This height was derived from the orbital information on the pass.
c. Photo scale 70mm format - 1:2,800,000 approximately
   Photo scale enlarged format - 1:700,000 approximately
d. Lens distortion - assumed nil
e. Reseau origin - assumed co-incident with principal point
f. Atmospheric refraction - assumed nil
g. Film distortion - assumed nil.

Subsequent receipt of SKYLAB Pre-flight Baseline Data of this system proved the assumptions to be reasonably valid. The maximum lens distortion was 0.8μm, calibrated reseau intersections correct to 1μm, and an effset of the optical axis with respect to the centre reseau intersection was 7μm in X and 16μm in Y.

As mentioned in Section 6.3 on the History of Investigation I, there were also problems involved in the identification and transferral of reliable road intersections for ground control both from photo to map and map to photo. However, after considerable delay, forty-seven points were established for observation.

6.6 Discussion of the Results of Investigation I

The results of the adjustments outlined in Section 6.3 indicated immediately that certain anomalies contained in Photo 314 of the small scale 70mm, 6" focal length diapositives could not be resolved by the 2-Dimensional transformations (Appendix B.1-b).

The Projectivity (8-parameter) solution was significantly better than the Similarity (9-parameter) solution but large residuals, especially at the non-used control points, remained.

The 3-Dimensional transformations again produced inferior results from the small scale 70mm photography but achieved particularly good solutions using the enlarged diapositives - especially in the PAT-M-43 adjustment where the model was formed numerically from comparator observations (Appendix B.1-c). The slightly inferior results of the Analytical Plotter tests could be attributed to its inability to measure directly to one micron and the optical-analytical method of model formation. In both cases, it was significant that only a very small number of the common model points were withheld from contributing to either solution and in the case of the Analytical Plotter adjustment, no reliable horizontal control points were withheld and only one vertical point was unused.

Error distribution throughout all adjustments appeared to be of a systematic nature with the largest deviations occuring at check-points near the edges of the photographs. Photo 314 showed the greater deviations.

The final horizontal positional errors of the adjustments were reduced to the displacement in inches at map scale of 1:250,000 and assigned a tentative map classification to each under NATO Circular Map Accuracy Standards. While recognizing that the classification assigned could only be approximate, this method provided a reasonable indicator of planimetric accuracy achieved (Appendix B.2).

On the whole, these adjustment results indicated several broad points:

a. Reliability of planimetric assessment could only be good on photos containing an adequate number of well-distributed, well-identified ground points. Reliability would decrease in remote areas having less well-defined map detail.

b. Instrument operators adapted quickly to observation of small scale photography as used in this investigation.

c. Enlargements to approximately 4X format offered the best mensuration possibilities which in part accounted for the better results achieved.

d. The 3-Dimensional transformations from the 4X enlargement provided the best overall results.

6.7 Conclusion to Investigation I

The results obtained indicate that photo products from the S190A system are capable of satisfying planimetric accuracy requirements at scales of 1:250,000 and smaller. In the case of the 3-dimensional adjustment of the enlarged model, 1:50,000 planimetric accuracy requirements were satisfied. These results were obtained from only a single model, but they lead one to believe that, given well-distributed, well-identified ground control, 4X enlarged diapositives, and good calibration data, planimetric accuracies adequate for Class B 1:50,000 mapping (NATO Specifications) are obtainable. Note that generally superior results were obtained from the 4X enlarged diapositives. The 2-dimensional adjustments did not account for the relatively large, systematic error input of photo 314. This points up the difficulty of assessing photography with such anomalies in areas that have little or no reliable ground control.

6.8 Recommendations from Investigation I

1. The method of adjustment to ground control of imagery from the S190A camera system or future similar systems should be in 3-Dimensional from analytically formed independent models.

2. Prior to any future space missions incorporating satellite photography, a method of targetting of known ground control points should be devised. Such a method could take the form of the parabolic mirror system which was employed with the ERTS photography or a type of optical targetting using high powered laser beams and prisms.

7. INVESTIGATION II: HORIZONTAL CONTROL EXTENSION WITH SKYLAB/EREP IMAGERY

7.1 Technical Approach and Task Description

The objective of this investigation was to ascertain the accuracy attainable for horizontal control points determined by aerial triangulation with the SKYLAB/EREP S190 system photography. A fully analytical procedure was employed for the aerial triangulation. The following items were computed and included in the analysis: standard error of the observations; accuracy of the relative orientation; root mean square error of the model coordinates; standard deviation of unit weight of the adjustment; the fitting accuracy to the ground control; and the root mean square error of discrepancies at check points. Four separate strips of photography were investigated.

7.2 Photography used for Investigation II

The four strips of photography used in this investigation were as follows:

a. Strip 1 and 2

Mission: 3, Sensor: S190A, Orbit. 52, Flight Date: 9/21/73

- Roll 47, Pan-X Black and White, Frames: 312, 313, 314, 315, 316
- Roll 46, Aerial Colour, Frames: 312, 313, 314, 315, 316

The geographic location of the coverage is Southern New Brunswick, Bay of Fundy and North-Western Nova Scotia in Canada. The approximate scale of the photos is 1:2,774,000.

b. Strip 3

Mission: 3, Sensor: S190A, Orbit: 14, Flight Date: 8/5/73 - Roll 23, Pan-X Black and White, Frames: 183, 184, 185, 186

The geographic location of the coverage is South Eastern Michigan, U.S.A. and South Western Ontario, Canada. The approximate scale of the photographs is 1:2,861,000.

c. Strip 4

Mission: 3, Sensor: S190B, Orbit: 14, Flight Date: 8/5/73 - Roll 83, Aerial Colour, Frames: 149, 150, 151, 152, 153

The geographic location of the coverage is South-Eastern Michigan, U.S.A. and South-Western Ontario, Canada. The approximate scale of the photographs is 1:955,000.

7.3 History of Investigation II; Discussion of Techniques and Procedures

The investigation of the four strips was performed in the order listed in Section 7.2: Photography used in Investigation II.

A large number of points was selected and marked on each strip. The image coordinates of these points were measured in a Zeiss PSK stereocomparator under 8 times magnification. The measurements of Strip 1 (Roll 47) and Model 1856 of Strip 3 (Roll 23) were performed in two independent sets. Appendix C.1 lists the standard error of one measurement as computed from the double measurements.

Next, independent models were formed in each strip with the Analytical Strip Triangulation Program NRC-34 of the National Research Council of Canada. Correction was applied for earth curvature and atmospheric refraction. All points measured in a particular stereo pair were included in the relative orientation. The accuracy of the model formation is indicated by the standard errors of the intersection of corresponding rays, which were computed from the residual parallaxes after relative orientation, (Appendix C.2). The maximum values for the residual parallaxes are also listed.

Finally, the models were assembled into strips and subjected to rigorous simultaneous adjustment to ground control points. The Stuttgart Adjustment Program PAT-M 43 was employed for this purpose.

Two sets of control points were used for the adjustment of Strip 1 (Roll 47). The first set contained 43 points distributed over the entire strip and the second set consisted of nine points with a band of three points being located at the beginning, the middle and at the end of the strip. Strip 2 (Roll 46) was adjusted only with the nine control point configuration. Two of the models in each strip were also adjusted separately. In each case four control points were employed.

Strip 3 (Roll 23) was adjusted with six ground control points, with a band of three points being located in the first and the last model. Two of the models were also adjusted separately with four control points each.

Strip 4 (Roll 83) was adjusted with nine control points, with a band of three points located at the beginning, the middle and at the end of the strip. All models were also adjusted separately with four control points each.

At all points that were not used for the adjustment, the discrepancies were formed between the map coordinates and the photogrammetrically determined coordinate values and then the root mean square error (RMSE) of the discrepancies was computed. Points which showed a discrepancy larger than three times the RMSE were rejected and excluded from the computation of the final RMSE value. Appendix C.3 lists for each test case the total number of check points available, the number of points rejected and the RMSE of the X and Y coordinates at ground scale in meters and at image scale in millimeters.

The following additional statistical tests were performed and are listed in Appendix C.4;

- Root mean square error of all model points, i.e. transfer points, perspective centres and control points. This value represents the internal accuracy of the model or strip.
- Standard deviation of a model coordinate with unit weight.
- The fitting accuracy, which is the root mean square error of the differences between the given value of a ground coordinate used for the adjustment and the transformed photo coordinate of the same point after adjustment.

7.4 Ground Truth Activities of Investigation II

No field measurements were conducted in this project. The coordinates of the ground control points were measured on topographic maps in a coordinatograph. For Strips 1 and 2 the maps scale was 1:50,000. For Strips 3 and 4, 1:24,000 scale maps were used over Michigan and 1:25,000 scale maps over Ontario. Road intersections outside densly populated areas and prominent points along the coastline and shore-line were selected as control points.

7.5 Problems Encountered during Investigation II

It was discovered that the calibration data of the S190A camera system, as published in the "Sensor Performance Report MSC-05528 (SL2), Vol. 1, 7.2 Geometric Distortion Evaluation", were not useable for defining the various image refinement parameters, customarily employed in analytical photogrammetry, for the following reasons:

- The calibration of the lenses for radial and tangential distortion was performed with a different lens-reseau configuration, than the one used in flight.
- The image coordinates of the principal point were not provided. The principal point of autocollimation specified in "Skylab Instrumentation Calibration Data, Vol. IV, MSC-07744, Revision B, Table 2.4.3" is not equivalent to the principal point as used in photogrammetry. The former is "the image formed by the camera lens when a parallel pencil of rays, which in object space is perpendicular to the image plane, enters at the exterior perspective centre", while the latter is defined as "the foot of the perpendicular from the interior perspective centre to the image plane".
- The calibrated value of the principal distance is specified to the nearest 0.001 inches, (Report MSC-07744, Review B, Table 2.4.3) which is equivalent to 25 μm. This accuracy is generally inadequate for precise analytical photogrammetric work.

Consequently, it was impossible to correct the measured image coordinates for radial and tangential lens distortion and for deformation of the emulsion base; the measured image coordinates had to be referenced to the centre reseau mark rather than to the principal distance used in the computations is questionable. These factors, no doubt, affected the internal accuracy of the triangulation.

The main problem encountered during the investigation of the S190B photography was in determining the exact location of the principal point. This camera has only two fiducial marks and the origin of the image coordinate system had to be established by the intersection of the frame diagonals. The location of the principal point was then defined with reference to this system in accordance with the data given in the calibration report.

It was rather inaccurate to define the principal point in this manner since the frame corners were somewhat rounded and could not be measured accurately. This was especially true of the corner where the clock data block was located. This difficulty could have been eliminated by manufacturing the camera with four standard fiducial marks on the focal plane frame.

7.6 Discussion of the Results of Investigation II

With reference to Appendix C.1, the precision of the measurements can be regarded as excellent, considering that natural features were observed. It should be emphasized, however, that this value indicated the precision by which the same spot was located twice in the same model. A more critical and difficult part of the data acquisition was to locate the same point in a neighbouring model and to correlate the image points with the map points.

With reference to Appendix C.2, the accuracy of the relative orientation was satisfactory and corresponded to expectations based on the precision of the measurements. The results obtained for the four strips are rather similar.

The results shown in Appendix C.4 proved that the internal accuracy of the strip was very good and compared favourably with accuracies attainable with conventional aerial photography. The largest values for the RMSE of model points and the standard deviation of unit weight occurred in Strip 2 (Roll 46). The accuracy improved in Strips 1 and 3 and the smallest errors were obtained in Strip 4 (Roll 83). The varying accuracy of point identification is the probable explanation for these varying results.

The terrain shown in Strips 1 and 2 is largely forest covered and easily identifiable features were in short supply. A bluish haze was evident on the colour photographs of Strip 2, which dimenished the contrast somewhat and decreased the resolution of the image. Strips 3 and 4 on the other hand covered mainly open terrain and urban areas, with a dense road pattern, so that the selection of easily identifiable targets was no problem. The high resolution of the S190B photographs of Strip 4 further improved the identification accuracy.

The adjustment of the strips to ground control proved satisfactory in all cases.

Appendix C.3 indicated that the RMSE of the coordinates at check points ranged from 12 μm to 31 μm at the scale of the image. Such results can be regarded as excellent, considering the fact that all control and check points were natural features and that the ground coordinates were obtained from 1:50,000 and 1:24,000 topographical map sheets. Under the circumstances, errors of 20 to 25 meters could have easily occurred in the identification of points and some of the ground coordinates could be in error by as much as 10 μm at the scale of the image. No doubt, the results could have been improved by more stringent point selection, by devising some form of targeting for the points (such as parabolic mirrors) and by employing ground survey techniques for the determination of the ground control.

7.7 Conclusion of Investigation II

As expected, Strip 3 (Roll 23) showed the best results since it was taken with the metric camera system. Most points selected were easily identifiable and the ground control data was more reliable because of the larger scale maps available in this area. At ground scale, however, Strip 4 had the highest accuracy. Apparently, the larger scale image provided by the S190B camera has more than offset the lower precision of the internal geometry. From a practical point of view, these results were the most significant since it proved that it is possible to establish ground control coordinates with an accuracy of 15 to 20 meters with space photography. It should also be noted that Strip 4 covered a large area of 200 km by 110 km and was controlled by only nine ground points.

With reference to Appendix C.3, the results obtained indicated that both the S190A and S190B Camera Systems are capable of satisfying certain NATO planimetric accuracy standards. Strip 4 (S190B) yielded the best results in that the requirements for 1:250,000 Class A specifications were far exceeded as well as Class B specifications for 1:50,000 mapping. Strip 3 (S190A, 0.6-0.7 μm, Black and White) also exceeded the accuracy requirements for Class A 1:250,000 mapping and bordered on those for Class B 1:50,000 standards. Strips 1 and 2, with slightly inferior results still met the specifications for planimetric accuracies of Class A mapping at scales of 1:250,000 and smaller.

7.8 Recommendations from Investigation III

1. A more comprehensive investigation of aerotriangulation with space photography should be considered in future satellite missions. Systematic uninterrupted photo coverage of large areas of the North-American continent at 60% or 80% overlap should be planned for this purpose to permit the triangulation of large blocks of photographs.

2. A long focal length, large format metric camera is more suitable for aerotriangulation than a short focal length multispectral camera, therefore such an instrument should be part of any future space photography mission.

3. Four standard fiducial marks should be established in future satellite camera systems to allow for better calibration conditions and a more precise means of establishing the principal points of the photographs.

4. A study should be conducted to devise some feasible method of targetting ground control points.

8. INVESTIGATION III: THE POTENTIAL OF EMPLOYING SKYLAB/EREP PHOTOGRAPHY AS CONTROL FOR HIGH ALTITUDE AIRCRAFT PHOTOGRAPHY

8.1 Technical Approach and Task Description

The main objective of this investigation was to determine the utility of SKYLAB photography in achieving the maximum possible accuracy for establishing control for either 1:50,000 or 1:100,000 scale maps. Various approaches which might improve the accuracy were investigated such as: (a) the correction of systematic image errors; (b) the use of imagery from more than one channel of the S190A multispectral camera system; (c) the incorporation of SKYLAB orbital parameters as a camera positioning device in a bundle adjustment; (d) the combination of several strips or blocks of high altitude aircraft photography with SKYLAB photography; and (e) the use of several combinations of available ground control for an adjustment of the photography.

8.2 Photography Used for Investigation III

The following groups of SKYLAB photography were employed for the investigation:

a. Sensor S190A, Orbit 52, Rolls 47 (312-316) and Rolls 48 (312-316). These photographs covered an area of the Atlantic Provinces, Canada.

b. Sensor S190A, Orbit 14, Rolls 23 (183-186) and Rolls 24 (183-186). These photographs covered the area of Lake Saint-Clair and Windsor, Ontario in Canada and parts of the States of Michigan Ohio and Pennsylvania in the U.S.A.

High altitude photography consisting of a block of four strips of six photographs each and covering an area in the State of Michigan was available for test purposes. These photographs had been taken in conjunction with the LANDSAT-1 mission and had the following specifications:

- An RC-10 camera with a 6 inch focal length. The film type was aerochrome infrared 2443 with a bandwidth of 0.510 - 0.990µm. The photography was flown 15 October 1972 at an altitude of 19.8 kilometers above mean sea level.

8.3 History of Investigation III; Discussion of Techniques and Procedures

The first step in the procedure was the establishment of sufficient ground control and pass points necessary to carry out the investigation. Intersections of roads and highways were chosen in most cases and care was taken to insure that common points, identifiable on both the SKYLAB S190A and high altitude photography involved, were obtained. The coordinates of the ground control points were determined from published 1:25,000 (Canada) and 1:24,000 (U.S.A.) map sheets. The points were then transferred to the photography using a Wild PUG instrument equipped with a 40µm drill, which was considered to be more suitable for high altitude photography like SKYLAB imagery than the larger standard 60µm drill.

For each SKYLAB photograph, the coordinates of the nine reseau crosses and all other points required in the investigation were measured on the Wild STK-1. A computer program, STKREDUC, was written at the Department of Photogrammetry of the Universite Laval to average the measured coordinates, reduce them to the centre of gravity of the photograph and obtain the standard deviations of the measurements. The same technique was applied to the high altitude photography employing the eight fiducials. Systematic errors in image coordinates due to film deformation, lens distortion and refraction were researched individually and appropriate computer programs were developed at Universite Laval to apply corrections for these errors (Appendix D.1).

After all the corrections were applied to the image coordinates, strip coordinates of the same points were obtained using a program previously written at Laval Universite. This program was adapted for this investigation to accept as input corrected image coordinates when either reseau (S190A) or fiducial marks (high altitude) were incorporated. Schut's program from the National Research Council, Canada, was used to adjust the strip coordinates. This program uses a third degree polynomial transformation in the adjustment of photogrammetric strips and blocks.

Strips 23 and 24 of the SKYLAB S190A photography were adjusted separately and then both rolls were combined and adjusted as one block. To maximize the effect of ground control, the ground coordinates of all image points were given as control and the residuals at each point determined. It was then thought that a strip of three S190A models might cover an area too large to be adjusted by a polynomial transformation, so the block was broken down and each roll was adjusted using either one, two or three models.

The four high altitude photography strips were also adjusted using Schut's program: first each strip separately, and subsequently all four strips combined to form one block. Again, the ground coordinates for all image points were used as control.

After the separate adjustments had been performed on the S190A and high altitude photography, further adjustments were carried out combining one SKYLAB model from each of the two rolls with either one, two, three or all four models of a high altitude strip. Again the ground coordinates of all the image points were used as control.

Since the use of all the image points as control does not correspond to practical applications, the previous tests were repeated employing only a necessary minimum of well distributed ground control points for either the SKYLAB or high altitude photography. For the first test (Case 1) on a single S190A model, only twelve (12) control points were used in the adjustment and the ground coordinates of all the other image points were calculated. The residuals were quite large so the adjustment (Case 2) was repeated with an additional ten (10) control points. The four high altitude strips were also adjusted independently (Case 3) holding only twenty-six (26) points as control.

Again the SKYLAB and high altitude photography were combined with a minimum amount of control. The first combination adjustment (Case 5) of this type incorporated 12 control points for the S190A model, 22 for the high altitude strip and 14 points as common to both. A final combined adjustment (Case 6) was performed using the same data with an additional 31 high altitude points as control.

Although the above adjustments produced valuable information, it had been felt from the beginning of the investigation that a bundle method of adjustment would be a more suitable type of adjustment for SKYLAB and high altitude photography. However, due to a lack of time and funds it was not possible to complete this aspect of the investigation.

A computer program AERTRING was written at Universite Laval to incorporate data from SKYLAB and high altitude photography into a bundle adjustment. The approximate coordinates of the SKYLAB camera station were obtained employing the orbital parameters. Again strips 23 and 24 of the S190A camera system were adjusted separately and later combined into one adjustment. In both cases the ground coordinates of all image points were given as observations and weights were applied both to the ground and image coordinates.

AERTRING was used again to adjust a single SKYLAB model incorporating twenty-six (26) control points as observations. Approximate values for the camera station coordinates were obtained from the previous adjustment and twenty-two (22) pass points were assumed as unknowns. This test was repeated combining one strip of high altitude photography with the SKYLAB model (Appendix D.3).

8.4 Ground Truth Activities of Investigation III

Published topographic map sheets were used to obtain the ground coordinates for the adjustment of the aerial triangulation and for the checking of the output results. In Canada, topographic maps at the scale of 1:25,000 and in the U.S., maps at the scale of 1:24,000 were available for the areas covered by both the SKYLAB and high altitude photography. American standards require that the horizontal accuracy of 90% of the well defined map points be plotted correctly within ±0.5mm which would correspond to ±12 and 12.5 meters on the ground for 1:24,000 and 1:25,000 scale maps.

The Universal Transverse Mercator (U.T.M.) ground coordinates were measured to an accuracy of ±0.1mm. The vertical coordinates were obtained by visual interpolation of contours. It was felt that for this investigation, a higher measuring accuracy was not justified due to the possibility of expansion and shrinkage of the map sheets.

Because of the large area covered by the SKYLAB photography, in which two zones were crossed, it was felt that the U.T.M. coordinate system was not suitable for aerial triangulation in this investigation. Consequently, all U.T.M. coordinates were transformed to the Secant plane coordinate system adopted by the U.S. Coast and Geodetic Survey. This system is a local three dimensional orthogonal system in which the Z-coordinate is equivalent to the combination of elevation and earth curvature.

8.5 Problems Encountered during Investigation III

The original plan was to extend the investigation to include imagery from the SKYLAB S190B terrestrial camera as well as from the S190A system. However, the S190B was not considered metric in the photogrammetric sense because its image frame was part of a removable magazine which prevented the exact positioning of the principal point, and it employed a focal plane shutter.

The choice of ground control points for the investigation presented a very tiring task. Many of the road intersections visible on SKYLAB photography did not exist on the corresponding map sheets. The reverse condition was also present in that well defined map sheet intersections were not visible on SKYLAB photographs. The large scale differences involved, indicated by the fact that one SKYLAB photograph of 70mm format covered the same area as 54 high altitude photography and approximately 250 map sheets, also presented problems in point identification. However, as shown by Table 8.1, sufficient points were finally gathered.

Table 8.1 Number of points in both SKYLAB and high altitude (H.A.) photography.

Photography Involved	Points in H.A.	Points in SKYLAB	Common Points	Sum
H.A. Strip #1	11		18	29
H.A. Strip #2	17		21	38
H.A. Strip #3	19		16	35
H.A. Strip #4	19		20	39
SKYLAB 3 Models/Strip		62	65	127
SKYLAB 2 Models/Strip		57	65	122
SKYLAB 1 Model/Strip		24	62	86

The final major problem encountered arose in the section of the investigation which dealt with aerial triangulation by bundle adjustment. Limited time and money prevented the entire completion of this aspect of the study at present time but it is hoped that further investigations will be carried out in the future.

8.6 Discussion of the Results of Investigation III

In the studies carried out to correct the systematic errors of the image point coordinates, it was discovered that film deformation for both SKYLAB and high altitude photography could reach more than ±10μm and it was necessary to correct for this deformation by a method such as the one described at Appendix D.1. For SKYLAB photography, the errors due to lens distortion were very small and could be ignored but for the high altitude photography, polynomial corrections (Appendix D.1) were applied. Refraction errors were also insignificant for SKYLAB imagery but were applied to the high altitude photography (see Appendix D.1).

Perhaps the most significant results of this investigation were those arising from the analytical aerial triangulation adjustments of the imagery involved in the study. The first group of adjustment results were those obtained using Schut's third degree polynomial transformation approach.

The results obtained from polynomial adjustments of Strips 23 and 24 of the SKYLAB data, each as single strip adjustments and later combined to form a block, and holding the ground coordinates of all image points as control, are shown at Appendix D.2-a. These results indicated that there were no significant differences in the standard deviations when the rolls were adjusted separately, combined as a block or even at a later stage when single models in a strip were adjusted independently. The average values of the standard deviations were 33 meters in X, 46.5 meters in Y and 128 meters in Z expressed in ground values.

The polynomial adjustment results of the four high altitude strips, both as separate strip adjustments and subsequently combined as a block, are shown at Appendix D.2-c and yielded standard deviations ranging from ±7 meters to ±23 meters in X and Y and ±3 meters to ±7 meters in Z. The ground coordinates of all image points were used as control.

The combination of one SKYLAB model with either one, two, three, or four high altitude strips into the polynomial adjustment offered no significant improvement in the planimetric or height accuracies (Appendix D.2-d) due probably to the fact that again all ground coordinates were used as control.

Several of the polynomial adjustments were repeated with fewer control points (Appendix D.2-e) as described previously in Section 8.3. Case 1, which employed only 12 control points on a SKYLAB model, yielded a very large σ_z and the addition of 10 extra control points (Case 2) into the adjustment led to a significant improvement in both planimetric and vertical accuracies. The polynomial adjustment performed on the high altitude photography, employing only 26 points as ground control (Case 3), yielded, as was to be expected, higher residuals than in the case where all image points were held as control. The combination of three high altitude strips with two SKYLAB models using only 12, 22, and 14 control points for SKYLAB, high altitude and common points respectively, resulted in a slight improvement of both the planimetric and height accuracies of the SKYLAB models (Case 4). Another strip of high altitude photography and 31 additional high altitude control points were added to the combined adjustment and, as shown by Appendix D.2-e, there were no significant differences in accuracies between Case 4 and Case 5.

Aerial triangulation by bundle adjustment (see Section 8.3) was performed on portions of the SKYLAB and high altitude photography employing program AERTRING. In the first test, where one model of each of the two SKYLAB rolls was adjusted separately and later both were combined, the maximum differences between the coordinates of the SKYLAB camera station obtained from the adjustment and those obtained from the orbital parameters were only 2.3, 1.0 and 5.2 kilometers respectively for X, Y and Z. The planimetric and vertical accuracies of the SKYLAB model improved over the polynomial transformation adjustments with the average σ_x = 8m, σ_y = 18m and σ_z = 18m (Appendix D.3-a). However, again all image points were used for control.

The second bundle adjustment carried out on a single SKYLAB model using only 26 control points as observations and the approximate coordinates of the camera station obtained from the previous adjustment, gave much poorer results than the first set of bundle adjustments with an especially huge error in Z. When the same test was repeated with an additional high altitude strip, the accuracies were somewhat improved (Appendix D.3-b) with a σ_x and σ_y of approximately ±30 meters and σ_z about ±200 meters.

On the whole, it was obvious that further testing was necessary and the results from the bundle adjustments must then be analysed more rigorously and from a statistical point of view before any specific conclusions can be formulated on this bundle adjustment procedure.

8.7 Conclusions to Investigation III

Using polynomial transformation adjustments for SKYLAB and/or high altitude photography produced the following accuracies:

(a) SKYLAB - σ_x and σ_y were approximately ±40 meters on the ground.

(b) High altitude photography - σ_x and σ_y were approximately ±18 meters and σ_z was approximately ±11 meters.

(c) The combination of SKYLAB photography with up to 24 high altitude photography did not significantly improve the accuracies in X, Y and Z. Perhaps significant improvements could be obtained employing a considerably larger block of high altitude photography.

Using the bundle adjustment approach on the two types of photography the following accuracies were obtained:

(a) SKYLAB - σ_x and σ_y were approximately ±30 meters.

(b) The differences between camera station coordinates obtained from the orbital parameters supplied by NASA and the output of the adjustments are no more than 5 kilometers in X, Y or Z.

(c) By combining one high altitude strip of six photographs with SKYLAB photography the accuracies improved by 25, 21 and 28% for the X, Y and Z coordinates respectively.

Based on these conclusions it was felt that there was indeed potential in employing SKYLAB/EREP photography as control for high altitude photography for small scale mapping when using the bundle adjustment method of analytical photogrammetry.

8.8 Recommendations from Investigation III

1. The selection and marking of ground points to be used as control or pass points in aerial triangulation with photography such as SKYLAB material should be planned and completed prior to the photo missions.

2. Further improvements in the algorithm used to solve the normal equations in program AERTRING should be made, and this is presently being studied at the Universite Laval.

3. A more stable film should be used for high altitude photography than the Aerochrome Infrared film employed in this investigation.

4. A greater number of high altitude photographs, well distributed over SKYLAB photography areas should improve the accuracies obtained through bundle adjustments.

9. INVESTIGATION IV: QUALITATIVE EVALUATION OF SKYLAB S190A PHOTOGRAPHY

9.1 Technical Approach and Task Description

The object of this project was to evaluate the image clarity for mapping purposes of photography obtained from the SKYLAB S190A multispectral camera system. This system provided a series of photographs from each of six simultaneously exposed cameras containing six different film-filter combinations. The method of evaluation was a visual intercomparison under magnification of the same image feature on each of the six simultaneous pictures, using second generation contact positive (70mm) transparencies of the imagery.

9.2 Photography used for Investigation IV

From the SKYLAB 3 Mission, a complete set of six simultaneous photographs from the S190A system was obtained for three areas of Canada: (a) Toronto area from Orbit 27, 9 September 1973, frame 016; (b) Southern Manitoba from Orbit 50, 19 September 1973, frame 214; and (c) the Bay of Fundy from Orbit 52, 21 September 1973, frame 316. The camera film-filter combinations of the S190A system are tabulated in Table 9.1.

Table 9.1 Camera Film-Filter Combinations of S190A System

Camera	Film	Filter	Bandwidth
1	IR aerographic B&W - type EK2424	CC	0.7-0.8 μm
2	IR aerographic B&W - type EK2424	DD	0.8-0.9 μm
3	Aerochrome IR Colour - type EK2443	EE	0.5-0.88μm
4	Aerial Colour - type SO-356	FF	0.4-0.7 μm
5	Pan-X aerial B&W - type SO-022	BB	0.6-0.7 μm
6	Pan-X aerial B&W - type SO-022	AA	0.5-0.6 μm

9.3 History of Investigation IV; Discussion of Techniques and Procedures

The three sets of photography were evaluated independently by employing a method of visual intercomparison of the same image feature on each of the six simultaneous pictures using second generation contact positive (70mm) transparencies. A rating of 1-10 was assigned to the image, where 1 represented the best defined image of the subject among the six samples and 10 represented no record of the subject at all. The images were also rated for granularity. The results of the individual evaluations were later totalled to form the overall evaluation, and thus the film with the smallest total indicated the best overall image quality.

9.4 Ground Truth Activities of Investigation IV

The cultural detail selected to determine the clarity of the image for map compilation included items such as airports, major and secondary roads, rivers, minor drainages and shoreline detail as well as a few specific objects such as a racetrack or pier.

9.5 Problems Encountered during Investigation IV

The rating system was very subjective and if totalled over several subjects could give a quite erroneous relative rating of the film-filter combination. In order to solve this problem, the selection of images was weighted in relation to importance of map content so that the totals (Appendix E.1) also provided a relative rating with respect to average map content.

9.6 Discussion of the Results of Investigation IV

The performance of the various film-filter combinations in recording cultural map features corresponded with what would be predicted from experience with normal aerial photography. The Pan-X Aerial black and white film and the Aerial Colour film exhibited low granularity and good image quality. The infra-red films, both black and white and colour, had a very noticeable granularity which affected the image resolution. The Panchromatic black and white film was the best general purpose film for delineating map features (roads, airports, warfs, water areas). Greater filtration of lower wavelengths improved the clarity of the image for high altitude photography. Everything seen on the 0.5-0.6μm bandwidth could be seen with better contrast on the 0.6-0.7μm bandwidth. The colour image was good but no better than black and white for any of the features compared. The black and white infra-red films provided excellent delineation of water features. The Aerochrome 1R colour image was much poorer than the normal colour image and the resolution was much poorer than the colour or panchromatic black and white films. Examples of the photography evaluated can be found at Appendix E.2.

9.7 Conclusions to Investigation IV

Of the six cameras of the S190A multicamera system, the camera containing the Panchromatic Black and White film fitted with a BB filter (bandwidth 0.6-0.7μm) provided the best resolution of specific cultural detail employed in mapping. The aerial colour film also presented a clear image but no better than the camera using the Pan X Aerial B&W film.

10. INVESTIGATION V: THE REVISION POTENTIAL OF SKYLAB PHOTOGRAPHY

10.1 Technical Approach and Task Description

The objective of this investigation was to evaluate S190A and S190B SKYLAB imagery for its revision potential, both in urban areas and rural-recreational areas. Planimetric compilations at scales of 1:250,000 and 1:50,000 using third generation reproduction, were produced on the Wild B-8 Stereoplotter, the Kern PG-2 and the Bausch and Lomb Zoom Transferscope.

10.2 Photography used for Investigation V

The Windsor area of Southern Ontario was selected from the SKYLAB-3 coverage in Canada as an area best representing urban mapping requirements. The actual photographs used included:

- S190A Camera with a six inch focal length and original scale of 1:2,850,000. Selected photography from this system:
  (a) Roll 23 (185-186), 0.6μm-0.7μm, 4X enlarged
  (b) Roll 22 (185-186), colour, 4X enlarged.
- S190B Camera with an eighteen inch focal length and original scale of 1:950,000. Selected photography from this system:
  (a) Roll 83 (152-153), colour, 2X enlarged.

The diapositives used in the investigation were third generation copies obtained by enlarging the second generation negatives (black and white) or positives (colour). The area was free of cloud and the pictures had 60% forward overlap.

The Mazinaw Lake region of Southern Ontario was chosen as being typical of the remotest area covered by SKYLAB photography. However, this region contained a few roads, power-lines and railways. The SKYLAB imagery depicting this area included:

- S190A Camera with six inch focal length and original scale of 1:2,850,000. Selected photography from this system:
  - (a) Roll 40 (17-18), colour, 4X enlarged
  - (b) Roll 40 (17-18), 0.6-0.7µm, 4X enlarged.
- S190B Camera with eighteen inch focal length and original scale of 1:950,000. Selected photography from this system:
  - (a) Roll 85 (298-299), black and white diapositives, 2X enlarged
  - (b) Roll 85 (298-299), black and white diapositives, 3.8X enlarged
  - (c) Roll 85 (298-299), black and white diapositives, 4X enlarged.

Again the photographs used in plotting were third generation copies obtained by enlarging the second generation negatives supplied by NASA. In this case, the photos from the S190A cameras had only 20% forward overlap, so that stereoviewing was limited to a small area. A few small clouds and shadows were present on the imagery.

10.3 History of Investigation V; Discussion of Techniques and Procedures

For the revision evaluation of SKYLAB imagery in urban areas, the map compilations from the colour diapositives of the S190A Camera system were produced using the Wild B-8, while the black and white diapositives were used in the Zoom Transferscope. The scale of both compilations was 1:250,000. The enlarged S190B photography used in the urban evaluation was plotted at scales of 1:250,000 and 1:50,000.

Th 1:250,000 plots of the S190B imagery were produced directly with the Kern PG-2, while the 1:50,000 maps were plotted at 1:100,000 on the B-8 and then enlarged using the Transferscope.

For the rural-recreational study, the colour diapositives of the S190A system were again used in the B-8 to produce a plot directly at 1:250,000. The S190B photography was used both in the B-8 and the Zoom Transferscope to produce plots at 1:250,000 scale. The S190B imagery was also used to produce 1:50,000 scale mapping in the same manner as in the urban evaluation. In addition, a portion of the imagery was enlarged four times making it possible to plot directly at 1:50,000 with the Zoom Transferscope.

Appendix F.3 displays samples of enlarged S190A and S190B photography to the scale of 1:250,000.

10.4 Ground Truth Activities of Investigation V

Published 1:50,000 and 1:250,000 map sheets served as a basis to establish scale and map content. However, the plotting of detail was done independently of the map and the compiler drew only what he could see and interpret from the photographs.

10.5 Problems Encountered during Investigation V

For the revision evaluation in both the urban and rural recreational areas, it was not possible to plot the enlarged S190B imagery directly at 1:50,000 in the B-8. Therefore, the detailed was plotted at a smaller scale (1:90,000 or 1:100,000) and then enlarged to 1:50,000 using the Zoom Transferscope.

The original intention of this investigation was to evaluate photography for revision potential over true wilderness areas. However, the most remote area covered by available SKYLAB imagery (Mazinaw Lake district) represented one for which the map sheet could be classified as "rural-recreational". For this classification, the imagery received was suitable for evaluation.

10.6 Discussion of the Results of Investigation V

The results of this investigation can be broken down under two topics for each study: (a) revision potential at the scale of 1:250,000 and (b) at the scale of 1:50,000.

At the scale of 1:250,000 and using the S190A imagery, the best results for both the urban and rural-recreational evaluations were obtained using the colour diapositives in the Wild B-8 plotter. (See Appendices F.1 and F.2 for sample overlays.) Roads were difficult to distinguish in the heavily built-up areas, but in rural areas roads were identifiable by the presence of houses and farms which usually could quite easily be seen. Power lines and large lakes could be plotted with an accuracy commensurate with revision requirements at this scale, as well as many other well defined features such as airports, subdivisions, farm complexes, sewage plants, gravel pits and oil and gas tanks. However, delineation of shorelines was of variable accuracy, and drainage patterns and railways could not be detected.

The use of the S190B imagery to produce plots at 1:250,000 improved the accuracy and content of the map both for the urban and rural-recreational evaluations. Some of the railroads could be plotted in the urban study and the identification of the road patterns was easier for both evaluations. However, in both cases, the delineation of drainage patterns and inland waters remained quite difficult in many areas.

In compiling the 1:50,000 maps from the enlargements of the 1:90,000 (rural-recreational) and 1:100,000 (urban) detail plotted on the B-8, which were obtained from the initial S190B third generation imagery, there was a very definite loss in resolution which in general left the detail fuzzy and difficult to define. (See Appendices F.1 and F.3.) Only power lines and hard-surface all-weather roads could be plotted with an accuracy adequate for 1:50,000 interim revision and only then in the rural areas. For the urban evaluation, it was impossible to depict the buildings accurately and again, in both cases, the water areas could not be delineated in detail. The results obtained in the rural-recreational evaluation from the plot at scale 1:50,000 on the Zoom Transferscope, using the four times enlarged S190B photography, produced an image that was objectionally fuzzy.

10.7 Conclusions to Investigation V

To a certain extent, photography from the S190B (colour) system and the S190A (colour) system could be used for road revision in the urban-agricultural areas for the scale of 1:250,000. Many other features such as airports, subdivisions, farm complexes sewage plants, gravel pits and tanks could be detected, but it is unlikely that their interpretation would be reliable enough to consider this photography as a complete revision source for such information. However, it could serve as an indicator of where additional information is required.

In the rural-recreational map sheet area studied, space photography of the type provided by the SKYLAB S190A camera system (aerial colour) could be used for interim revision mapping at a scale of 1:250,000 for the detection of new features such as major roads, power lines and new reservoirs. The SKYLAB S190B photography increased the confidence with which these features could be identified at the 1:250,000 scale but offered no additional reliable map revision potential.

For both urban and rural-recreational revision, the map revision potential at a scale of 1:50,000 using the better S190B camera photography was limited, and could be applied with certainty only to major roads and powerlines.

10.8 Recommendations of Investigation V

1. Imagery from space photography similar to the SKYLAB S190A and S190B Camera systems may be used for map revision at the scale of 1:250,000. However, this imagery may be used with certainty only for the revision of new major roads and power lines in non-urban areas.

2. Space photography with characteristics similar to SKYLAB S190A and S190B imagery can serve as a valuable indicator to where revision of 1:50,000 maps detail is required. It may then be necessary to obtain additional revision information such as conventional aerial photography, to complete the actual revision.

11. INVESTIGATION VI: THE POTENTIAL OF SKYLAB PHOTOMAPPING APPLICATIONS

11.1 Technical Approach and Task Description

To determine the photomapping applications of SKYLAB imagery, a partial photomap at the scale of 1:250,000 of an area north of the Bay of Quinte, Southern Ontario, was produced from both SKYLAB S190A and S190B photography. These were compared with each other and evaluated as input products to a complete photomap at this scale. The potential of producing photomaps from this imagery was also evaluated against photomaps produced from standard aerial photography at one end of the scale and LANDSAT-1 imagery at the other end of the scale.

11.2 Photography used for Investigation VI

Table 11.1 indicates the photography used to produce the photomaps of the selected area (Bay of Quinte north to latitude 44° 45'):

Table 11.1 Input Photography and Imagery

Camera	Original Scale	Bandwidth	# Pictures	Enlargement
6" f.l., 9"x9" Wild, Zeiss	1: 36,000	0.5-0.68μm	240	0.14
SKYLAB S190A 6" f.l., 70mm	1:2,850,000	0.5-0.6 μm	1	11.4
SKYLAB S190A 6" f.l., 70mm	1:2,850,000	0.6-0.7 μm	1	11.4
SKYLAB S190B 18" f.l., 4½"	1: 950,000	0.5-0.68μm	1	3.8
LANDSAT-1 70mm	1:3,369,000	0.6-0.7 μm	1	13.5

11.3 History of Investigation VI; Discussion of Techniques and Procedures

The area selected for evaluation covered about one third of a standard 1:250,000 map sheet (99 statute miles E-W by 69 miles N-S) of the National Topographic Series (N.T.S.). This area was covered by black and white photography from both the S190A and S190B camera systems, by conventional aerial photography and by LANDSAT imagery. The scale of 1:250,000 was the only scale studied since the next larger N.T.S. scale, 1:50,000, is within the capability of conventional aerial photography, and the next smaller scale, 1:500,000, is within the capability of the LANDSAT system.

To produce one of the photomaps of the evaluation area, 240 standard aerial photographs at the scale of 1:36,000 were used. A second photomap of the same area was produced from one black and white S190A image of spectral bandwidth 0.5-0.6µm, and a third photomap from a S190A image having a spectral bandwidth of 0.6-0.7µm. In the latter two cases, it was required that the enlargement from 1:2,850,000 to 1:250,000 be done in two stages. For these test samples, the 70-millimeter second generation positive copy was enlarged to a 9"x9" negative, which was then rectified to a map base at 1:250,000 with considerable loss of resolution and contrast. The fourth photomap produced was rectified directly from the S190B imagery. The fifth photomap was produced from LANDSAT-1 imagery. (See example reproductions at Appendix G).

11.4 Ground Truth Activities of Investigation VI

Published 1:50,000 and 1:250,000 map sheets of the N.T.S. series were used as map bases for the rectifications of the photographs as required.

11.5 Problems Encountered during Investigation VI

The SKYLAB photographic system provided small scale coverage in both black and white and colour for limited areas in Canada. None of the passes provided complete coverage of a 1:250,000 map sheet. Photography suitable for evaluation covered approximately one third of a standard 1:250,000 sheet.

The 70 millimeter format S190A imagery had to be enlarged to 9"x9" negatives before rectification to a map base at 1:250,000. This led to a relatively poor image with evident granularity and poor image resolution along with the possibility of additional defects acquired at each reproduction stage.

11.6 Discussion of the Results of Investigation VI

Although technically possible, the production of photomaps at 1:250,000 from conventional aerial photography is time consuming because of the number of pictures involved, and the product often suffers from several well known defects. The number of pictures required can range from 100 super wide angle photos at 1:110,000 scale to as many as 800 if the smallest scale available is 1:36,000, as was the case in this investigation. Density and contrast matching problems increase with increasing numbers of pictures. Other evident defects of photomaps produced in this manner arise due to banding, tone control and specular reflection from water. The planimetric accuracy, however, was excellent in this case as the compilation was based on 1:50,000 map manuscripts. The amount of detail present in the copy negative far exceeded that which would usefully reproduce in a lithographic process, and would be more appropriate to the production of 1:50,000 or larger scale photomaps.

As mentioned in Section 11.5, the enlargement of the two sets of S190A photography had to be accomplished in two stages. The results of neither were outstanding. Film granularity in the final products was quite evident and image resolution was less than could be reproduced in a lithographic process. Contrast control through the numerous reproductions can present problems, and image defects are easily acquired at each reproduction stage. Of the two spectral bands, the range 0.5-0.6µm was the better although delineation of water features was poor. The photography in the bandwidth 0.6-0.7 resulted in too high a contrast image with a loss of detail in all the cultivated areas. However, the planimetric accuracy was good and well within the accuracies required for 1:250,000 photomapping.

The SKYLAB S190B photography taken with panchromatic film and a conventional Wratten 12 (0.5µm) filter provided an excellent image for 1:250,000 photomapping. The enlargement factor of 3.8X did not exceed the resolution capabilities of the film, and the planimetric accuracy was well within the requirements of 1:250,000 photomapping.

The use of LANDSAT imagery for 1:250,000 photomapping had been previously explored by the Research and Development Section, Topographical Survey Directorate, and discarded because of short comings in planimetric accuracy and image quality. However, the LANDSAT experiments did present interesting comparisons with the SKYLAB products. The water areas and drainage systems were perhaps more readily identifiable on LANDSAT imagery than any of the other products but resolution of detail was much inferior. The coverage per map sheet was the largest of all the products studied (1.9 times). However, the difficulties of obtaining map sheet coverage, even with an image this size, from cyclic cloud coverage has been well demonstrated during the three years LANDSAT has been in operation and this experience can be extrapolated to a SKYLAB-type product.

The coverage of a single image from the S190A system is about 1.4 times the area of a southern 1:250,000 map sheet, but because of the direction of the orbital paths it would require at least 4 frames from 2 or more orbits to cover a conventional sheet. A single SKYLAB image from the S190B camera system covers about 65% of a southern 1:250,000 map sheet and again since the orbital paths are not compatible with efficient coverage of a map grid system such as the N.T.S. system, it would be expected that parts of at least 4 to 6 photos would be required to cover a single sheet. As soon as more than one image is required in any case, the same problem is encountered as in conventional aerial photography - that of obtaining cloud-free photography in a short time period.

11.7 Conclusions and Comments of Investigation VI

The SKYLAB S190B camera system operating with normal panchromatic film and a Wratten 12 filter produced the most appropriate image for 1:250,000 photomapping - of any of the five systems evaluated. The resolution of this system was adequate, the planimetric accuracy was good and a single image replaced a multitude of aerial photos.

Notwithstanding the above advantages of the S190B image, a non-directed photographic system such as an orbiting satellite has serious shortcomings for a country with weather systems like those over Canada. Experience with LANDSAT has shown that cyclic coverage of a country as sporadically cloud-covered as Canada is not efficient, and it would not be unexpected to find that it would take one year to several years (depending on the area) to obtain the 4 to 6 compatible cloud-free photographs required to cover a standard map sheet.

A 1:250,000 map sheet can be photographed in one day by conventional methods under cloud-free conditions, although the aircraft may have been waiting for several weeks (or months) for that weather condition.

Directed systems (airborne photography with conventional mapping cameras) can provide scales as small as 1:150,000 on a commercial basis (Jet with super-wide angle lens). Military technology has operated aircraft at 80,000 feet (U-2) which, with a conventional super-wide mapping camera provides a scale of 1:275,000. Such systems would offer as great a potential for 1:250,000 photomapping as the SKYLAB S190B camera system, even though the number of pictures required to cover a standard sheet of this scale would be between 15 (U-2) and 45 (Jet) compared to 4-6 S190B photographs.

Although cloud-free imagery from satellite sensors such as SKYLAB S190B Camera System provides excellent photography for small scale photomapping purposes, it can not be considered to be an efficient method of obtaining imagery of frequently cloud covered areas. As a practical consideration, it must be pointed out that directed photographic systems, such as those employed by Jet aircraft and U-2 aircraft, offer as great a photomapping potential as SKYLAB imagery, take less time to acquire the necessary photography, and would use conventional auxiliary equipment (enlargers, rectifiers, differential rectifiers) already in existence for mapping for aerial photography.

12. GENERAL CONCLUSIONS

12.1 Conclusions - Quantitative Investigations I, II, III

The results of Investigation I, which was carried out on a single S190A (bandwidth 0 6-0.7μm) model, satisfied the planimetric accuracy requirements at mapping scales of 1:250,000 and smaller, using two dimensional transformations on data obtained from a four times enlarged image. In addition, it was shown that NATO planimetric accuracy requirements for Class B 1:50,000 mapping were obtainable, using a three dimensional adjustment of this enlarged image data. Investigation II indicated that the extension of horizontal control on small strips of S190A (bandwidth 0.6-0.7μm) imagery through a fully analytical adjustment could also achieve 1:250,000 scale mapping requirements. The introduction of imagery from the S190B camera system, although not considered metric in the photogrammetric sense, increased the planimetric accuracy significantly in that Class B 1:50,000 accuracy specifications were met. Investigation III, which examined the potential of employing S190A imagery as control for high altitude aircraft photography, resulted in an improvement in the accuracies of the ground X, Y and Z coordinates by 25, 21 and 28% respectively, when using a bundle method of adjustment on the combined photography. In this investigation, Class A 1:250,000 mapping standards were also obtained on S190A (0.6-0.7μm) photography.

Although the three quantitative investigations were undertaken by three separate agencies, employing different techniques of aerial triangulation adjustments, the overall results were quite compatible. In all three cases, 1:250,000 mapping requirements were achieved quite easily on the S190A photography, which employed Pan X Aerial Black and White Film with a bandwidth of 0.6-0.7μm. The ground control for all three investigations was obtained in similar manners from already existing medium scale map sheets, where the actual positioning of these points could be in error by as much as ±20 meters. In Investigation I when a 3-Dimensional PAT-M adjustment procedure was carried out on the STK-1 data of the single enlarged S190A model, the standard deviation at control was approximately 20 meters in both X and Y. The same results were obtained from the two strips of S190A (0.6-0.7μm) photography examined in Investigation II, which also employed the PAT-M-43 adjustment. Investigation III, which led to the development of a bundle method of adjustment employing SKYLAB orbital parameters, also yielded standard deviations of approximately 20 meters in both X and Y at control. The 2-Dimensional transformations performed on the data from the S190A imagery (4X enlarged) in Investigation I yielded slightly larger standard deviations of approximately 26 meters at control, which the polynomial adjustments of Investigation III averaged 30 meter standard deviations in X and Y. Considering the origin of the ground control, these results are extremely good and consistent.

The best adjustment results of all three quantitative investigations were obtained in Investigation II from the data derived from the S190B photography. The standard deviation at control was approximately 10 meters in both X and Y, with an RMS error of 23 meters at check points. Although this camera system does not meet the specifications of a metric camera, the larger scale image provided by the system has apparently more than offset the lower precision of the internal geometry.

A strong recommendation from all three of these investigations advised the development of some method of targeting of ground control prior to future satellite imagery gathering missions. For example, a specially designed mirror/light system could be employed. Another recommendation from these quantitative studies involved the installation of a metric camera with a fairly long focal length for future space missions.

12.2 Conclusions - Qualitative Investigations IV, V, VI

The qualitative evaluation of the photography of each of the six simultaneously exposed cameras of the S190A camera system (Investigation IV) showed that the camera containing the Panchromatic Aerial Black and White film fitted with a BB filter (bandwidth 0.6-0.7μm), provided the best resolution of specific cultural detail required in mapping. The aerial colour film also presented a clear image but no better than the Pan X Black and White. However, for map revision purposes (Investigation V), the aerial colour film offered the greatest potential of the S190A system cameras, for revision at scales of 1:250,000 and smaller. In any case, this map revision potential was limited to the detection of major roads, powerlines, and new reservoirs and thus may serve only as an indicator as to where revision might be necessary. For 1:50,000 mapping, the necessary two-stage enlargement procedure involved with the S190A imagery resulted in a very definite loss of resolution and detail. The same enlargement difficulties occurred in the production of partial photomaps (Investigation VI) employing the S190A imagery.

The S190B photography increased the confidence with which features could be identified for map revision purposes at the scale of 1:250,000, but again it was unlikely that the interpretation of these features was reliable enough to consider this photography as a complete revision source. However, the S190B photography would serve better than the S190A photography as an indicator of the location of new features at the scale of 1:250,000, and could only be applied with certainty at the scale of 1:50,000 for the identification of major roads and powerlines. The S190B imagery proved the most appropriate type of photography for the production of photomaps at the scale of 1:250,000 of the five samples studied during Investigation VI. The major drawback in using this photography for photomapping in a country as frequently cloud covered as Canada lies in obtaining compatible cloud-free imagery. Directed systems of obtaining small scale photography, such as the U-2 aircraft equipped with super-wide angle cameras, could offer as great a photomapping potential as S190B photography with fewer problems due to weather.

12.3 Overall Comments on Total Investigation

The results of the six independent investigations carried out on the SKYLAB/EREP imagery clearly indicated that certain selected sets of this photography were adequate for planimetric mapping purposes at scales of 1:250,000 and smaller. In limited cases, the NATO planimetric accuracy requirements for Class B 1:50,000 scale mapping were also achieved.

Of the S190A photography system, the camera containing the Pan X Aerial Black and White film (0.6-0.7μm) offered the greatest potential to mapping at small scales. However, the S190B system continually proved to offer more versatility throughout the entire investigation in that the larger and clearer image achieved up to Class B 1:50,000 planimetric accuracy requirements; depicted more clearly than S190A photography specific ground features for map revision potential at scales of 1:50,000 and 1:250,000; and offered the best input product of all studied to the production of photomaps at the scale of 1:250,000. For future applications, a metric camera with similar characteristics to the S190B camera could provide a multi-purpose system for mapping from satellite imagery.

APPENDIX A

TO

"INVESTIGATION OF SELECTED IMAGERY FROM
SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

EXHIBIT "A"

STATEMENT OF WORK

FOR THE

INVESTIGATION OF SKYLAB

EREP DATA

NASA HEADQUARTERS PROPOSAL
REGISTRATION NO. 558

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA

EXHIBIT "A"

STATEMENT OF WORK

FOR THE

INVESTIGATION OF SKYLAB

EREP DATA

NASA HEADQUARTERS PROPOSAL

REGISTRATION NO. 558

"INVESTIGATION OF SELECTED IMAGERY FROM
SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

Manned Spacecraft Center
Principal Investigations Management Office
TF6

PROVISIONS
FOR PARTICIPATION IN THE NASA
SKYLAB EARTH RESOURCES EXPERIMENT PROGRAM

1. Investigation to be Conducted:

1.1 The Department of Energy, Mines, and Resources will use its best efforts to arrange for furnishing the necessary personnel, facilities, and services for the Principal Investigator to conduct an investigation and analysis of Earth Resources Experiment Program (EREP) data. The general approach, intent, and objectives of this investigation and analysis are detailed in the proposal entitled "Investigation of Selected Imagery from Skylab/ EREP S190 Photographic System," dated April 1971. Submitted by Mr. R. A. Stewart.

1.2 The purpose of these provisions is to identify the services, tasks, and deliverable products required of the Principal Investigator, his associated Co-Investigators, and their related organizations for the investigation and analysis of Skylab EREP data.

1.3 Technical Approach

The investigation will assess the imagery, accuracies obtainable and cost effectiveness, of photography from the EREP S190A and S190B sensors, for 1:50,000, 1:100,000 and 1:250,000 scale mapping and/or revision, activities. More specifically, it is proposed to conduct the following studies:

(1) Ground resolution capabilities of satellite photography, specifically S190 system photography.

(2) Utilization of S190 photography for the production of planimetric graphical maps and photo maps at scales of 1:50,000, 1:100,000 and 1:250,000.

(3) Formation of geometrical models of the terrain using stereoscopic satellite photography.

(4) Exterior orientation of analytically constructed models using satellite photography.

(5) Feasibility and accuracy of using analytical aerotriangulation and numerical adjustment with satellite photography for planimetric mapping in northern Canada where control is sparse.

Glass and/or film diapositives will be produced from both the colour and black and white originals. Photogrammetric mensuration and resolution evaluation will be performed on each type of imagery received. Measurement of single photographs and stereo models will be performed on comparators and the Analytical Plotter. Analytical aerotriangulation and adjustment will be performed throughout the maximum number of models available.

Graphical (line) planimetric mapping will be produced at scales of 1:50,000 and smaller, and evaluated against redundant ground control already available, and against existing larger scale mapping at 1:25,000. Photomap sections will also be produced and evaluated as to their usefulness for mapping - particularly in the Canadian northland.

The mensuration, map production, analysis and evaluation will result in a quantitative and qualitative assessment of the value of satellite metric photography (S190 system) for mapping and map revision.

The S192 multispectral scanner data will be used in the development of interpretation techniques. The Canada Centre for Remote Sensing (CCRS) will conduct research investigations in automatic interpretation of image data from aircraft and spacecraft. Emphasis will be placed on classification of cover types. CCRS will be assisted in the collection of ground truth along the satellite path by several federal and provincial agencies. CCRS will make use of its ERTS and aircraft data handling facility and an interactive multispectral analyzer display system in these investigations.

Several other Canadian government departments are very interested in obtaining the S192 imagery from CCRS for resource studies within their jurisdiction. These include the Department of the Environment (forestry, oceanography, inland waters) and the Department of Agriculture.

1.4 These provisions shall become effective on the date of signature and remain in effect until 12 months from last receipt of data unless extended by the mutual agreement of NASA and the Principal Investigator.

1.5 The efforts required by this agreement are limited to those identified in the PI proposal, as amended and/or modified by this agreement.

1.6 Any change in the scope or the objective of the approved investigation and analysis as defined in the Task Description requires the prior approval of NASA.

Requests for changes should be sent as noted below:

Six copies to: Director, Earth Observations Programs
Code ER, NASA Headquarters
Washington, D.C. 20546

One copy to: NASA Office of International Affairs
Code I, NASA Headquarters
Washington, D.C. 20546

Two copies to: EREP Technical Monitor, Code TF6
NASA Manned Spacecraft Center
Houston, Texas 77058

1.7 Should the requirements stipulated in the Principal Investigator's proposal differ from the requirements stipulated in these provisions, the requirements of these provisions will prevail.

2. Phase Approach:

The approved investigation and analysis will be performed in two major phases:

2.1 Phase I--Preparation

2.1.1 The Principal Investigator should establish a state of readiness to receive, process and analyze the Skylab data. Typical preparations include, but are not limited to, participation in generating the Investigation Requirements Document (IRD), equipment setups, test runs using simulated data (as available), data analyses, literature searches and surveys, etc.

2.1.2 Milestone Plan

Concurrent with 2.1.1 above, the Principal Investigator will generate as detailed and firm a schedule as possible that identifies start/stop dates for each data activity; data (by type) need dates; major analysis program milestones; etc.

2.2 Phase II--Data Analysis

This phase will begin upon receipt by the Principal Investigator of Skylab EREP data. The purpose of this phase is to utilize the Milestone Plan and data reduction and analysis techniques developed in Phase I to complete the investigation proposed. This phase will complete the period of performance of the investigation.

More specifically the Principal Investigator will:

2.2.1 Process (as required) and analyze Skylab data received from NASA.

2.2.2 Evaluate and, if necessary, revise or modify the Investigation Requirements Document, task description, and milestone plans to assure compatibility with any revised and improved data processing procedure and/or analysis technique.

2.3.3 The Principal Investigator shall publish the results of his efforts as soon as possible in the open literature; however, NASA concurrence to release such results and related data as delineated in paragraph 8, "Data Release and Use Restrictions" should be obtained.

2.3.4 Prepare a Final Report as specified in paragraph 4.2.

3. Tasks Description

3.1 EREP Technical Investigations

3.1.1 Mission Support

. The PI shall assist NASA/MSC in mission planning activities related to the proposed investigation. The mission planning activities shall include but not be limited to:

a. Site definition and constraints
b. Scientific and calibration data and photographic requirements
c. Normal and contingency operations

In addition, the PI shall assist NASA/MSC during the mission in providing guidance concerning real time EREP pass planning.

3.1.2 Scientific Requirements

The PI shall be responsible for establishing the scientific requirements and/or objectives for the investigative tasks and shall participate as may be required in reviews relating to the performance, operation and data requirements.

3.1.3 Supporting Studies

The PI shall conduct those supporting studies (i.e., ground measurements, analysis of aircraft data) that are required to complete the approved tasks.

The PI shall prepare reports which describe the results and analysis of the studies and shall be submitted to NASA/MSC as part of the progress report.

3.1.4 Scientific Data Reduction and Analysis

The PI shall be responsible for the reduction, analysis and interpretation of the EREP data. Specifically these activities include completion of tasks identified in items (1) through (5) in Section 1.3.

4. Reports

The Principal Investigator will prepare the documents and reports listed below and forward them with all transportation costs prepaic to the addresses indicated.

4.1 Quarterly Reports

Four copies of Quarterly Progress Reports will be prepared in English and forwarded to NASA as noted in paragraph 5.0. The first Progress Report will be submitted three months after initiation of Phase I and should be received at NASA within ten days after the end of the period reported. This report may be in letter form and will contain as a minimum the following information.

4.1.1 Title of the Investigation.

4.1.2 NASA Headquarters proposal identification number, (i.e., SR 558-1/2).

4.1.3 A discussion and summary of the accomplishments during the reporting period and those planned for the next reporting period.

4.1.4 A discussion of significant results and their relationship to practical applications and/or operational problems.

4.1.5 A description of major problems impeding the progress of the investigation.

4.1.6 A list of published articles and/or papers, preprints, etc. that were released during the reporting period.

4.1.7 Recommendations concerning practical changes in analytical operations or additional investigative effort leading to the maximum utilization of the Skylab EREP data.

4.2 Final Report

Ten copies of the Final Report will be prepared in English and forwarded to NASA as noted in paragraph 5.0; such report to be prepared not later than the final 90 days of Phase II. One draft copy, in English, will be submitted to the NASA Technical Monitor not later than 60 days prior to the end of Phase II for review. The Principal Investigator will be notified of any NASA comments on the report within 30 days after receipt of the draft by NASA.

4.2.1 Content - The Final Report will be a comprehensive summary of the information submitted in the Quarterly Reports and will be a complete and self sufficient document defining all aspects and results of the investigation. As a minimum the following information will be included:

4.2.1.1 Front cover in format of attached Figure 1., "Sample Report Cover."

4.2.1.2 Index of the major categories of information included.

4.2.1.3 The Technical Approach and Task Description as included herein.

4.2.1.4 A narrative history of the investigation.

4.2.1.5 A discussion of the techniques and procedures used.

4.2.1.6 A summary of the Skylab data furnished and a definition of the conditions under which the data was obtained.

4.2.1.7 A summary of ground truth activities. (Rough field notes shall be included as an addendum to the Final Report).

4.2.1.8 A discussion of the problems encountered and their resolution.

4.2.1.9 A discussion of the results and findings of the investigation.

4.2.1.10 The recommendations of the Principal Investigator with respect to utilization of space sensed data for practical application of the findings of the investigation to earth related tasks and problems.

4.3 Professional Reports

Five copies of all published reports, in-house reports, scientific papers, theses, etc., resulting from the effort performed under this agreement shall be forwarded in English, to NASA as noted in paragraph 5.0.

5. Report Submission - Formal submission of reports required in the performance of this agreement shall be to the addressee and in the quantities specified below.

Addressee	Quarterly Reports	Final Report	Professional Reports
Director, Earth Observations Programs Code ER, NASA Headquarters Washington, D.C. 20546	One Copy	One Copy	One Copy
NASA Office of International Affairs Code I, NASA Headquarters Washington, D.C. 20546	One Copy	One Copy	One Copy
EREP Technical Monitor Code TF6 NASA Manned Spacecraft Center Houston, Texas 77058	Two Copies	Seven Copies	Two Copies
Technical Library Branch Code JM6 NASA Manned Spacecraft Center Houston, Texas 77058	None	One Copy	None

6. Investigation Data Availability

NASA will use its best efforts to obtain and process the data required by the Principal Investigator in such a manner as to achieve the quality and timeliness required to support the Principal Investigator's efforts. Because of the multiplicity of requirements for data by numerous Principal Investigators and as a result of other Skylab program requirements and limitations, some compromises in data acquisition and processing may result, but such decisions will include the most careful consideration of the requirements of these provisions.

6.1 Substitute Data

If the data required to perform the tasks specified in these provisions are not available for the site requested, then upon mutual agreement of the NASA and the Principal Investigator, data relating to an alternate site may be provided.

7. Investigation Data Definition

The Skylab EREP data to be furnished in support of this investigation will be specified in an Investigation Requirements Document (IRD) which shall be initiated by the Technical Monitor based on the proposal received and will be verified by the Principal Investigator prior to the applicable Skylab missions.

8. Data Use and Release Restrictions

A. The Principal Investigator and Department of Energy, Mines, and Resources will not use for other than government purposes, nor release nor publish, any analysis/findings, or techniques developed under this agreement or any information derived therefrom, until such analysis/findin or techniques have been reported to NASA in the manner prescribed by this agreement and the Principal Investigator has been informed by NASA in writing that such reported analysis/findings or techniques have been made available to the general public.

B. If it is necessary in fulfilling the requirements of this agreement that the Principal Investigator release or disclose to others said analysis/findings or techniques, or any information derived therefrom, prior to being advised by NASA that such has been made available to the general public, the Principal Investigator will, before such release or disclosure, obtain a written agreement from the recipient to abide by the foregoing release and use restrictions.

9. Delivery and Archiving of Data:

9.1 The EMAR will arrange for meeting the cost of shipping EREP data to the Principal Investigator. Insofar as possible, NASA will ship the data in the manner requested. However, data will be shipped to the Principal Investigator by the most expedient and direct route possible so as not to delay the investigation.

9.2 The data can be shipped in accordance with paragraph 1, 2, or 3 below:

9.2.1 The data can be sent air freight-collect from the NASA Manned Spacecraft Center, Houston, Texas to the Principal Investigator or sponsoring agency.

9.2.2 The data can be mailed from the NASA Manned Spacecraft Center, Houston, Texas to the appropriate foreign embassy or mission in Washington, D.C., or be picked up at the NASA Manned Spacecraft Center by a designated contact. The embassy, mission or other designated contact may then forward the data to the Principal Investigator or sponsoring agency.

9.2.3 (Other), as requested by the Principal Investigator and agreed to by NASA.

9.3 Any anticipated delay in scheduled completion of the agreed effort resulting directly from untimely availability of required data or for other reasons should immediately be brought to the attention of the Technical Monitor in writing.

9.4 NASA is presently in the process of establishing a system for cataloguing and archiving EREP investigation data. When the NASA cataloguing and archiving system is finalized, the Principal Investigator will be sent information which will explain how the system operates. Thereafter, the Principal Investigator may be requested to aid in the identification of, and the incorporation of EREP data related to his investigation into the NASA system.

10. Use of the International System of Units (SI):

Measurement values should be expressed in the International System of Units. Both SI units, and customary units can be used where the use of SI units would impair communications or reduce the usefulness of the report. When both systems are used, SI units should be stated first and customary units afterwards; i.e., 1000 KM (621.4 miles .

In each case, the report should state which system of units was used for the original measurements and calculations.

11. Disposition of NASA Property:

Any magnetic tapes furnished by NASA will remain the property of NASA. The Principal Investigator will be responsible for maintaining an accurate record of the quantity of such tapes furnished him and return the same no later than six months following completion of the investigation or whenever the data contained on them has served its useful purpose and is no longer required by the investigator. Return shipment should be to:

NASA Manned Spacecraft Center
Houston, Texas 77058
Attention: Code FD5 - CMDF

12. Technical Direction

NASA Technical Direction to the Principal Investigator will be through the NASA Technical Monitor and will be limited to directions which fill in details, suggest possible lines of inquiry or otherwise more specifically, define the work set forth in these provisions. This technical direction will not materially change the intent of the Technical Approach or Tasks Description as stated herein. All such technical direction will be in writing. The Technical Monitor for this investigation is:

Mr. Roger D. Hicks
Code TF6
NASA Manned Spacecraft Center
Houston, Texas 77058

13. NASA Sponsored Conferences

A NASA sponsored conference may be held relative to the EREP Investigations. This conference will be for the purpose of presenting the results of the final report submitted. The Principal Investigator or, if necessary, his designee agrees to attend the conference if requested.

Dept. EMR.
Signature for Sponsoring Institution

Feb 2 1973
Date

C. Stewart
Principal Investigator

Feb. 6, 1973
Date

EXAMPLE

Title of Investigation —— WIND EROSION OF SOILS

Principal Investigator —— Claudius Xenia

Name and address of Principal Investigator's Organization —— ____________________
____
____

Date —— September 1972

Type of report and period covered —— Quarterly Progress Report for Period July-September 1972

Name and address of national sponsoring agency —— ____________________
____
____

NASA Manned Spacecraft
Center
Houston, Texas 77058

Figure 1. Sample Report Cover

APPENDIX B

TO

"INVESTIGATION OF SELECTED IMAGERY FROM SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

APPENDICES RELATED TO

INVESTIGATION I

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA

APPENDIX B.1

RESULTS OF ADJUSTMENTS
OF INVESTIGATION I

PRE-ADJUSTMENT CORRECTIONS INVOLVED

Type of Transformation	Plate #	Focal Length Inches	Corrections		
			Lens Dist.	Earth Cur.	Reseau
Similarity	314	6		✓	✓
	315	6		✓	✓
	314	24		✓	✓
	315	24		✓	✓
Similarity (9-point)	314	6		✓	✓
	315	6		✓	✓
	314	24		✓	✓
	315	24		✓	✓
Projectivity	314	6		✓	✓
	315	6		✓	✓
	314	24		✓	✓
	315	24		✓	✓
Projectivity (9-point)	314	6		✓	✓
	315	6		✓	✓
	314	24		✓	✓
	315	24		✓	✓
3D - PATM (input - STK1)	Model 314/315	6		✓	✓
3D - PATM (input - STK1)	Model 314/315	24		✓	✓
3D - Shut (input - A/Plotter	Model 314/315	24		✓	

ADJUSTMENT RESULTS OF 2-DIMENSIONAL TRANSFORMATIONS

Type of Transformation	Plate #	Focal Length	Total Cont.	# Used	%	R.M.S. (meters)			Not Used	%	R.M.S. (meters)		
						X	Y	Pos'n			X	Y	Pos'n
Similarity	314	6	29	21	72	319	303	440	8	28	882	1759	1968
	315	6	34	27	79	69	63	93	7	21	418	307	519
	314	24	30	26	87	90	77	119	4	13	246	261	359
	315	24	34	27	79	66	67	94	7	21	136	275	307
Similarity (9-point)	314	6	29	9	31	382	352	520	20	69	599	1131	1280
	315	6	34	9	27	73	69	100	25	73	222	170	280
	314	24	30	9	30	86	85	121	21	70	140	127	188
	315	24	34	9	27	67	77	102	25	73	97	158	185
Projectivity	314	6	29	22	76	34	31	46	7	24	943	2076	2280
	315	6	34	30	88	32	18	37	4	12	570	195	603
	314	24	30	23	77	25	21	33	7	23	156	207	259
	315	24	34	30	88	30	24	38	4	12	129	131	185
Projectivity (9-point)	314	6	29	9	31	99	67	120	20	69	518	1234	1339
	315	6	34	9	27	25	22	33	25	73	228	97	248
	314	24	30	9	30	24	30	38	21	70	101	120	157
	315	24	34	9	27	29	24	37	25	73	66	74	99

APPENDIX B.1-c

ADJUSTMENT RESULTS OF 3-DIMENSIONAL TRANSFORMATIONS

Type of Transformation	Model	Focal Length	Control			# Used		R.M.S. (meters)				# Not Used		R.M.S. (meters)		
			H	V		H	V	X	Y	Z		H	V	X	Y	Z
3D - PATM (input - STK1)	314/315	6"	17	17	#	12	11	100	88	72	#	5	6	763	761	1322
								Position = 133						Position = 1077		
					%	71	65				%	29	35			
3D - PATM (input - STK1)	314/315	24"	17	17	#	16	13	18	19	110	#	1	4	215	354	1483
								Position = 26						Position = 414*		
					%	94	76				%	6	23			
3D - Shut (input - A/Plotter)	314/315	24"	17	28	#	17	27	41	28	114	#	0	1	0	0	176
								Position = 51						Position = 0		
					%	100	96				%	0	4			

APPENDIX B.1-c

APPENDIX B.2

POSITIONAL ACCURACY
OF
S190A PHOTOGRAPHY
WITH RESPECT TO
NATO MAP STANDARDS

POSITIONAL ACCURACY W.R.T. NATO MAP STANDARDS

Type of Transformation	Plate or Model	Focal Length Inches	Control Used			Control Not Used			NATO Map Class.
			Position Error (meters)	Inches at 1:250000	% of Control	Position Error (meters)	Inches at 1:250000	% of Control	
Similarity	314	6	440	.069	72	1968	.310	28	C
	315	6	93	.015	79	519	.082	21	C
	314	24	119	.019	87	359	.056	13	C
	315	24	94	.015	79	307	.048	21	C
Similarity (9-point)	314	6	520	.082	31	1280	.202	69	C
	315	6	100	.016	27	280	.044	73	C
	314	24	121	.020	31	188	.030	70	B
	315	24	100	.016	27	185	.029	73	B
Projectivity	314	6	46	.007	76	2280	.359	24	C
	315	6	37	.006	88	603	.095	12	C
	314	24	33	.005	77	259	.041	23	C
	315	24	38	.006	88	185	.029	12	B
Projectivity (9-Point)	314	6	120	.019	31	1339	.211	69	C
	315	6	33	.005	27	248	.039	73	B
	314	24	38	.006	30	157	.025	70	B
	315	24	37	.006	27	99	.016	73	A

POSITIONAL ACCURACY W.R.T. NATO MAP STANDARDS

Type of Transformation	Plate or Model	Focal Length Inches	Control Used			Control Not Used			NATO Map Class.
			Position Error (meters)	Inches at 1:250000	% of Control	Position Error (meters)	Inches at 1:250000	% of Control	
3-D PATM (input - STK1)	314/315	6	133	.021	71	1077	.170	29	C
3-D PATM (input - STK1)	314/315	24	26	.004	94	414*	.065	6	A
3-D Shut (input-A/Plotter)	314/315	24	51	.008	100	NIL	.000	NIL	A

* Not valid; one point only

APPENDIX B.3

IDENTIFICATION OF GROUND
CONTROL POINTS
INVESTIGATION I

SKYLAB - BAY OF FUNDY

PLANIMETRIC ACCURACY TEST

APS #954 552

Ground co-ordinates of selected photo points in U.T.M. Zone 20.

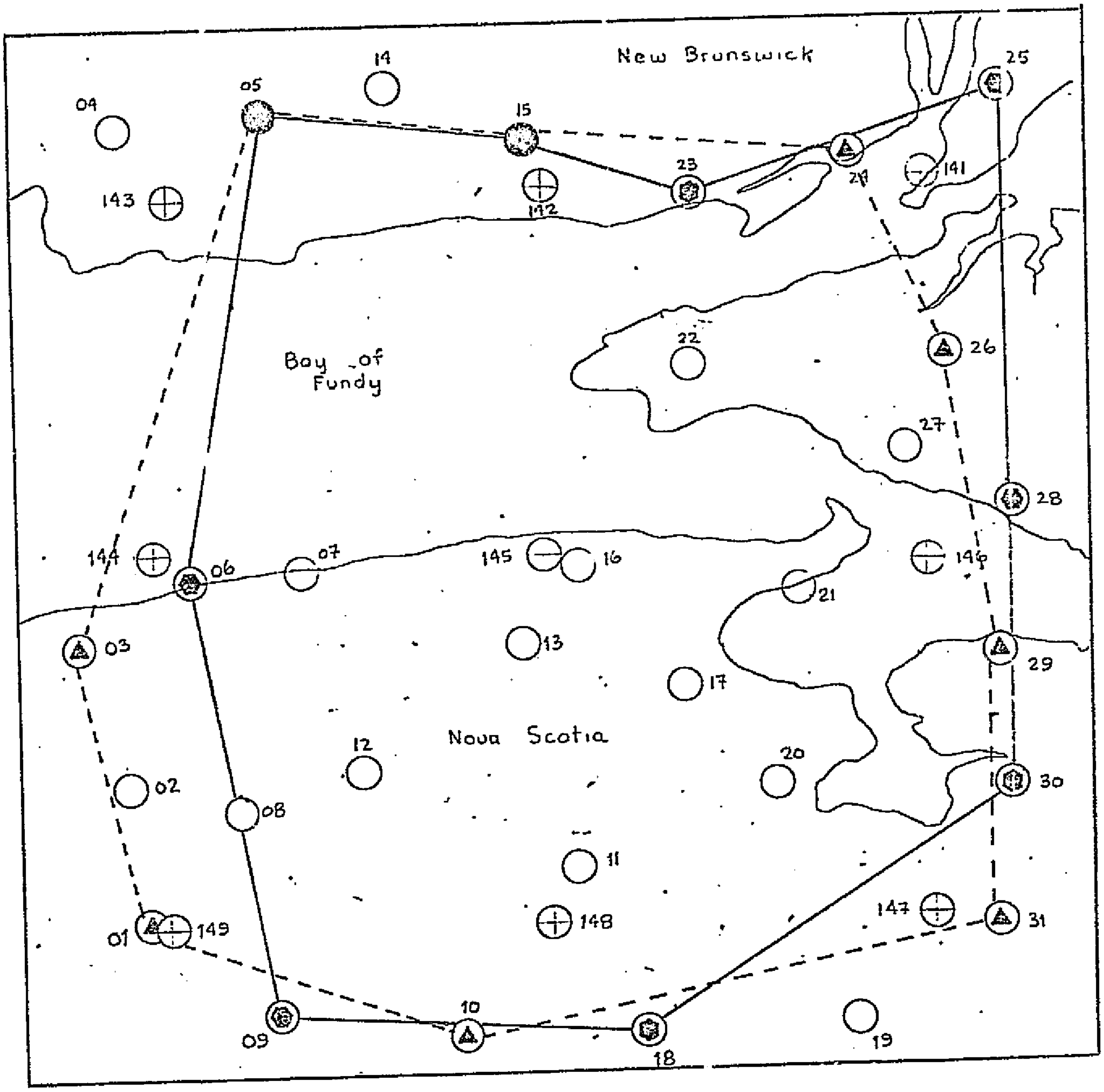
Point No.	E.	N.	Elev. (ft.)	Map Sht. No.
1	321 245	4 921 205	310	21A/6
2	308 930	4 938 595	550	21A/11W
3	293 745	4 954 595	65	21A/12E
4	267 625	5 030 290	200	21H/5
5	286 910	5 040 665	160	21H/5
6	305 670	4 969 055	210	21A/14W
7	320 645	4 977 665	320	21A/14W
8	327 030	4 940 910	645	21A/11E
9	343 445	4 916 165	285	21A/7W
10	369 840	4 923 510	270	21A/7E
* 11	375 850	4 954 175	545	21A/10E
12	339 770	4 953 585	670	21A/11E
* 13	354 425	4 982 615	135	21A/15W
14	302 400	5 051 385	490	21H/12E
* 15	324 275	5 052 370	964	21H/11W
* 16	357 160	4 995 990	665	21H/2W
* 17	378 795	4 986 370	700	21H/2E
* 18	394 660	4 934 500	45	21A/9W
* 19	422 820	4 948 255	165	11D/12
* 20	397 300	4 976 240	325	21A/16W
* 21	388 365	5 005 815	630	21H/1W
* 22	362 325	5 032 490	295	21H/7
* 23	350 170	5 053 890	225	21H/10W
* 24	369 005	5 069 205	50	21H/15E
* 25	386 500	5 087 370	475	21H/16W
* 26	394 340	5 046 305	130	21H/9W
* 27	393 995	5 030 395	90	21H/8
* 28	413 120	5 029 650	75	21H/8
* 29	419 505	5 008 010	140	21H/1E
* 30	429 860	4 990 065	190	11E/4W
* 31	436 680	4 969 520	470	11D/13
32	459 740	4 970 320	420	11D/13
33	449 340	4 993 260	370	11E/4E
34	437 270	5 014 785	123	11E/5W
35	419 310	5 050 870	630	21H/9E
36	413 505	5 068 125	480	21H/16E
37	405 650	5 088 320	45	21H/16E
38	418 665	5 102 025	27	21I/1
39	438 160	5 076 265	150	11E/13W
40	445 600	5 051 420	475	11E/12

.../2

* Common Control

Point No.	E.	N.	Elev. (fr.)	Map Sht. No.
41	463 720	5 029 665	140	11E/6W
42	477 050	4 996 870	78	11E/3
43	481 320	4 981 215	90	11D/14
44	494 890	4 991 960	150	11E/3
45	483 890	5 041 565	575	11E/11E
46	470 635	5 068 585	140	11E/14W
47	434 605	5 109 225	38	11L/4

Appendix B.3-1



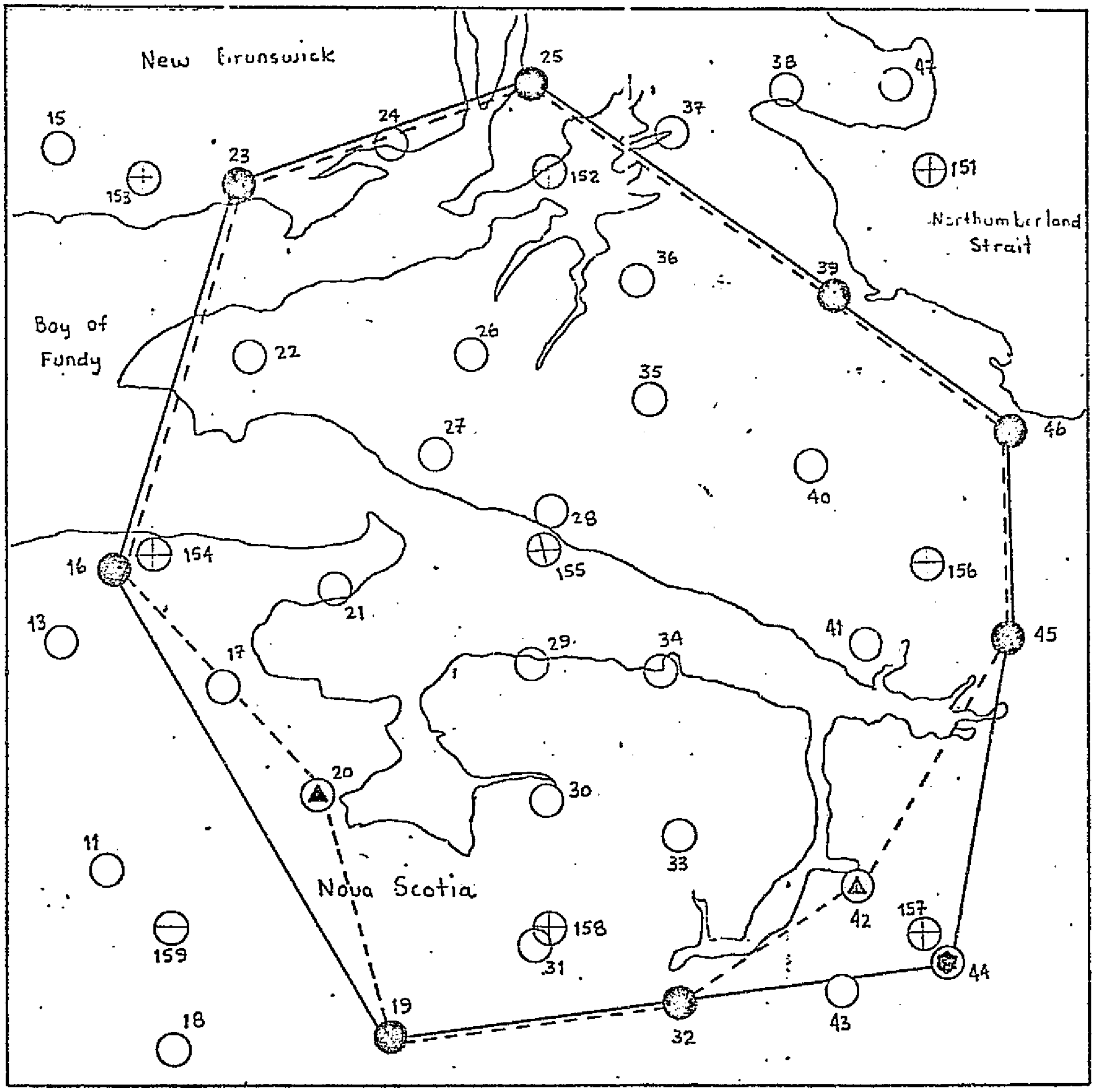
Diagrammatic Sketch of SKYLAB Photo 314

SIMILARITY TRANSFORMATION

9-Point Control Distribution

● - points used on 6" format
▲ - points used on 24" enlarged format
⊛ - points used in both cases
⊕ - reseau points

Appendix B.3-b



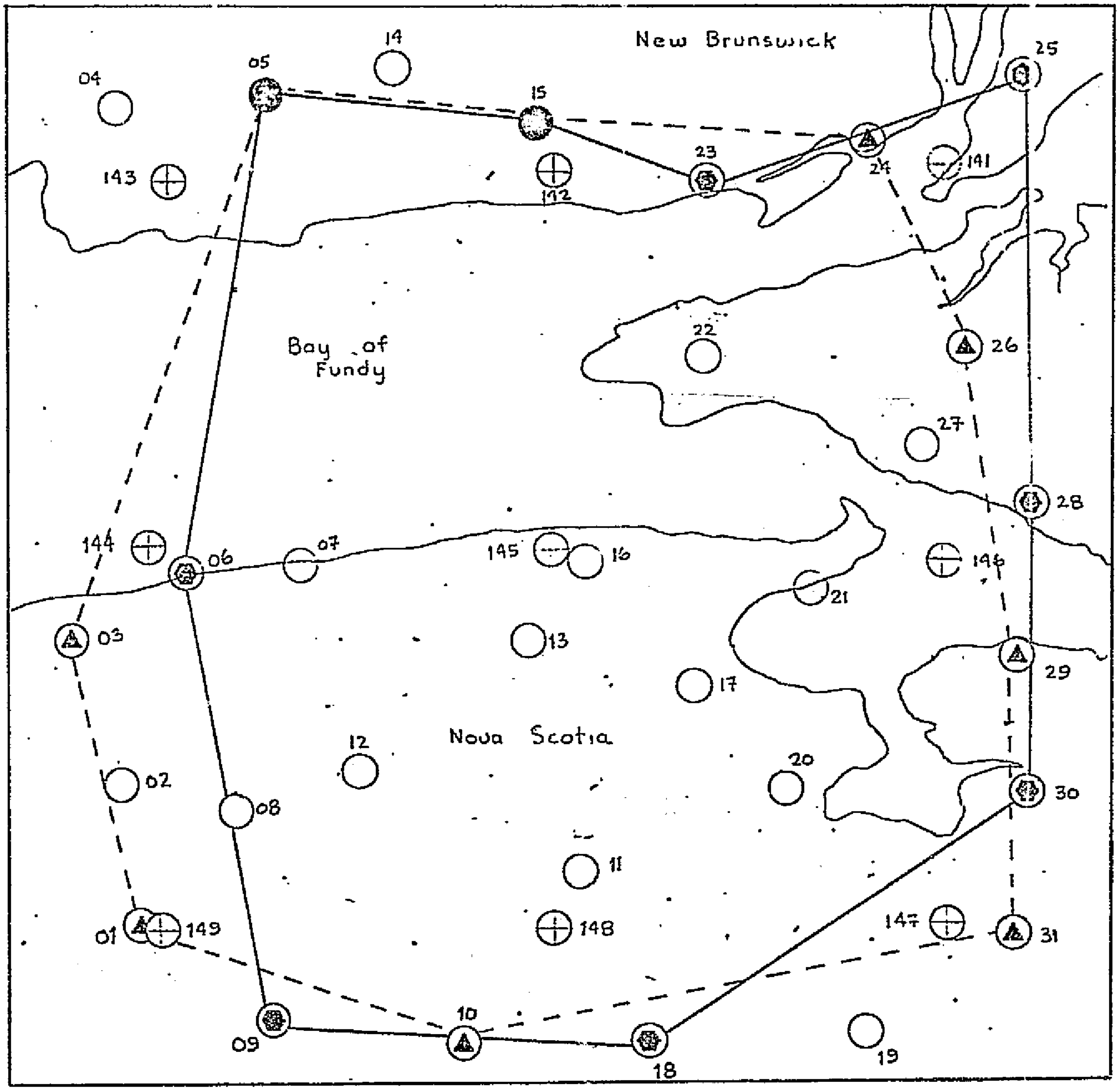
Diagrammatic Sketch of SKYLAB Photo 315

SIMILARITY TRANSFORMATION

9-Point Control Distribution

⬢ - points used on 6" format
△ - points used on enlarged 24" format
● - points used on both
⊕ - reseau points

Appendix B.3-b



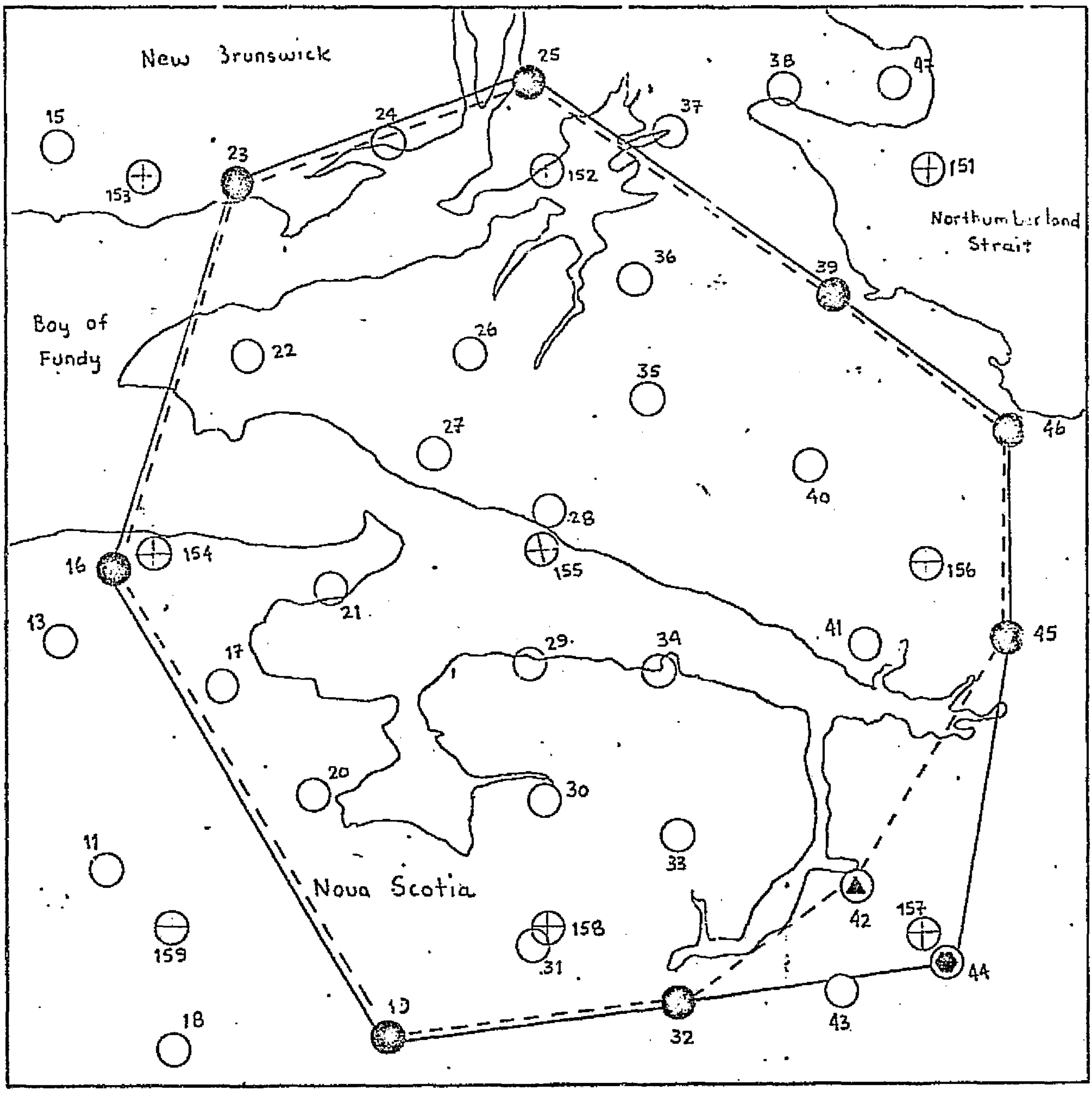
Diagrammatic Sketch of SKYLAB Photo 314

PROJECTIVITY TRANSFORMATION

9-Point Control Distribution

⊙ - points used on 6" format
Ⓐ - points used on 12" enlarged format
● - points used in both cases
⊕ - reseau points

Appendix B.3-b



Diagrammatic Sketch of Skylab Photo 315

PROJECTIVITY TRANSFORMATION

9-Point Control Distribution

⊛ - points used on 6" format
◬ - points used on 24" enlarged format
● - points used in both cases
⊕ - reseau points

APPENDIX B.4

REPORT ON SKYLAB OBSERVATIONS
PERFORMED BY THE
MAPPING AND CHARTING ESTABLISHMENT

4 Jul 74

MAPPING AND CHARTING ESTABLISHMENT

COMPILATION DIVISION

AS11A SECTION

NASA SKYLAB PLANIMETRIC ACCURACY TEST FOR EMR

1. Request: An absolute orientation of two (2) Skylab film positives and supply the following information and manuscript to Energy, Mines and Resources:

    a. the scale of the model after absolute orientation;

    b. a model point coordinate listing of common points observed;

    c. a listing of reseau intersection coordinates, observed monocularly on each diapositive;

    d. listed differences at model scale of common points observed;

    e. a pencil trace of coastal outline (including island at "A" shown on print) at scale of 1/250,000.

2. Requested by: Mr A. Sturrock - Dept of Energy, Mines and Resources.

3. Date of Request: 2 July 1974

4. Source Information:

    a. Camera Station 5 of Multispectral System S190A.

    b. Calibrated "f" - 6" (original format)

    c. Format Size - 70 mm (original)

    d. Flying Height - 425 km (average)

    e. Lens Distortion - Nil (alleged distortion free)

    f. Size of Reseau - 20 mm (at original format size)

    g. Reseau Origin - Assume centre intersection is the PP.
    No offset to be applied.

.../2

h. Atmospheric Refraction - Nil

j. Film Dist. Correction - Nil.

5. Source Material:

a.	Flagged Film Positives	314-315
b.	Annotated Prints	314-315

c. Film clip of Second Generation 70 mm size Diapositives

d. Ground Horizontal Coords and Map Identities of annotated points, Zone 20.

e. Extracts from Skylab Data Publications.

6. AS11A Procedure:

a. Find Photo Scale.

b. Record Reseau Intersections (monocularly).

c. Perform a material evaluation.

d. Prepare Model Data.

e. Compute radius of the earth.

f. Compute enlargement factor and principal distance.

g. List map derived elevations.

h. Perform a relative orientation.

j. Perform an absolute orientation.

k. Read points and run through a linear adjustment.

m. Compile shoreline of the Bay of Fundy.

n. Model Scale after absolute orientation was 1/667167.

7. Adjustment Results - with linear terms [illegible]

x = STD = 36.96 metres
y = STD = 26.87 metres
ELV = STD = 148.00' or 45.11 metres

.../3

C.2

8. Remarks:

   a. Photo reproduction of the film positives was poor.

   b. Relative orientation was very difficult and some pockets of parallax were impossible to remove. I believe a Lens Distortion Correction is needed.

   c. Earth's radius was introduced into the AS11A System not the Adjustment.

   d. Some water elevations were picked up to aid the Vertical Adjustment. It appears that with more vertical control, the vertical adjustment improves.

9. Completion: 4 July 1974

MENSURATION MATERIAL EVALUATION - ASIIA

JOB NO. & NAME: NASA SKYLAB PHOTOG: P or F FRAME PHOTO NOS: 314 - 3

EVALUATION BY: G. G. DALGITY (M.C.E.) DATE: 2 / JULY / 1974

Legend: N - Nil, VP - very poor, P - poor, F - fair, G - good, VG - very good

PHOTO # 314

43 41

	P	P
	F	F
	F	F

49 47

Reseau FAIR

Density POOR

Contrast POOR

Features POOR

Film defects SCRATCHES

FILM IS TOO DARK

Gen. Definition: FAIR

PHOTO # 315

53 51

P	P	
F	F	
F	F	

59 57

Reseau FAIR

Density POOR

Contrast POOR

Features POOR

Film defects SCRATC

FILM IS TOO DARK

Gen. Definition: FAIR

MODEL: 314-315

P	VP	P
F	F	F
F	F	F

Percent. Stereo: 95%

PHOTO #

Reseau

Density

Contrast

Features

Film defects

Gen. Definition:

PHOTO #

Reseau

Density

Contrast

Features

Film defects

Gen. Definition:

MODEL:

Percent. Stereo:

Remarks:

1. FILM REPRODUCTION IS THE CAUSE OF SOME AREAS OF POOR DEFINITION AND CONTRAST
2. REASEAUS ARE NOT CLEAR AND PRONOUNCED.
3. SOME CLOUD AREAS.

1 OF 2

NASA SKYLAB PLANIMETRIC ACCURACY TEST

AS11A PLOTTER M.C.E.

MAP DERIVED ELEVATIONS FOR HORIZONTAL CONTROL

POINT NUMBER	ELEVATION IN FEET
1	310
2	550
3	65
4	200
5	160
6	210
7	320
8	645
9	285
10	270
11	545
12	670
13	135
14	490
15	* 964
16	665
17	700
18	45
19	165
20	325
21	* 630
22	* 295
23	225
24	50
25	475
26	130
27	90
28	75
29	140
30	190
31	470
32	420
33	370
34	* 123
35	630
36	480
37	45
38	27
39	150

CON'T......

* indicates B.M elevation

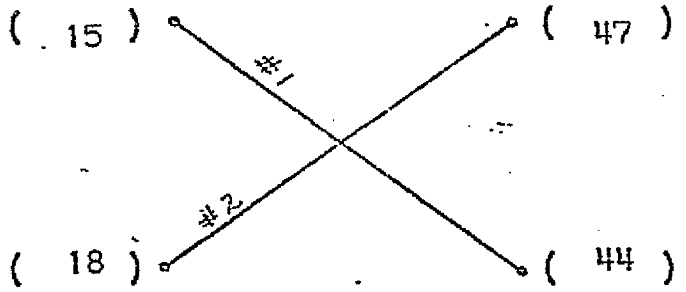
40	475
41	140
42	* 78
43	90
44	150
45	575
46	140
47	38

PREPARATION FORM - AS11A

Classified: ~~Yes~~/No

COMPUTE PHOTO SCALE

Job: NASA SKYLAB Line: ______ W.O. No. ______ Photo: 314-315



MEASURED PHOTO DISTANCE

Diagonal No. 1 = .259 mtrs

Diagonal No. 2 = .256 mtrs

COMPUTED GROUND DISTANCE

			E.	N.
Diagonal No. 1	Point	15	324 275	5 052 370
	Point	44	494 890	4 991 960
			ΔE= 170615	ΔN= 60 410

$\sqrt{\Delta E^2 + \Delta N^2}$ = 180994.05 metres

Photo Scale No. 1 = 1: 698 819

Diagonal No. 2	Point	18	394 660	4 934 500
	Point	47	434 605	5 109 225
			ΔE= 39 945	ΔN= 174 725

$\sqrt{\Delta E^2 + \Delta N^2}$ = 179232.88 metres

Photo Scale No. 2 = 1: 700 128

Average Photo Scale = 1: 699 473

Computed by: G G DALGITY Checked by: ______ Date: 2/JUL

RESEAU INTERSECTION COORDINATES OBSERVED MONOCULARLY ON EACH DIAPOSITIVE

DIAPOSITIVE 314			DIAPOSITIVE 315		
41	x	80.533	51	x	80.533
	Y	80.635		Y	80.633
42	x	0.008	52	x	0.003
	Y	80.608		Y	80.608
43	x	- 80.487	53	x	- 80.490
	Y	80.612		Y	80.615
44	x	- 80.505	54	x	- 80.515
	Y	0.025		Y	0.028
45	x	0.000	55	x	0.000
	Y	0.000		Y	0.000
46	x	80.550	56	x	80.553
	Y	0.018		Y	0.003
47	x	80.590	57	x	80.583
	Y	- 80.660		Y	- 80.670
48	x	0.003	58	x	- 0.007
	Y	- 80.655		Y	- 80.655
49	x	- 80.562	59	x	- 80.577
	Y	- 80.612		Y	- 80.615

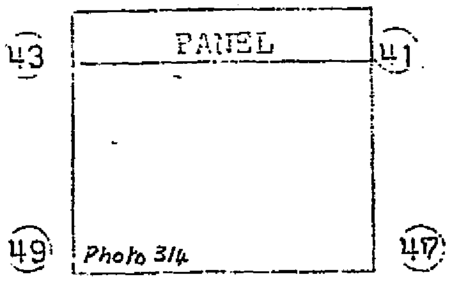
PREPARATION FORM - ASITA

Classified: ~~Yes~~/No

COMPUTE PRINCIPAL DISTANCE OF DIAPOSITIVE - NORMAL PHOTOGRAPHY NO C_F FACTOR APPLIED

Job: NASA SKYLAB Line: ______ W.O. No. ______ Photos: 314-315

FIDUCIALS



Camera type:
Lens type:
Lens number:
Date of calib:

Cal focal length = 152.400 MM

CALIBRATED FIDUCIAL DISTANCES (m.m.)

43 - 41 40.000 41 - 47 40.000 47 - 49 40.000 49 - 43 40.000

Averaged Calibrated Distance = 40.000

OBSERVED FIDUCIAL COORDINATES: Plate No.: 314

	43	49	47	41
x	-80.487	-80.562	+80.590	+80.533
y	80.612	-80.612	-80.660	80.635

OBSERVED DISTANCES:

43 - 41 161.020 41 - 47 161.295 47 - 49 161.152 49 - 43 161.224

Averaged Observed Distance = 161.1727

$$\text{ENLARGEMENT FACTOR (\_\_\_\_ exposures used)} = \frac{\overset{161.1758}{\text{AVERAGED OBSERVED DISTANCES}}}{\underset{40.0000}{\text{AVERAGED CALIBRATED DISTANCES}}} = 4.0293$$

PRINCIPAL DISTANCE = CAL. FOCAL LENGTH X E.F. = 614.653

Computed by: G. G. DALCIT Checked by: ______________ Date: 2/ JULY / 74

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PREPARATION FORM - AS11A

COMPUTE PRINCIPAL DISTANCE OF DIAPOSITIVE - NO CF (Cont'd)

OBSERVED FIDUCIAL COORDINATES: Plate No.: 315

(53) - x -80.490 (59) - x- 80.577 (57) - x +80.583 (51) - x +80.533
y +80.615 y- 80.615 y -80.670 y +80.633

OBSERVED DISTANCES:

(53) - (51) 161.023 (51) - (57) 161.303 (57) - (59) 161.160 (59) - (53) 161.230

AVERAGED OBSERVED DISTANCE = 161.1790

Plate No.: ____

A' - x ___.___ B' - x ___.___ C' - x ______ D' - x ______
y ___.___ y ___.___ y ______ y ______

A' - B' ___.___ B' - C' ___.___ C' - D' ___.___ D' - A' ______

AVERAGED OBSERVED DISTANCE = ___.___

Plate No.: ____

A' - x ___.___ B' - x ___.___ C' - x ___.___ D' - x ___.___
y ___.___ y ___.___ y ___.___ y ___.___

A' - B' ___.___ B' - C' ___.___ C' - D' ___.___ D' - A' ___.___

AVERAGED OBSERVED DISTANCE = ___.___

Computed by: ____ Checked by: ____ Date: ____

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OF POOR QUALITY

1 of 2

ASIIA PREPARATION

CLASSIFIED? ~~YES~~/NO

Job: NASA SKYLAB Line: W.O.# Model(s) 314 + 315 Map#

Check Type of Work Requirement :- Production, Training, ~~Other~~ / ~~Bridging, Compilation~~, Other.

PHOTOGRAPHY.

Type: FRAME C.F.L.: 614.653MM. Fl.Ht.: 425 KM ~~ft.~~ H-h: ft.

COMPUTE GEAR RATIOS.

Photo Scale: 1: 699473

Required Manu. Scale: 1: 250000

Ratio: Photo Scale / Manuscript Scale = 1: 2.798

Closest listed Ratio from Gear Tables = 1: 2.666

Model Scale to be used = Manu. Scale x listed Ratio = 1: 666500

Gears to be used	PLOTTER	CO-ORDINATOGRAPH
1:2	L	1:1

COMPUTE CONVERSION FACTORS AT MODEL SCALE OF 1: 666500

1 m.m.	=	Scale denominator/1000	=	666.5	metres.	A
1 m.m.	=	A x 3.2808333	=	2186.675	Feet.	B
1 foot ~~m.m.~~	=	1/B	=		m.m.	C

RADIUS of Earth (R) at Scale

$$\frac{6\ 378\ 000}{\text{Scale Denominator}} \cdot 1000$$

R = 9560 m.m.

G.G. DALGITY

2 of 2

AS11A PREPARATION ~ GROUND CONTROL

CLASSIFIED? ~~YES~~/NO

Job: NASA SKYLAB Line: Zone: 20 • Model Scale: 1: 666500

COMPUTE :- GROUND CONT. TO MODEL SCALE

Hor: Ground Co-ord/A = Model Co-ord.

Vert: a) Elev. in ft / 3.2808333 = Elev. in metres.

b.) Elev. in metres/A = Model Elev. in m.m.

ENT.	EASTING	MODEL EASTING	DIFF. FROM REF.	NORTHING	MODEL NORTHING	DIFF. FROM REF.	ELEV. (metres)	MODEL (m.m.)	DIFF. FROM REF.	REMARKS
15	324 275	486.534	- 96.159	5 052 370	7580.450	+ 69.850	297.18 975 FT	.446	+.158	C1
25	386 500	579.895	- 2.798	5 087 370	7632.963	+122.363	144.78 475 FT	.217	-.071	C2
21	388 365	582.693	0.000	5 005 815	7510.600	0.000	192.02 630 FT	.288	.000	REF POIN
11	375 850	563.916	- 18.777	4 954 175	7433.121	-77.479	163.07 535 FT	.245	-.043	C1
31	436 680	655.184	72.491	4 969 520	7456.144	-54.456	144.78 475 FT	.217	-.071	C2

Classified: ~~Yes~~/No

SHUTDOWN - AS11A INSTRUMENT READINGS

* Job: NASA SKYLAB * Line: ______ * Model: (L) 314 (R) 315

After: ( ) Interior (X) Relative ( ) P.A.C. ( ) F.A.O.

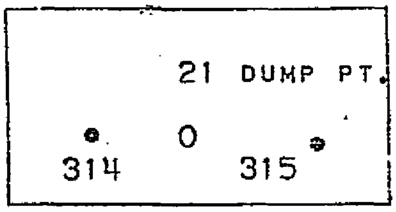
Focal Length: 614.653 Earth Curv. Factor: 9560 Base (x) in ( ) out

Model Point

Xm + 2.828

Ym − 7.550

Em − 0.050



Sketch of Shutdown Point

Photo Point

X_1 + 52,825

Y_1 − 7.550

X_2 − 45.630

Y_2 − 8.740

ORIENTATION ELEMENTS

	Photo No.			Photo No.	
	1 – 7: 31400	CARD #1		1 – 7: 31500	CARD #2
bx_1	8 – 14: - 50.000		bx_2	8 – 14: + 50.000	
by_1	15 – 21: + 0.000		by_2	15 – 21: + 1.158	
bz_1	22 – 28: + 614.653		bz_2	22 – 28: + 612.973	
K_1	+ 0.0000		K_2	+ 0.0009	
W_1	+ 0.0000		W_2	+ 0.0010	
ϕ_1	+ 0.0000		ϕ_2	+ 0.1548	

Operators Remarks	Final Residual Y Parallax			
Completion Time: hrs mins	1		7	
	2		8	
	3		9	
	4		10	
	5		11	
	6		12	
	Final Iteration		No.	

Note: Items marked with asterisks must also be recorded on the Shutdown Tape.

* Operator: G.G. DALGITY Date: 4/7/74

Classified: ~~Yes~~/No

SHUTDOWN - AS11A INSTRUMENT READINGS

* Job: NASA SKYLAB * Line: ______ * Model: (L) 314 (R) 315

After: ( ) Interior ( ) Relative (x) P.A.O. ( ) F.A.O.

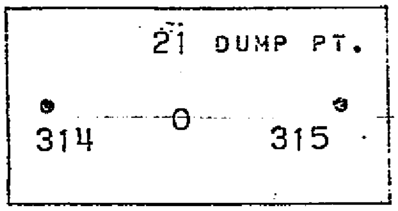
Focal Length: 614.653 Earth Curv. Factor: 9560 Base (x) in ( ) out

Model Point

Xm + 2.970

Ym - .7.915

Em + 0.008



Sketch of Shutdown Point

Photo Point

X_1	+ 52.830	X_2	- 45.620
Y_1	- 7.550	Y_2	- 8.740

ORIENTATION ELEMENTS

	Photo No.			Photo No.	
	1 — 7 31400	CARD #1		1 — 7 31500	CARD #2
bx_1	8 — 14 - 65.670		bx_2	8 — 14 + 39.165	
by_1	15 — 21 - 3.055		by_2	15 — 21 - 1.842	
bz_1	22 — 28 +643.095		bz_2	22 — 28 +643.500	

K_1	+ 0.00000	K_2	+ 0.0009
W_1	+ 0.2720	W_2	+ 0.2730
$\emptyset_1$	- 1.1800	$\emptyset_2$	- 1.0253

Operators Remarks	Final Residual Y Parallax			
Completion Time: hrs mins	1		7	
	2		8	
	3		9	
	4		10	
	5		11	
	6		12	
	Final Iteration		No.	

Note: Items marked with asterisks must also be recorded on the Shutdown Tape.

* Operator: G.G. DALGITY Date: 4/7/74

ABSOLUTE ORIENTATION - SCALING

1.

Mode : 314-315

NASA SKYLAB TEST

DIAGONAL NO. 1

CONTROL AT 1: 666500 SCALE				MODEL AT 1: SCALE			E (GRND)
ID	Xc Microns	Yc Microns	Ec Microns	Xm Microns	Ym Microns	Em Microns	Ec - Em
15	-96.159	69.850	.446	- 56.325	94.953	.443	
31	72.491	-54.456	.217	46.998	- 87.295	.258	
	-168.650	124.306	.229	-103.323	182.248	.185	

CONTROL DISTANCE = CD = $\sqrt{X_c^2 + Y_c^2 + E_c^2}$ MODEL DISTANCE = MD = $\sqrt{X_m^2 + Y_m^2 + E_m^2}$

CD = 209.51099

MD = 209.49943

SCALE FACTOR NO. 1 = $\frac{CD}{MD}$ = $\frac{209.51099}{209.49943}$ = 1.00005

DIAGONAL NO. 2

CONTROL AT 1: 666500 SCALE				MODEL AT 1: SCALE			E (GRND)
ID	Xc Microns	Yc Microns	Ec Microns	Xm Microns	Ym Microns	Em Microns	Ec - Em
11	-18.777	- 77.479	.245	-45.765	- 71.127	.175	
25	- 2.798	122.363	.217	50.123	104.948	.125	
	-21.575	-199.842	.028	- 95.888	-176.075	.050	

CONTROL DISTANCE = CD = $\sqrt{X_c^2 + Y_c^2 + E_c^2}$ MODEL DISTANCE = MD = $\sqrt{X_m^2 + Y_m^2 + E_m^2}$

CD = 201.00325

MD = 200.4917

SCALE FACTOR NO. 2 = $\frac{CD}{MD}$ = $\frac{201.00325}{200.4917}$ = 1.00256

AVERAGE MODEL SCALE = 1: 1.001

2. FINAL SCALING PROCEDURE

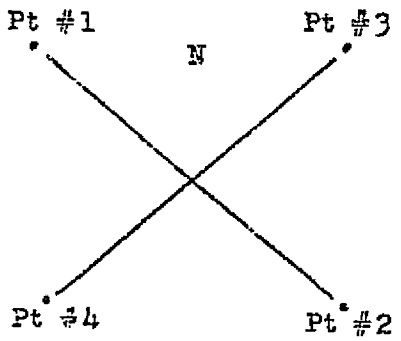
STEP NO. 1 Select the Model Diagonal which is closest to the desired scale.

STEP NO. 2 Multiply the scale factor times bx, by, and bz.

(bx_1)	-	(bx_2)	=	(bx)	•	(Scale Factor)	=	(Scaled bx)	(bx_1)	-	(Scaled bx)	=	(Corrected bz_2)
(by_1)	-	(by_2)	=	(by)	•	(Scale Factor)	=	(Scaled by)	(by_1)	-	(Scaled by)	=	(Corrected by_2)
(bz_1)	-	(bz_2)	=	(bz)	•	(Scale Factor)	=	(Scaled bz)	(bz_1)	-	(Scaled bz)	=	(Corrected bz_2)

STEP NO. 3 Enter the corrected bx_2, by_2, and bz_2 values.

STEP NO. 4 Read and punch selected model diagonal point coordinates and verify the desired scale.



Pt #1 ID ______ ΔZ ______ ft

Pt #2 ID ______ ΔZ ______ ft

Pt #3 ID ______ ΔZ ______ ft

Pt #4 ID ______ ΔZ ______ ft

OPERATORS REMARKS:

ORIGINAL PAGE IS
OF POOR QUALITY

OPERATOR: G.G. DALGITY

DATE: 4/7/74

(Circle selected scaling points)

APPENDIX C

TO

"INVESTIGATION OF SELECTED IMAGERY FROM SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

APPENDICES RELATED TO

INVESTIGATION II

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA

APPENDIX C.1

- STANDARD ERROR OF ONE OBSERVATION, ROLL 47 AND 23, BLACK AND WHITE

ROLL TYPE	FRAME NUMBER	NO. OF POINTS	σx IN MM	σy IN MM
	312 R	53	0.007	0.009
	313 L	53	0.007	0.008
Roll	313 R	57	0.005	0.008
47	314 L	57	0.006	0.009
B & W	314 R	74	0.007	0.008
	315 L	74	0.007	0.009
	315 R	96	0.006	0.007
	316 L	96	0.005	0.007
Roll 23	185 L	43	0.011	0.017
B & W	185 R	43	0.010	0.016

NOTE: L and R indicate the left and right half of a frame respectively.

APPENDIX C.2

ACCURACY OF RELATIVE ORIENTATION

Roll Type	Model Number	No. of Points	σpy in mm	Max Vpy in mm
Roll 47 B & W	3123	51	0.009	0.024
	3134	54	0.010	0.031
	3145	71	0.011	0.041
	3156	95	0.009	0.022
Roll 46 Colour	3123	51	0.013	0.029
	3134	54	0.012	0.031
	3145	74	0.011	0.032
	3156	96	0.010	0.024
Roll 23 B & W	1834	20	0.010	0.024
	1845	41	0.011	0.027
	1856	43	0.008	0.017
Roll 83 Colour	1490	42	0.012	0.029
	1501	49	0.011	0.025
	1512	47	0.010	0.020
	1523	35	0.009	0.021

Note: The last two digits of the model numbers indicate the two frames used to form the model; σpy = standard error of the intersection of corresponding rays; Max Vpy = maximum value of residual parallax

APPENDIX C.3

ROOT MEAN SQUARE ERROR OF DISCREPANCIES AT CHECK POINTS

Roll Type	Model Number	No. of Control Points	No. of Check Points	Check Points Rejected	Ground Scale		Image Scale	
					µX in m	µY in m	µx in mm	µy in mm
Roll 47 B & W	Strip	43	164	7	49.4	63.2	0.018	0.023
	Strip	9	191	13	47.9	67.8	0.017	0.024
	3145	4	58	9	44.0	82.0	0.016	0.030
	3156	4	58	9	42.0	77.1	0.015	0.028
Roll 46 Colour	Strip	9	196	18	76.6	74.6	0.028	0.027
	3145	4	64	7	86.4	83.6	0.031	0.030
	3156	4	87	5	56.7	65.2	0.020	0.024
Roll 23 B & W	Strip	6	81	7	35.9	33.7	0.012	0.012
	1845	4	34	4	35.6	46.1	0.012	0.016
	1856	4	37	4	35.3	34.7	0.012	0.012
Roll 83 Colour	Strip	9	130	5	19.1	28.5	0.020	0.030
	1490	4	41	1	22.3	15.9	0.023	0.017
	1501	4	48	1	19.9	22.8	0.021	0.024
	1512	4	46	–	26.8	19.8	0.028	0.021
	1523	4	33	2	29.8	24.1	0.031	0.025

STATISTICAL TESTS OF THE ADJUSTMENT

Roll Type	Model	RMSE Model Points							Fitting Accuracy				
		No. of Model Points	Ground Scale			Image Scale			No. of Control Points	Ground Scale		Image Scale	
			μX in m	μY in mm	σ_o in m	μx in mm	μy in mm	σ_o in mm		μFX in m	μFY in m	μFx in mm	μFy in mm
Roll 47 B&W	Strip	122	23.1	25.0	36.9	0.008	0.009	0.013	43	35.1	29.0	0.013	0.010
	Strip	108	16.3	20.1	27.9	0.006	0.007	0.010	9	17.4	22.2	0.006	0.008
	3145	4	8.0	10.2	18.3	0.003	0.004	0.007	4	8.0	10.2	0.003	0.004
	3156	4	21.6	5.7	31.6	0.008	0.002	0.011	4	21.6	5.7	0.008	0.002
Roll 46 Colour	Strip	112	26.6	38.7	50.1	0.010	0.014	0.018	9	29.7	34.6	0.011	0.012
	3145	4	28.1	23.1	51.4	0.010	0.008	0.019	4	28.1	23.1	0.010	0.008
	3156	4	14.1	19.8	34.4	0.005	0.007	0.012	4	14.1	19.8	0.005	0.007
Roll 23 B&W	Strip	32	13.6	10.4	21.2	0.005	0.004	0.007	6	18.6	18.4	0.006	0.006
	1845	4	15.4	17.3	32.8	0.005	0.006	0.011	4	15.4	17.3	0.005	0.006
	1856	4	12.6	6.2	19.5	0.004	0.002	0.007	4	12.6	6.2	0.004	0.002
Roll 83 Colour	Strip	83	7.1	8.2	12.9	0.007	0.009	0.013	9	12.0	15.2	0.013	0.016
	1490	4	4.9	9.4	15.0	0.005	0.010	0.016	4	4.9	9.4	0.005	0.010
	1501	4	6.0	9.1	15.4	0.006	0.009	0.016	4	6.0	9.1	0.006	0.009
	1512	4	5.0	8.2	13.6	0.005	0.009	0.014	4	5.0	8.2	0.005	0.009
	1523	4	11.1	13.6	24.8	0.012	0.014	0.026	4	11.1	13.6	0.012	0.014

Note; μX, μY = root mean square error of all model points;

σ_o = standard deviation of unit weight of the adjustment;

μFX, μFY = root mean square error of the ground control points.

APPENDIX D

TO

"INVESTIGATION OF SELECTED IMAGERY FROM
SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

APPENDICES RELATED TO

INVESTIGATION III

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA

APPENDIX D.1

CORRECTIONS FOR SYSTEMATIC ERRORS
OF THE
IMAGE COORDINATES

Extracted from the
Technical Report
on
"Aerial Triangulation with SKYLAB Photography and High Altitude Aircraft Photography - Consideration of SKYLAB Orbital Parameters"
by

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Research Assistant
Department of Photogrammetry
Universite Laval
Quebec

July, 1975

II-4 Correction for Systematic Errors of the Image Coordinates

One of the advantages of analytical photogrammetry is the possibility of correcting for systematic image errors. The film deformation correction will be discussed in Section II-4-a. For the lens distorsion correction, a new method was tested and used. This method will be explained in Section II-4-b. An explanation for a refraction correction being unsignificant for SKYLAB photography, as well as the algorithm used for the refraction correction of H.A. photography will be given in Section II-4-c.

II-4-a Film Deformation

The causes and the correction of film deformation have been studied by many authors; see for example Keller (11), Ziemann (23, 24), Vlcek (22) and Tewinkel (20). After a careful review of previous investigations, the following polynomial was used to correct for film deformation:

$$\begin{aligned} x_F &= x_m + a_1 + a_2x + a_3y + a_4xy + a_5x^2 + a_6y^2 + a_7xy^2 + a_8x^2y \\ y_F &= y_m \quad b_1 + b_2x + b_3y + b_4xy + b_5x^2 + b_6y^2 + b_7xy^2 + b_8x^2y \end{aligned} \qquad (2.1)$$

where,

x_F, y_F are the photo coordinates after film deformation correction,

x_m, y_m are the measured photo coordinates, and

a_1, ..., a_8, b_1, ..., b_8 are the sixteen polynomial coefficients to be determined.

For the SKYLAB photography, the nine reseau marks yield eighteen equations. A computer program, FILMDEFO, was written to use a least squares technique for determining the coefficients, and, afterwards, to compute the corrected coordinates x_F, y_F for any given point whose measured coordinates are x_m, y_m. From the output of the program, it was found that two to three iterations were necessary to determine the coefficients. The variance of the unit weight after adjustment ranges from 106.1 μ^2 to 0.1 μ^2; with an average of 8.7 μ^2. Table 2.2 gives the variances of the unit weight for various SKYLAB photographs as they were obtained from the output using the FILMDEFO program.

For the H.A. photography, it was felt, in view of the type of film used (Aerochrome Infrared 2443), that the film deformation is larger and more significant. Unfortunately, no reseau marks are available and the eight fiducial marks had to be used. If the polynomial given by Equation 2.1 is used, then, this would give sixteen equations to determine sixteen unknown coefficients. It was thought that eventually another type of polynomial would fit better the film deformation of the H.A. photography. For this reason the following two polynomials were also used and tested against the one given by Equation (2.1).

$$\begin{aligned} x_F &= x_m + a_1 + a_2x + a_3y + a_4xy + a_5x^2 + a_6y^2 \\ y_F &= y_m + b_1 + b_2x + b_3y + b_4xy + b_5x^2 + b_6y^2 \end{aligned} \qquad (2.2)$$

$$\begin{aligned} x_F &= x_m + a_1 + a_2x + a_3y + a_4xy \\ y_F &= y_m + b_1 + b_2x + b_3y + b_4xy \end{aligned} \qquad (2.3)$$

where

x_F, y_F, x_m, y_m, and $a_1, \ldots a_6$, $b_1, \ldots b_6$ have the same meaning as defined for Equation (2.1).

Table 2.3 gives the variances of unit weight for each H.A. photograph using Polynomials (2.2) and the variances of unit weight range from ±194 to ±54 μ^2 and are slightly larger for Polynomial (2.2).

Orbit No.	Roll No.	Plate No.	Variance of unit weight (μ^2)	Absolute amount of maximum residuals (μ)
14	23	183	4.0	1.8
		184	4.1	1.9
		185	1.9	1.1
		186	8.3	2.5
	24	183	0.1	0.2
		184	1.0	0.9
		185	0.7	0.8
		186	4.1	1.8
52	47	312	2.9	1.2
		313	7.3	2.3
		314	3.9	1.4
		315	2.4	1.2
		316	7.1	2.3
	48	312	106.1	9.1
		313	0.4	0.4
		314	0.9	0.8
		315	0.9	0.7
		316	1.5	1.0

Table 2.2 - Variances of unit weight and maximum residuals (SKYLAB film deformation, 18 equations with 16 unknown polynomial coefficients)

No. of photograph	Variances of unit weights (μ^2)		Absolute amounts of maximum residuals (μ)			
	12 coeff.	8 coeff.	12 coeff.		8 coeff.	
			V_x	V_y	V_x	V_y
15188	258	242	18	2	22	15
15189	269	200	17	3	22	16
15190	274	200	17	4	22	15
15191	194	100	15	4	16	9
15192	320	200	18	8	21	22
15193	400	300	21	6	21	22
25181	390	300	15	4	30	19
25182	320	300	18	4	24	18
25183	400	300	21	3	27	15
25184	410	300	22	1	27	15
25185	250	200	17	3	22	14
25186	330	200	20	5	28	14
35175	290	200	18	2	23	14
35176	390	300	21	3	25	21
35177	400	300	21	4	24	16
35178	360	300	21	5	27	17
35179	270	200	18	3	24	16
35180	360	300	20	6	28	22
45169	400	300	20	4	28	13
45170	540	400	26	4	31	17
45171	370	300	21	3	27	12
45172	400	300	22	5	28	14
45173	290	200	17	6	24	15
45174	430	300	22	6	27	19
Average	346	260				

Table 2.3 - Variances of unit weight and maximum residuals, film deformation, H.A.-photography

The corrected coordinates x_F, y_F for all points measured on the photographs, using either Polynomial (2.2) or Polynomial (2.3), were compared with the ones using Polynomial (2.1). Table 2.4 shows the standard residual errors resulting from this comparison and for eac- H.A. photography. It can be seen from this table that the maximum and minimum differences are 10.3 μ, and 1.4 μ respectively, while the average is about 4 μ. Based on this analysis, it can be concluded that Polynomial 2.2 yields a better approximation for the film deformation of the H.A. photography than Polynomial 2.3. Also, it becomes evident that the values x_F, y_F, calculated from Polynomial 2.2 are more close to the ones calculated by using Polynomial 2.1 when compared with those calculated using Polynomial 2.3.

As a consequence of this analysis and based on previous investigations, it was decided to use Polynomial 2.1 for the correction of the film deformation.

II-4-b Lens Distortion

The SKYLAB S-190A camera design requirement for the image matching of point sets at each image angle θ (26) was that, when using the six lenses, the image points would be within an ellipse of dimensions $20 \cdot \tan\theta \cdot \mu$ tangentially by 10 μ radially. The lens distortion match test was performed by ITEK Corporation, Lexington, Mass. The results of this test are given in (26) and were available to the author. In the test, the readings were taken every 2° off-axis along four diameters. This gives a total of 48 readings as shown in Figure 2.1. In view of the good quality of the SKYLAB camera lenses and of the small image size (7 x 7 cm), it was decided to correct the lens distortion for all image coordinates. After a review of some of the publications which discuss the lens distortion and its correction

No. of photograph	Standard residual errors (μ)				Absolute amounts of maximum residuals (μ)			
	12 coeff.		8 coeff.		12 coeff.		8 coeff.	
	X	Y	X	Y	X	Y	X	Y
15188	±6.8	±1.4	±9.0	±15.7	10.9	1.8	13.9	25.0
15189	8.7	1.4	12.7	16.2	16.5	2.6	21.9	27.0
15190	6.5	2.1	9.5	11.2	13.9	3.6	20.3	19.8
15191	6.0	1.7	7.0	10.6	12.3	3.4	13.9	13.9
15192	6.7	2.8	7.3	15.0	15.7	7.5	13.7	21.7
15193	10.3	3.4	10.3	20.1	19.5	5.1	20.3	27.0
25181	7.1	1.7	11.2	16.8	10.6	2.6	21.9	21.3
25182	5.3	1.8	6.4	19.9	14.6	3.7	19.3	28.7
25183	8.9	1.3	9.9	11.4	19.7	2.8	24.5	22.1
25184	7.7	0.6	7.5	15.0	18.7	0.9	22.8	22.2
25185	8.5	1.9	8.5	10.8	15.1	2.9	19.7	18.8
25186	8.3	2.1	6.1	13.8	16.9	4.1	9.2	19.9
35175	7.4	0.8	10.8	13.3	15.3	1.7	21.3	22.9
35176	7.7	1.4	9.4	16.9	18.4	3.0	21.5	30.5
35177	7.3	1.5	6.2	16.9	17.6	3.0	14.5	24.0
35178	4.5	2.1	7.4	11.1	11.1	4.0	19.9	20.8
35179	7.8	1.7	8.4	8.3	14.7	2.7	15.8	16.7
35180	7.0	4.0	8.1	11.8	18.0	6.2	16.3	22.6
45169	8.7	1.6	12.9	13.1	17.0	3.4	24.6	20.1
35170	9.8	2.3	11.5	15.8	22.2	3.4	27.8	27.5
45171	8.9	1.6	9.8	11.7	17.2	3.1	19.3	19.4
45172	9.2	2.0	9.8	14.2	18.0	4.3	24.4	25.9
45173	8.0	3.5	9.1	9.3	14.7	5.3	20.0	17.1
45174	9.0	3.0	8.8	16.5	16.9	5.0	16.7	25.6
Average	7.7	2.0	9.1	14.0				

Table 2.4 - Standard residual errors and maximum residuals, film deformation for H.A.-photography (correction with 16 coeff. - correction with either 12 or 8 coeff.)

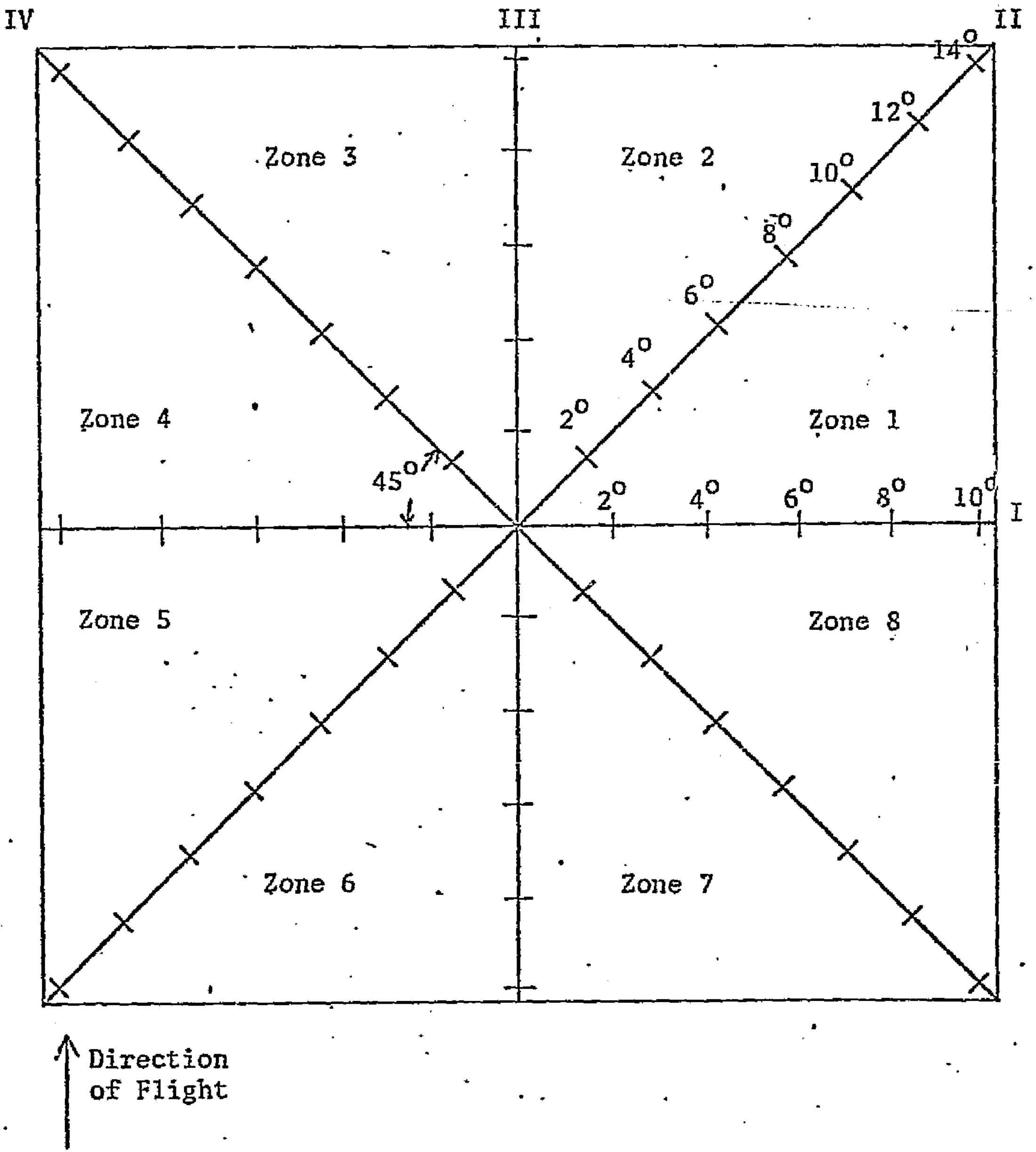

Fig. 2.1- Lens distortion test data format for SKYLAB

(5, 6, 10, 11, 14, 22); it could be concluded that the two polynomials given by Equations 2.4 were the most frequently used to correct for the lens distortion The difference between the various approaches consists of the numbers of coefficients used. If Δr and Δt were assumed to be the corrections for the coordinates due to lens distortion in radial and tangential directions respectively, then

$$\Delta r = a_1r + a_2r^3 + a_3r^5 + a_4r^7 + a_5r^2\sin\theta + a_6r^2\cos\theta \qquad (2.4)$$

$$\Delta t = b_1r^2\sin\theta + b_2r^2\cos\theta$$

where

$a_1, a_2 \ldots a_6, b_1, b_2$ are the polynomials' coefficients to be determined

r is the radial distance from the principal point, and can be expressed as:

$$r = x^2 + y^2$$

where

x and y are the photo coordinates.

The conventional method for the determination of the coefficients uses all distortion measurements over the whole format as one entity and the least squares techniques is used for the solution. It was thought by the author that eventually by dividing the format into various zones, and by determining the coefficients for each zone separately, would produce more reliable values for the coefficients. Consequently, each SKYLAB photograph was divided into 8 zones as shown in Figure 2.1. The coefficients for each zone were determined from the points on the straight lines surrounding the zone in question.

A computer program, LENSCOFF, was written using a least squares adjustment, to compute the polynomial coefficients. The data for the three lenses Nos.4, 5 and 6 (mentioned as Stations 4, 5 and 6 in Tables 2.5 to 2.8) of the Multi-Spectral Photographic Camera (MPC) S-190A was analysed. Table 2.5 shows the variance of unit weight (m_0) as obtained by the LENSCOEF program for both radial and tangential distortions using a single zone only. Although m_0 is small, and indicates that the coefficients will yield a sufficient accuracy, the coefficients were also determined for the case of dividing the entire format into eight zones. Tables 2.6, 2.7 and 2.8 show the m_0's for the eight zones, using six and four radial and two tangential coefficients.

The H.A. photography was taken with a Wild RC-10 camera. The calibration report (27) was prepared by the U.S. Geological Survey, and was available to the author. Twenty-four readings along four radii, as shown in Figure 2.2, were given for the radial distortion. The same procedure as for the SKYLAB photography was applied. All readings were used as an entity, the format was divided into four separate zones (as shown in Figure 2.2) and the polynomial coefficients were determined in both cases. Tables 2.9 and 2.10 show the m_0-values, as obtained from the LENSCOEF program, for various numbers of coefficients and dividing the format into one and four zones, respectively.

Considering Tables 2.5 to 2.8, it can be concluded that:

1) SKYLAB photography: although the use of a single zone covering the entire format produced a satisfactory accuracy, the division of the format into eight zones reduced m_0 by one magnitude, and by 50 per cent when six and four radial coefficients were determined, respectively; for the tangential coefficients, m_0 was reduced by about two magnitudes.

Numb. of equations	Numb. of used coefficient	Variance of unit weight in μ^2			Remarks
		Station 4*	Station 5	Station 6	
48	6	0.4	0.8	0.1	Radial distortion
	4	0.7	1.6	0.7	
	3	0.6	1.5	0.7	
	2	0.6	1.5	0.7	
	1	0.6	1.5	0.8	
	2	0.20	0.04	0.6	Tangential distortion

* Station No.: refers to the positions of the MPC lens as shown in Fig. 1-1

Table 2.5 - Variances of unit weights (SKYLAB photography and tangential lens distortion, various numbers of coefficients, use of only one zone for the entire format).

Numb. of equations	Numb. of coefficients	No. of zones	Variance of unit weight in μ^2		
			Station 4*	Station 5	Station 6
12	6	1	0.06	0.14	0.03
		2	0.07	0.12	0.03
		3	0.08	0.04	0.05
		4	0.08	0.03	0.03
		5	0.04	0.05	0.05
		6	0.05	0.05	0.03
		7	0.06	0.02	0.04
		8	0.07	0.05	0.02
Average			0.06	0.06	0.04

* Station No.: refers to the positions of MPC lens as shown in Fig. 1-1

Table 2.6 - Variances of unit weights (SKYLAB photography radial lens distortion, six coefficients, format divided into eight zones).

Number of equations	Number of coefficients	No.of zones	Variance of unit weight in μ^2		
			Station 4*	Station 5	Station 6
12	4	1	1.08	1.51	0.02
		2	0.18	0.60	0.05
		3	0.07	0.29	0.30
		4	0.32	0.68	0.14
		5	0.89	1.85	0.09
		6	0.07	0.35	0.07
		7	0.08	0.31	0.33
		8	0.40	0.73	0.05
Average			0.39	0.79	0.13

* Station No.: refers to the positions of the MPC lens as shown in Fig. 1-1

Table 2.7 -Variances of unit weights (SKYLAB photography radial lens distortion, four coefficients, format divided into eight zones).

Number of equations	Number of coefficients	No.of zones	Variance of unit weight in μ^2		
			Station 4*	Station 5	Station 6
12	2	1	0.001	0.004	0.002
		2	0.002	0.002	0.001
		3	0.005	0.004	0.001
		4	0.004	0.008	0.007
		5	0.001	0.004	0.030
		6	0.004	0.002	0.024
		7	0.005	0.005	0.001
		8	0.002	0.006	0.002
Average			0.004	0.004	0.009

* Station No.: refers to the positions of the MPC lens as shown in Fig. 1-1

Table 2.8 - Variances of unit weights (SKYLAB photography tangential lens distortion, two coefficients, format divided into eight zones).

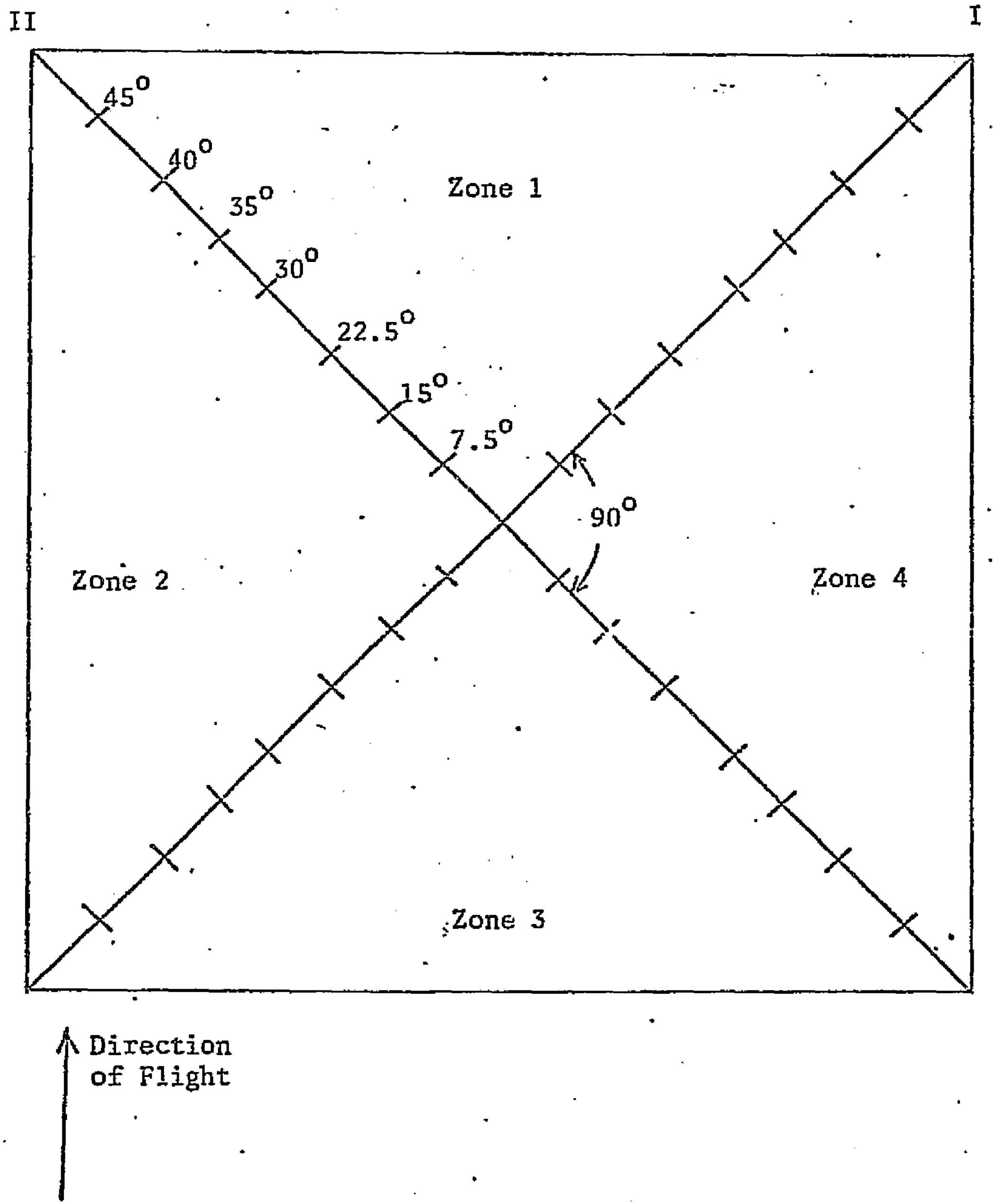

Fig. 2.2- Lens distortion for H.A. photography.

Number of equations	Variance of unit weight in μ^2				
	6 coeff.	4 coeff.	3 coeff.	2 coeff.	1 coeff.
24	13.3	14.5	14.0	15.4	16.3

Table 2.9 - Variance of unit weight (H.A. radial lens distortion, various numbers of coefficients, format with only one zone.

Number of equations	No. of zone	Variance of unit weight in μ^2				
		6 coeff.	4 coeff.	3 coeff.	2 coeff.	1 coeff.
12	1	1.1	20.8	18.5	18.3	19.0
	2	2.5	6.1	5.6	7.2	9.1
	3	3.2	10.2	9.7	11.6	11.6
	4	1.3	28.1	25.2	24.9	23.6
Average		2.0	16.3	14.8	15.5	15.8

Table 2.10 - Variances of unit weights (H.A. photography radial lens distortion, various numbers of coefficients, format divided into four zones).

2) H.A. photography: In case that four or less radial coefficients were determined, a slight change in m_0 was observed, and when the format was covered by one and four zones, respectively; however, when using six coefficients m_0 became significantly smaller when dividing the format into four zones.

By considering the above analysis, all SKYLAB and H.A. photographs were corrected for lens distortion using six coefficients and by dividing the format into eight and four zones, respectively. A computer program LDISCORR, was written to read the coordinates of a point, determine its zone and apply the corrections by using the appropriate coefficients.

II-4-c Refraction

When an optical ray travels in space, it crosses two different regions of the atmosphere: the troposphere, extending upwords to about 30 km, and the ionosphere, extending from about 30 to 400 km. In photogrammetry, it can be safely assumed that there is no refraction in the ionosphere region. Vlcek (22) and Schut (18) investigated the refraction correction for photogrammetric measurements, considering various weather conditions, the earth curvature, the ground heights and the tilt of the camera. Based on the above publications, the refraction correction Δr at any radial distance r for near vertical photographs taken in the troposphere region can be given by:

$$\Delta r = (f \cdot \Delta\alpha / \cos^2\alpha) \cdot \tan\alpha \qquad (2.5)$$

where

f is the focal length of the camera,

α is the angle between the optical ray and the nadir direction, at the exposure station

$\Delta\alpha$ is the angle between the theoretical straight ray path and the tangent to the actual ray path at the exposure station and can be given by the following formula:

$$\Delta\alpha = \left(\frac{2410\ H}{H^2 - 6H \quad 250} - \frac{2410\ h}{h - 6h \quad 250} \cdot \frac{h}{H}\right) 10^{-6} \qquad (2.6)$$

where

H is the flight altitude above sea level in km

h is the ground elevation above sea level in km

Since the H.A. photographs were taken at an altitude of about 20 km, the image coordinates of these photographs were corrected using this formula.

For SKYLAB photography the refraction correction is not significant as follows from the following derivation:

Assuming that (see Figure 2.3):

H_I is the upper limit of the troposphere region being about 30 km,

H_S is the altitude of the SKYLAB camera (435 km),

α_I, α_S are the angles between the theoretical ray paths and the nadir directions, for photographs taken at altitudes H_I and H_S, respectively,

$\Delta\alpha_I$, $\Delta\alpha_S$ are the angles between the theoretical straight ray paths and the tangents to the actual ray paths at the exposure station, for photographs taken at heights H_I, and H_S, respectively.

From Figure 2.3 follows:

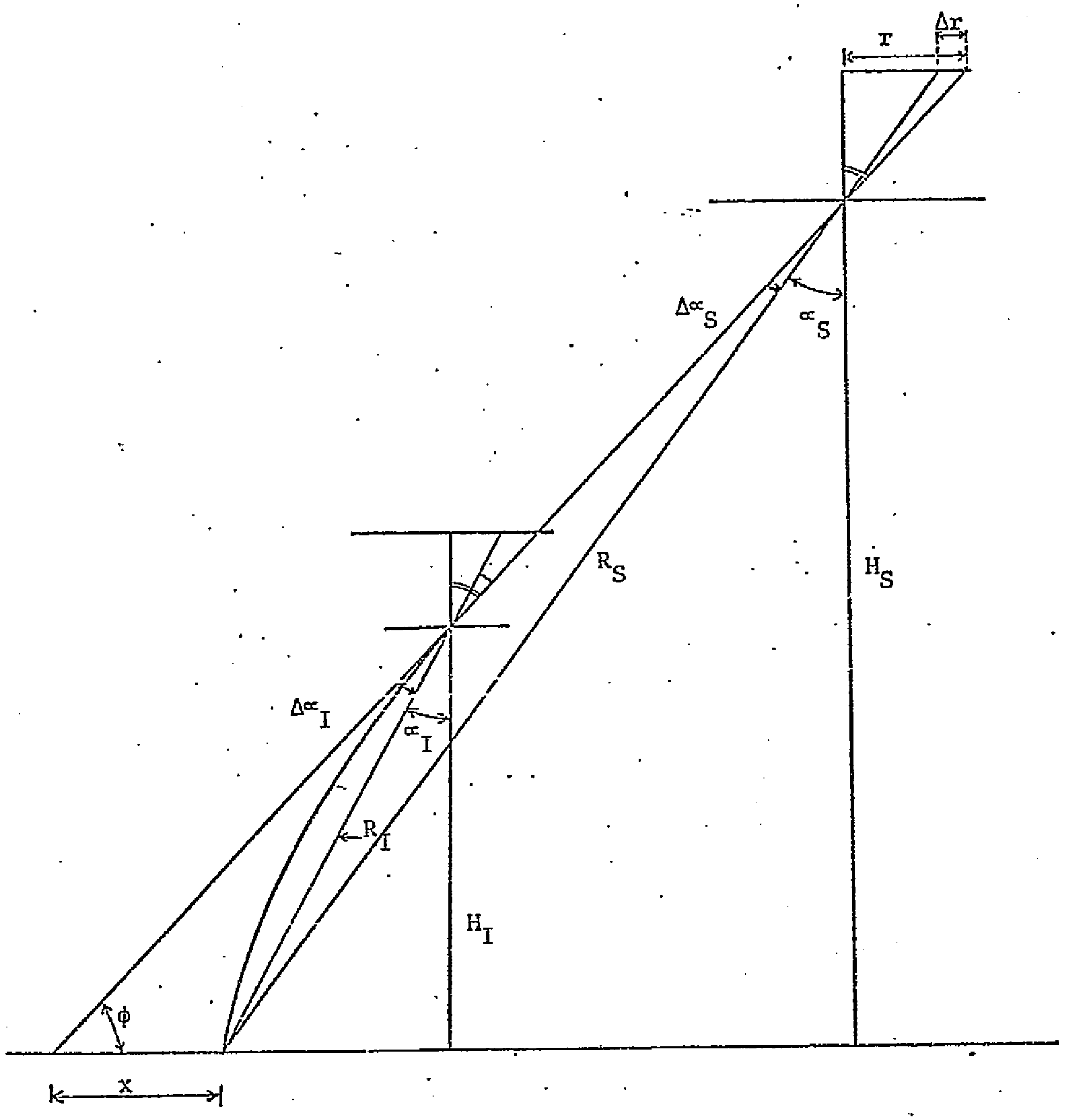

Fig. 2.3- Refraction for SKYLAB photography.

$$\frac{R_I}{\sin\phi} = \frac{X}{\sin\Delta\alpha_I} , \tag{2.7}$$

$$\frac{R_S}{\sin\phi} = \frac{X}{\sin\Delta\alpha_S} , \tag{2.8}$$

$$\cos\alpha_I = \frac{H_I}{R_I} \tag{2.9}$$

and

$$\cos\alpha_S = \frac{H_S}{R_S} . \tag{2.10}$$

From Equations 2.7 and 2.8 one obtains:

$$\frac{R_I}{R_S} = \frac{\sin\Delta\alpha_S}{\sin\Delta\alpha_I} \tag{2.11}$$

and from Equations 2.9 and 2.10:

$$\frac{R_S}{R_I} = \frac{\cos\alpha_I}{\cos\alpha_S} \cdot \frac{H_S}{H_I} \tag{2.12}$$

Since $\Delta\alpha_S$, $\Delta\alpha_I$ are very small angles, and since α_I and α_S will not exceed 11^o, it follows from Equations 2.11 and 2.12:

$$\frac{H_I}{H_S} \approx \frac{\Delta\alpha_S}{\Delta\alpha_I} \tag{2.13}$$

By using Equation 2.6, and assuming that:

$H = H_I = 30$ km, $H_S = 435$ km

$h = 0.2$ km

$f = 152.0$ mm

$\alpha = \alpha_I = \alpha_S = 10^0$

One obtains: $\Delta\,\alpha_I = 13.14 \cdot 10^{-6}$ radians

and from Equation 2.13:

$\Delta\alpha_S = 0.928 \cdot 10^{-6}$ radians

and from Equation 2.5:

$\Delta r_S = 0.15\ \mu$

This amount is not significant, if one considers the accuracy for the measurements of the photo coordinates is not better than ± 1 μ.

APPENDIX D.2

POLYNOMIAL ADJUSTMENT RESULTS
INVESTIGATION III

APPENDIX D.2-a

No. of the Model in the strip	No. of roll	No.of points	σ_x m	σ_y m	σ_z m
5	23	124	±34.6	±46.8	±159.3
	24	128	32.65	46.1	104.3
Above strips combined	23	124	34.5	46.1	157.6
	24	128	32.8	47.7	103.6

– Standard deviations for a separate adjustment of each SKYLAB roll and for an adjustment of both rolls combined.

APPENDIX D.2-b

No. of the Model in the strip	No. of roll	No.of. points	σ_x m	σ_y m	σ_z m
1	23	84	±28.1	±42.2	±194.5
	24	77	37.2	50.9	112.0
2	23	118	32.5	45.3	180.5
	24	115	31.5	44.9	107.3
3	23	127	34.45	46.1	157.6
	24	132	32.8	47.7	103.6

– Standard deviations after adjustment of one, two, and three SKYLAB models.

No. of the strip	No. of models per strip	No.of points	σ_x m	σ_y m	σ_z m
1	6	29	±8.25	±15.3	±3.41
2	6	37	9.86	17.70	4.21
3	6	35	9.69	14.41	7.08
4	6	39	9.91	9.39	6.56
1	6	29	7.14	7.37	3.34
2	6	37	9.41	17.68	4.22
3	6	35	10.02	23.32	6.98
4	6	39	9.65	9.16	6.48

Standard deviations for a separate adjustment of each strip and for an adjustment of all four strips combined - H.A. photography.

Type of photography	No.of points	σ_x m	σ_y m	σ_z m	Remarks
H.A. strip 1	29	± 7.14	± 7.37	± 3.34	one H.A. strip and two SKYLAB rolls (one model each).
S.K. roll 23	84	28.54	41.88	192.88	
S.K. roll 24	77	32.07	39.72	112.01	
H.A strip 1	29	7.14	7.37	3.34	two H.A. strips and two SKYLAB roll (one model each).
H.A. strip 2	38	9.72	17.46	4.15	
S.K. roll 23	84	28.54	41.88	192.88	
S.K. roll 24	77	32.07	39.72	112.01	
H.A. strip 1	29	7.14	7.37	3.34	three H.A. strips and two SKYLAB rolls (one model each).
H.A. strip 2	38	9.65	17.48	4.17	
H.A. strip 3	34	9.52	14.20	7.06	
S.K. roll 23	84	28.54	41.88	192.88	
S.K. roll 24	77	32.07	39.72	112.01	
H.A. strip 1	29	7.14	7.37	3.34	four H.A. strips and two SKYLAB rolls (one model each)
H.A. strip 2	38	9.67	17.50	4.17	
H.A. strip 3	34	9.57	14.19	7.08	
H.A. strip 4	39	9.66	9.17	6.48	
S.K. roll 23	84	28.54	41.88	192.88	
S.K. roll 24	77	32.07	39.72	112.01	

[illegible] - Standard deviations for the adjustment of various numbers of H.A. photography strips combined with both SKYLAB photography rolls.

APPENDIX D.2-e

Type of photography	Number of control points	No.of points	σ_x m	σ_y m	σ_z m
S.K. roll 23	12	57	± 38.00	± 44.79	± 670.75
S.K. roll 24	(Case 1)	50	35.31	40.93	232.45
S.K. roll 23	22	57	24.90	40.05	151.28
S.K. roll 24	(Case 2)	50	28.73	32.65	151.90
H.A. strip 1	26	18	10.1	9.3	6.8
H.A. strip 2		24	10.2	13.8	6.4
H.A. strip 3		20	10.6	18.0	11.4
H.A. strip 4	(Case 3)	23	11.9	10.7	8.7
H.A. strip 1	12 points S.K.	18	12.23	20.27	64.55
H.A. strip 2	22 points H.A.	24	17.55	20.20	88.89
H.A. strip 3	14 common points	20	13.80	19.07	58.02
H.A. strip 4		23	14.29	15.49	70.89
S.K. roll 23		57	20.09	37.21	128.55
S.K. roll 24	(Case 4)	50	28.98	31.03	134.39
H.A. strip 1	12 points S.K.	13	12.54	22.81	61.99
H.A. strip 2	53 points H.A.	16	20.91	21.36	76.93
H.A. strip 3	14 common points	13	16.30	22.24	57.49
H.A. strip 4		13	16.51	17.85	95.01
S.K. roll 23		57	20.13	37.15	127.37
S.K. roll 24	(Case 5)	50	29.08	30.90	132.87

\- Standard deviations for various numbers of control points.

APPENDIX D.3

RESULTS FROM BUNDLE ADJUSTMENT INVESTIGATION III

APPENDIX D.3-a

Number of models/strip	No. of roll	Number of points	σ_x m	σ_y m	σ_z m	Maximum residuals		
						V_x m	V_y m	V_z m
1	23	84	±9.7	±12.6	±19.3	31.5	63.0	59.0
	24	77	10.9	21.2	14.5	40.0	158.0	41.0
	23 and 24 together	86	12.9	20.8	20.3	38.7	122.0	57.9

Standard deviations and absolute amounts of the maximum residuals. Bundle adjustment; all points being used as observations.

APPENDIX D.3-b

Type of photography	Numb. of control points	σ_x m	σ_y m	σ_z m	Max. residuals		
					V_x m	V_y m	V_z m
One model from Roll 23	22	±28.3	±30.7	±203.5	71.5	60.0	339.0
One model from Roll 23 & Strip 1 of H.A. photography (6 photographs)	26	21.2	24.2	146.1	39.1	50.0	307.0

Standard deviations and absolute amounts of the maximum residuals. Bundle adjustment; 26 and 22 points, respectively, being used as observations.

No. of SKYLAB photograph	No. of roll	X_o m	Y_o m	Z_o m	ϕ	ω	χ	Remarks
184	—	-60117.9	1052.1	435995.0	00° 00′ 00″	00° 00′ 00″	-29° 00′ 00″	Orbit parameters
	23	-59769.6	692.7	441011.2	00 17 29	00 09 05	-29 44 02	Roll 23 alone
	24	-60485.0	1194.5	441261.7	00 23 08	00 12 03	-29 27 42	Roll 24 alone
	23	-59763.6	678.9	441006.7	00 17 26	00 08 59	-29 01	Rolls 23 and 24 together
	24	60384.7	1218.7	441273.7	00 22 22	00 12 15	-29 27 42	
185	—	2456.0	-36936.1	436132.7	00 00 00	00 00 00	-29 00 00	Orbit parameters
	23	227.9	-36868.8	441261.0	00 06 05	00 06 51	-29 45 59	Roll 23 alone
	24	2033.6	-36145.5	441404.0	00 02 10	00 07 34	-29 28 30	Roll 24 alone
	23	320.7	-37011.5	441231.5	00 05 22	00 07 59	-29 46 04	Rolls 23 and 24 together
	24	1704.9	-36067.8	441439.3	00 05 01	00 01 33	-29 28 29	

Camera station coordinates and rotation angles obtained from the orbital parameters tabulation and after least squares adjustment.

APPENDIX D.3

APPENDIX E

TO

"INVESTIGATION OF SELECTED IMAGERY FROM
SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

APPENDICES RELATED TO

INVESTIGATION IV

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA

COMPARATIVE RATINGS OF IMAGE QUALITY FOR SPECIFIC FEATURES (1 = BEST, 10 = NOT VISIBLE) ON SKYLAB S190A SIMULTANEOUS PHOTOGRAPHY IN 6 SPECTRAL BANDS

1. TORONTO AREA S190A Image 016 Orbit 29, 09/09/73	1 B&W IR 0.7-0.8 μm	2 B&W IR 0.8-0.9 μm	3 COLOUR IR 0.5-0.88 μm	4 COLOUR 0.4-0.7 μm	5 B&W Pan 0.6-0.7 μm	6 B&W Pan 0.5-0.6 μm
Granularity	3	3	2	1	1	1
Malton Airport	8	9	4	2	1	2
Yonge Street	6	6	7	1	1	2
401 Hwy.	10	10	4	1	1	2
Suburban Roads	10	10	10	8	6	8
Lake Scugog/Marsh	1	1	2	5	4	5
Rivers	1	2	4	5	5	5
Piers into lake	9	8	4	2	1	2
Race Track	10	10	5	2	1	2
2. BAY OF FUNDY S190A Image 316 Orbit 52, 21/09/73						
Granularity	3	3	3	1	1	1
Airport 1	9	8	7	2	1	3
Airport 2	10	10	5	3	1	3
New Highway	10	9	5	1	1	2
Secondary Roads	10	10	5	2	1	3
Shoreline Detail	5	6	3	2	1	4
Minor Drainage	3	2	10	9	10	10
Lakes	1	1	6	3	5	4
3. SOUTHERN MANITOBA						
S190A Image 214	3					
Orbit 50, 09/19/73	10					
Granularity	3	3	2	1	1	1
Small Town	10	10	8	2	1	2
Reservoir	1	1	3	4	4	5
Roads	7	7	5	1	1	2
Minor Drainage	1	1	10	8	5	10
Airport	8	8	5	2	1	2
Total Score:	139	138	119	68	55	81
	worst				best	

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APPENDIX E.2

EXAMPLE PAPER PRINTS OF ENLARGED
SKYLAB PHOTOGRAPHY
USED IN THE QUALITATIVE EVALUATION
OF
INVESTIGATION IV

S190A PAN-X AERIAL BLACK AND WHITE

(4X enlargements from 2nd generation 70mm negatives)

Fig. 1. 0.6 to 0.7um band - Best redition of cultural detail.
Note: Example slightly blurred by lettering overlay.

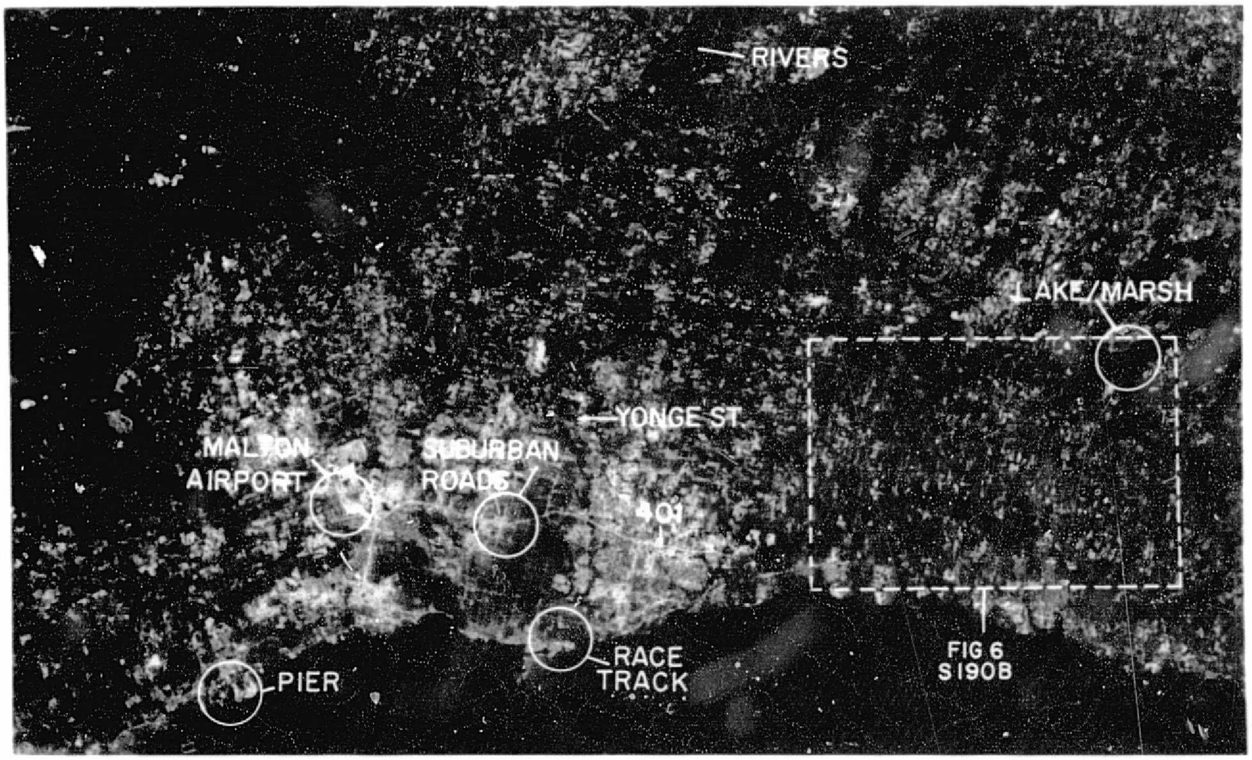

Fig. 2. 0.5 to 0.6um band.

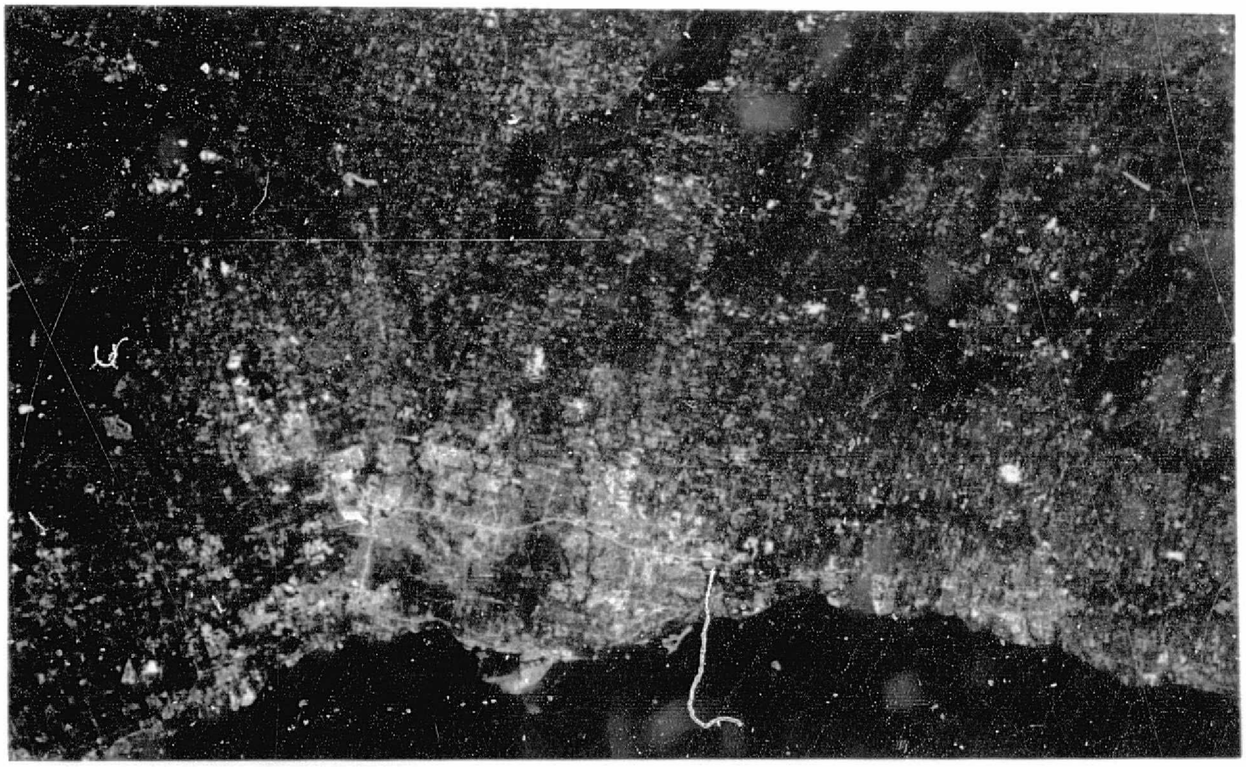

Fig. 3. S190A Aerial Colour (4X enlargement from 2nd generation colour positives) 0.4 to 0.7um band.

Fig. 4. S190A Aerochrome IR (4X enlargement from 2nd generation colour positives) 0.5 to 0.88um band.

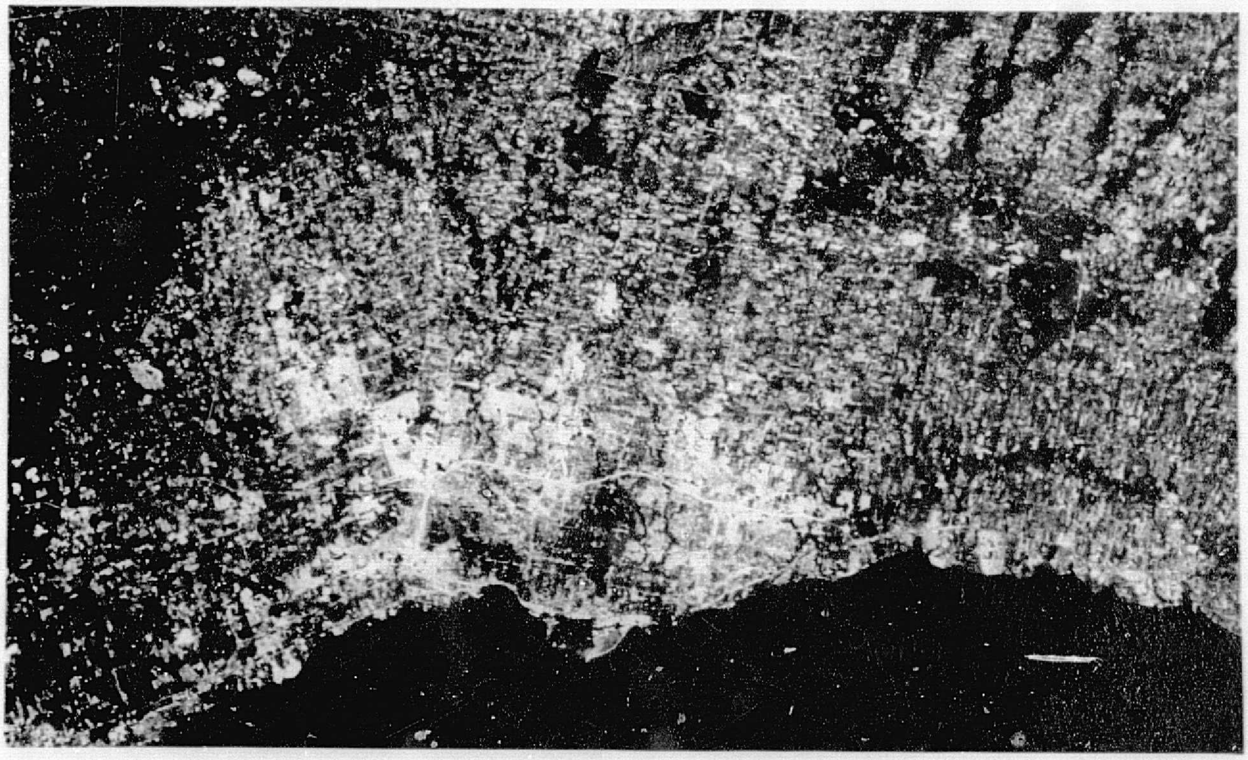

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Fig. 5. S190A IR Aerographic (4X enlargement from 2nd generation 70mm negatives) 0.8 to 0.9μm band = 0.7 - 0.8μm band.

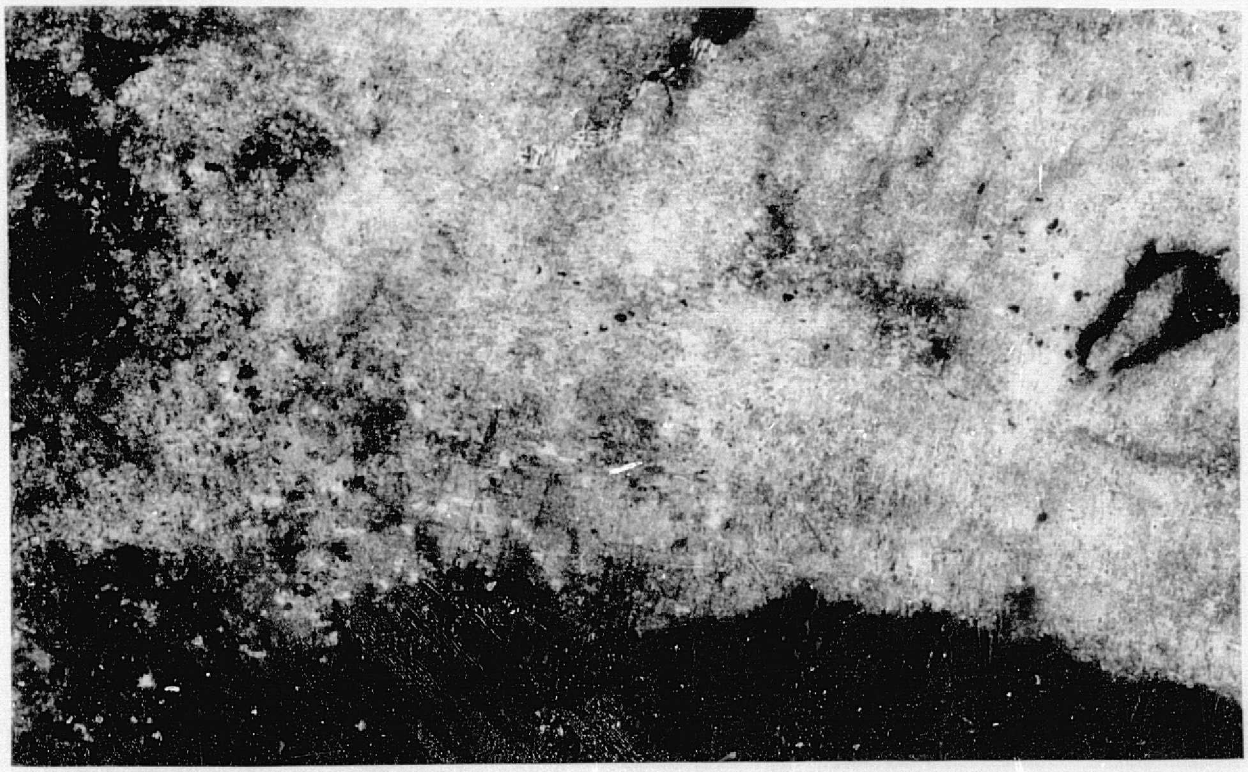

Fig. 6. S190B Panchromatic Black and White with W12 filter. (i.e. standard survey combination) 4X enlargement from 2nd generation. 5" negative - 18" focal length.

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APPENDIX F

TO

"INVESTIGATION OF SELECTED IMAGERY FROM SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

APPENDICES RELATED TO

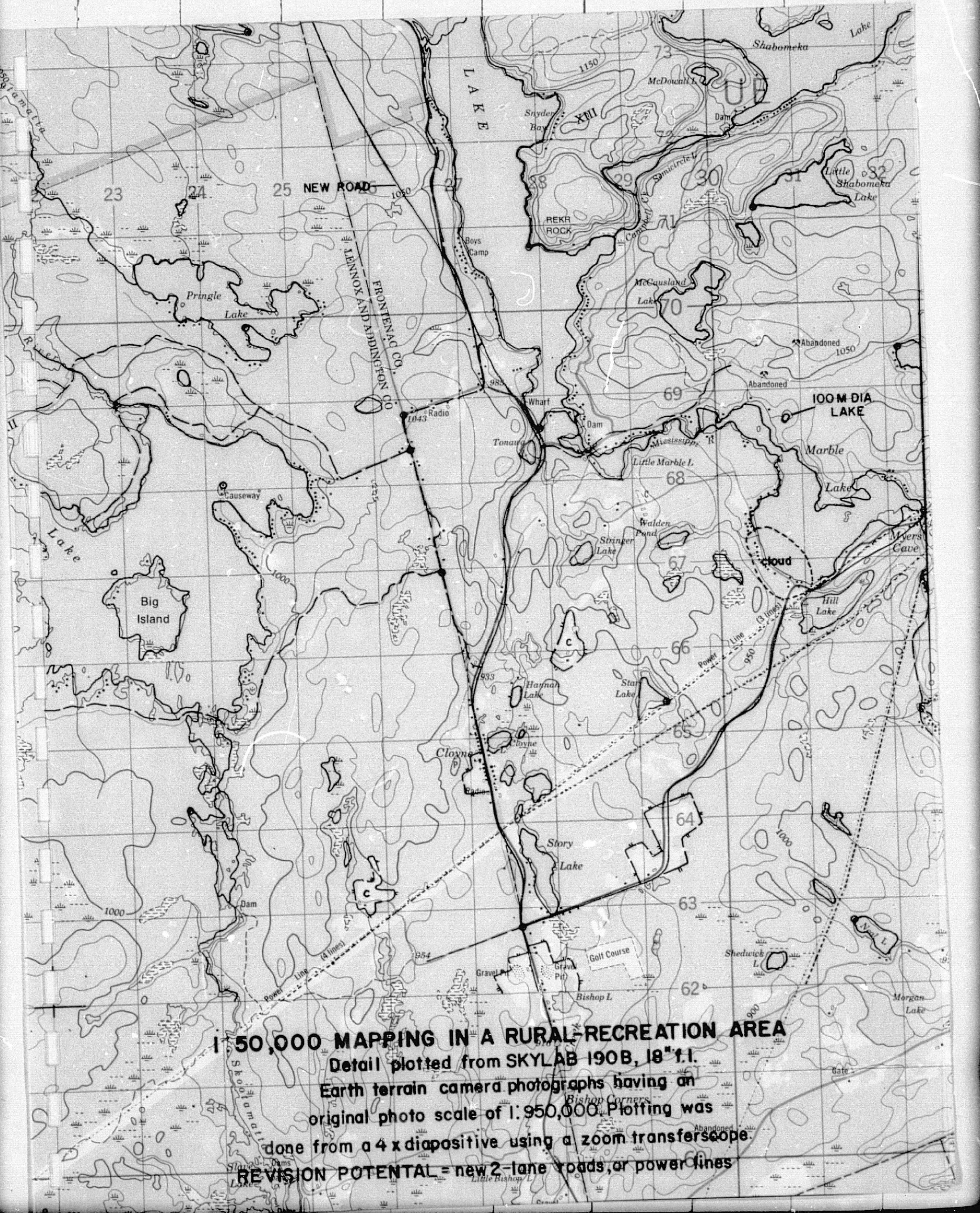
INVESTIGATION V

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA

APPENDIX F.1

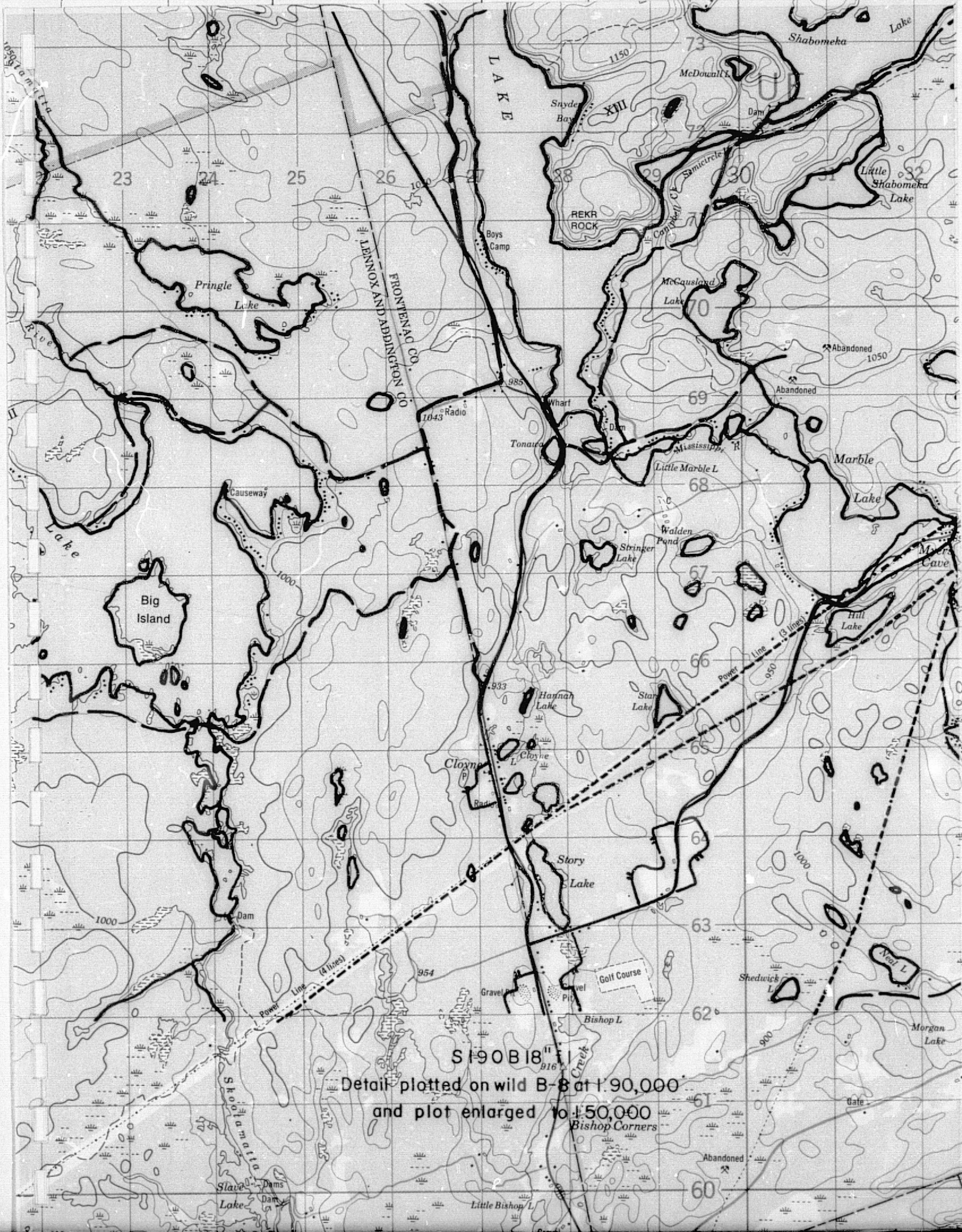
EXAMPLE OVERLAYS PRODUCED FROM
SKYLAB PHOTOGRAPHY
FOR MAP REVISION POTENTIAL IN A
RURAL RECREATIONAL AREA
AT SCALES OF 1:50,000 and 1:250,000

INVESTIGATION V



1:50,000 MAPPING IN A RURAL-RECREATION AREA

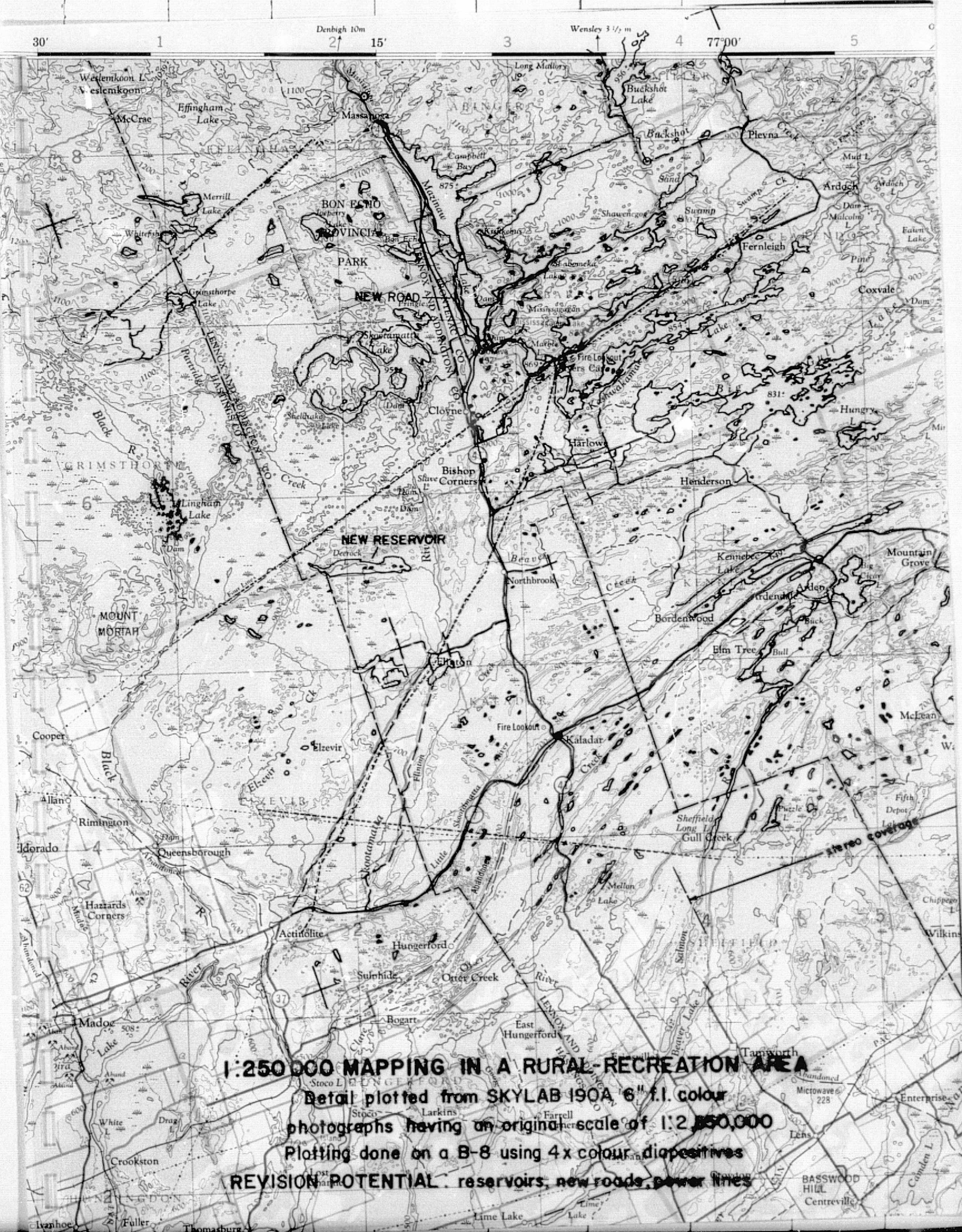
Detail plotted from SKYLAB 190B, 18" f.l.
Earth terrain camera photographs having an
original photo scale of 1:950,000. Plotting was
done from a 4 x diapositive using a zoom transferscope.
REVISION POTENTAL = new 2-lane roads, or power lines



S190B18" E1

Detail plotted on wild B-8 at 1:90,000

and plot enlarged to 1:50,000

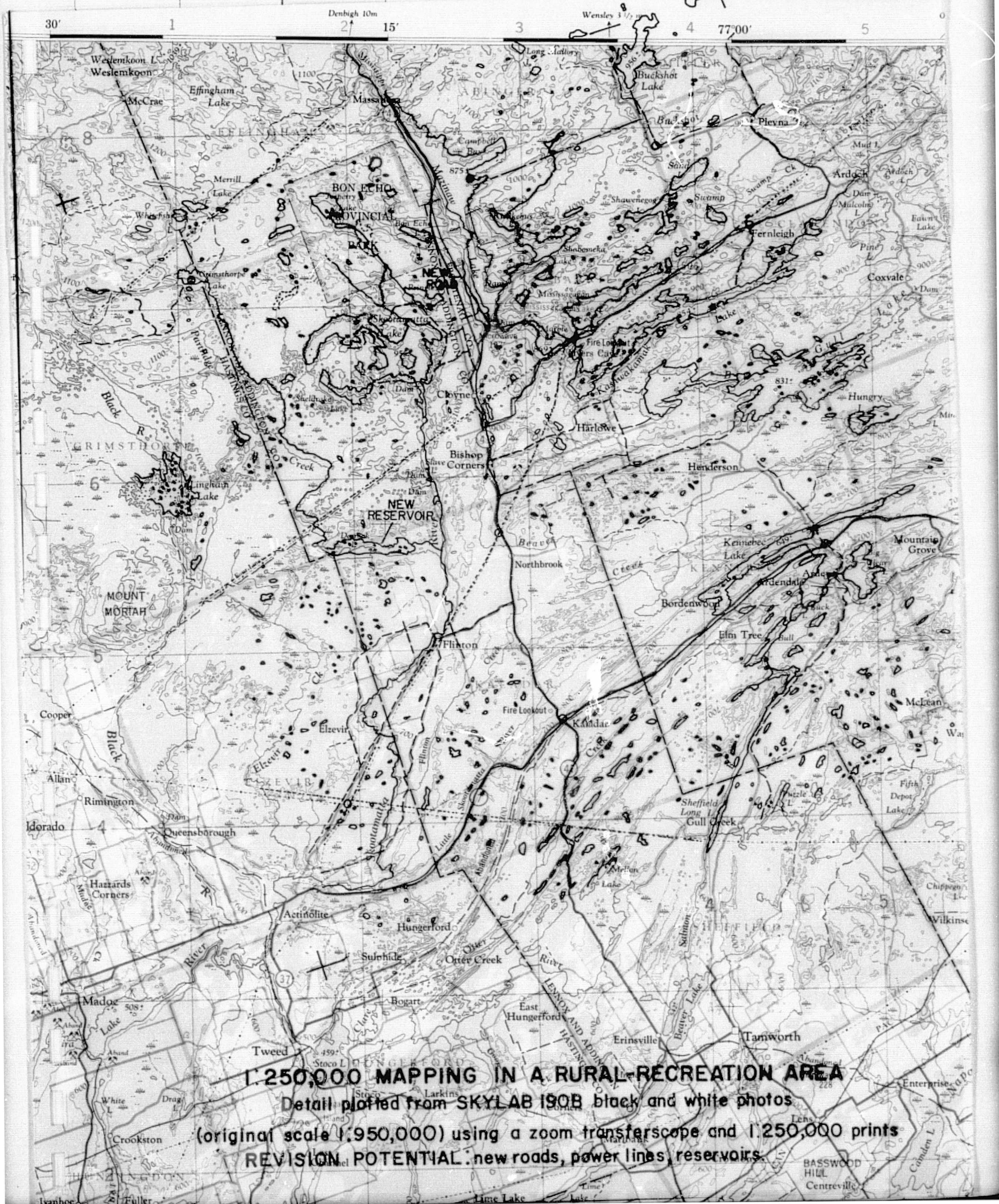


1:250 000 MAPPING IN A RURAL-RECREATION AREA

Detail plotted from SKYLAB 190A 6" f.l. colour photographs having an original scale of 1:2,850,000

Plotting done on a B-8 using 4x colour diapositives

REVISION POTENTIAL. reservoirs, new roads, power lines



1:250,000 MAPPING IN A RURAL-RECREATION AREA

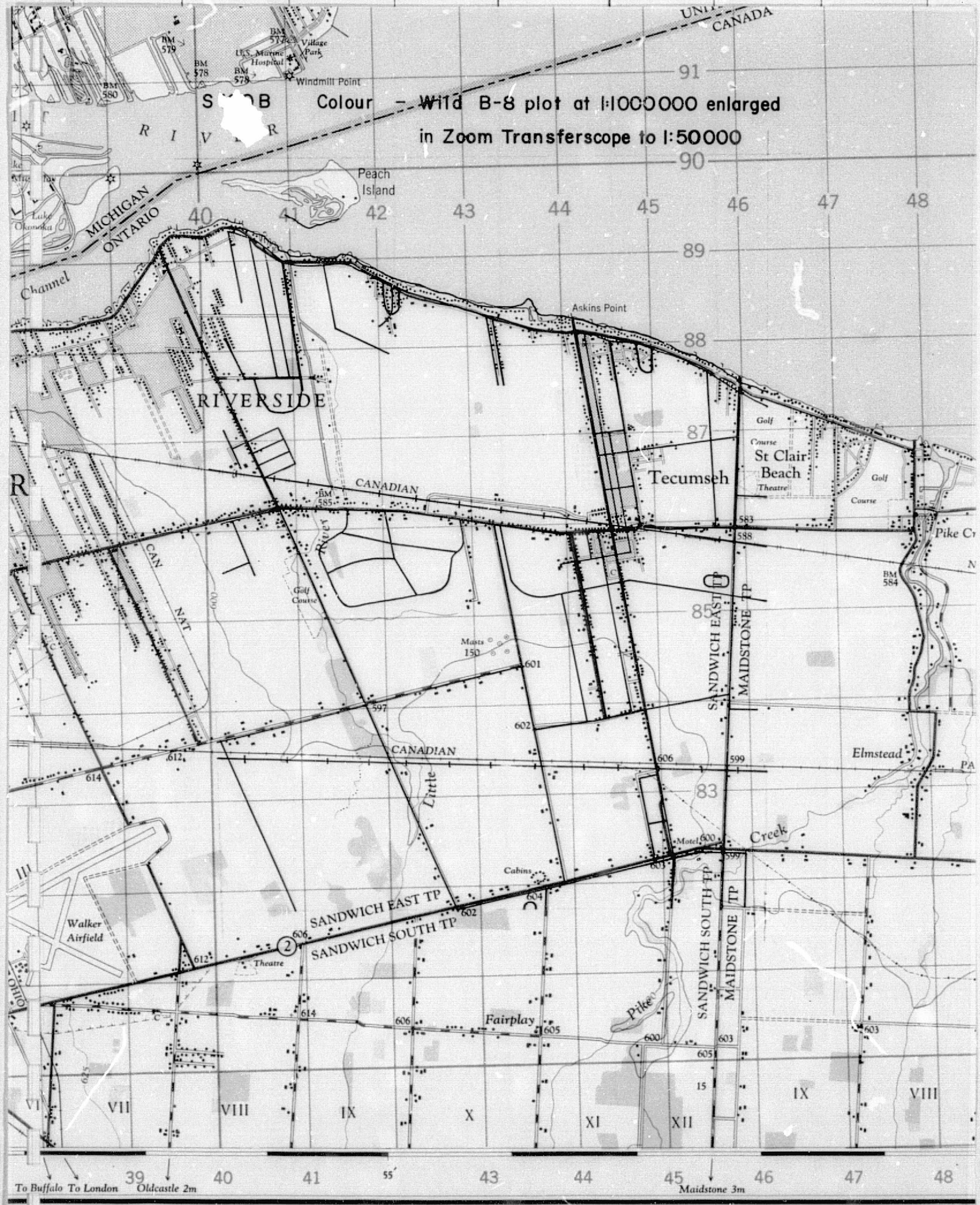
Detail plotted from SKYLAB 190B black and white photos

(original scale 1:950,000) using a zoom transferscope and 1:250,000 prints

REVISION POTENTIAL: new roads, power lines, reservoirs.

APPENDIX F.2

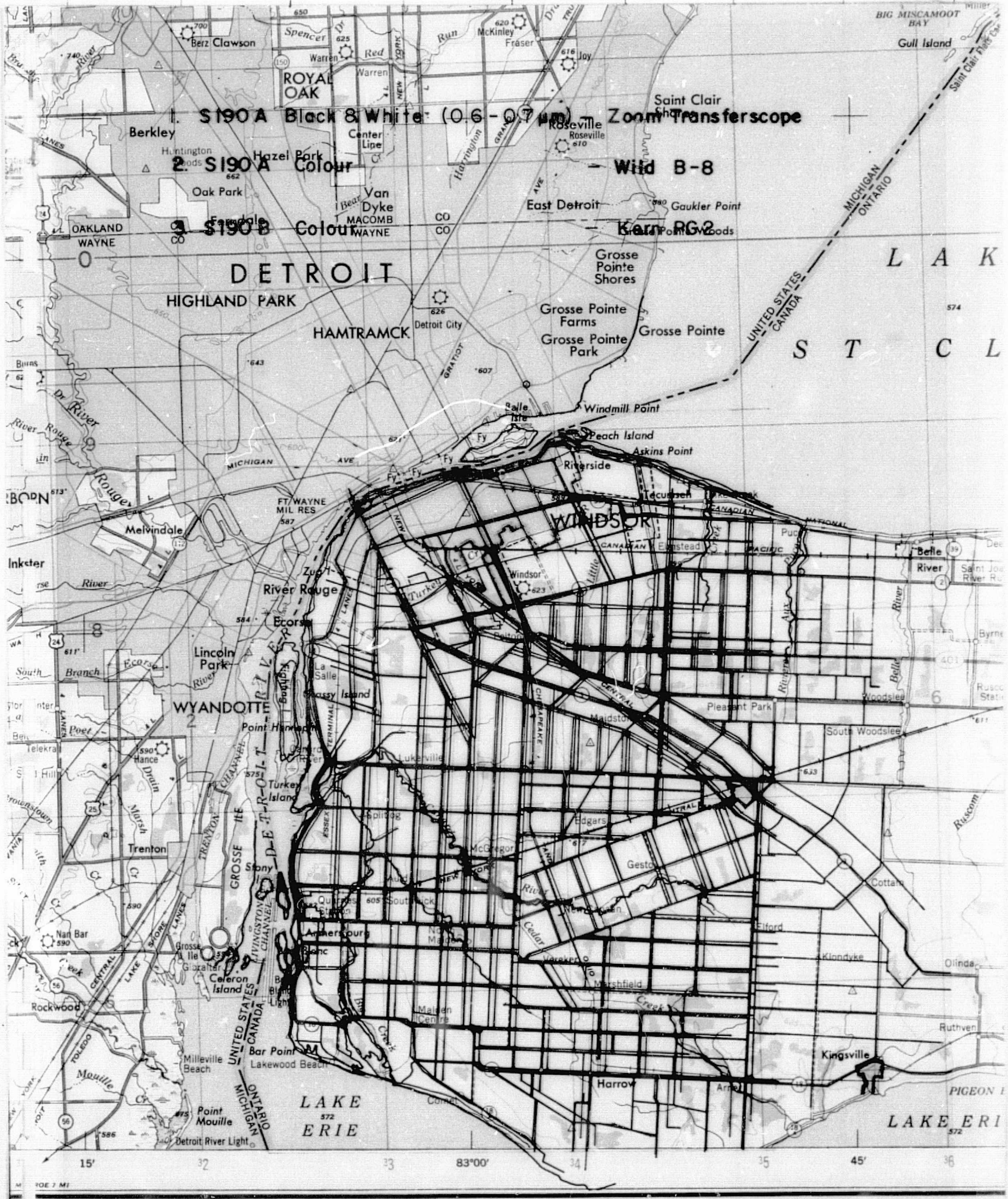
EXAMPLE OVERLAYS PRODUCED FROM
SKYLAB PHOTOGRAPHY
FOR MAP REVISION POTENTIAL IN
URBAN AREAS
AT SCALES OF 1:50,000 AND 1:250,000
INVESTIGATION V



S[illegible]B Colour – Wild B-8 plot at 1:1000000 enlarged

in Zoom Transferscope to 1:50000

BELLE RIVER



1. S190A Black & White (0.6-0.7 µm) - Zoom Transferscope

2. S190A Colour - Wild B-8

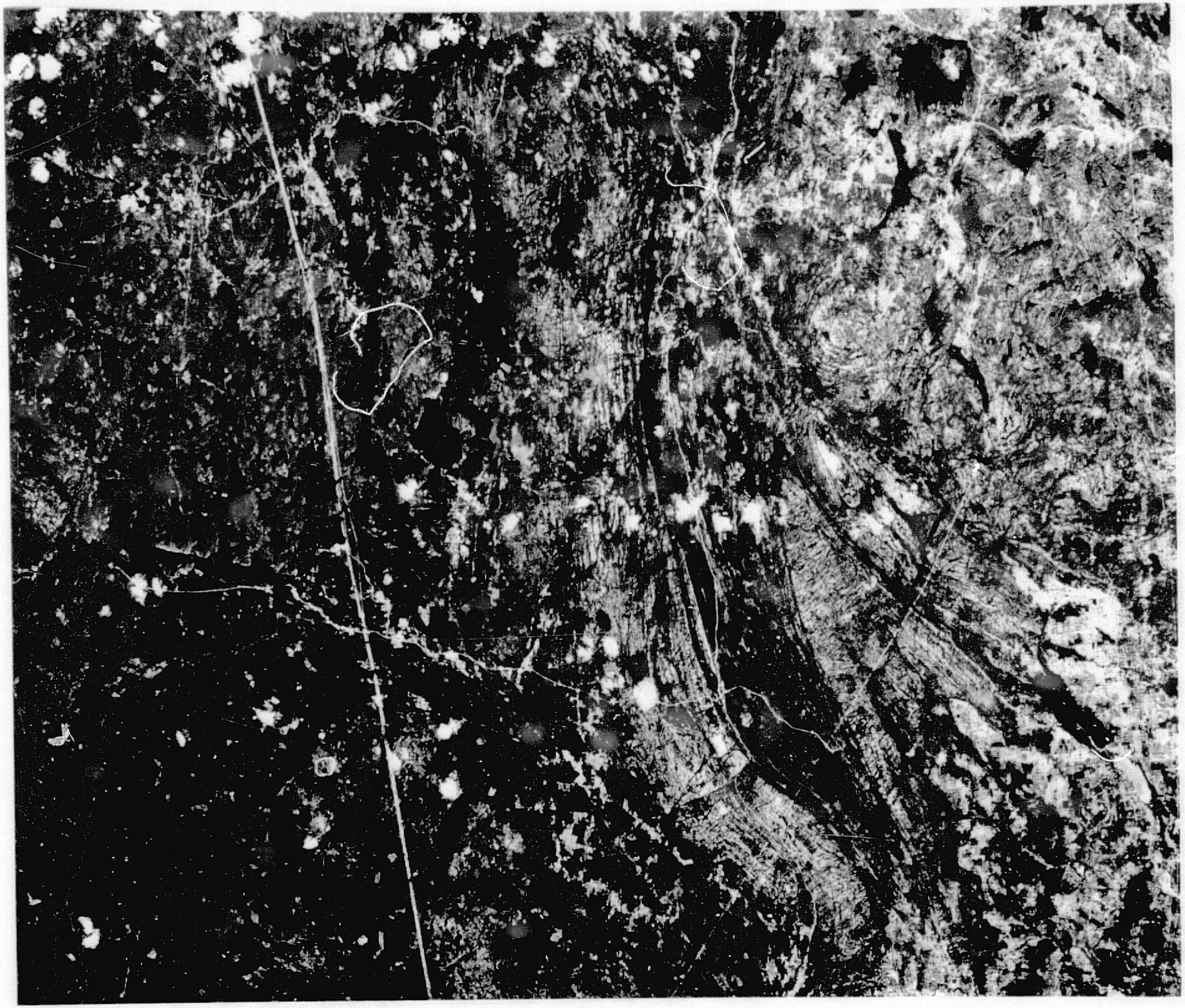
3. S190B Colour - Kern PG 2

DETROIT

CANADA AND UNITED STATES

APPENDIX F.3

EXAMPLE ENLARGED PAPER PRINTS OF SKYLAB PHOTOGRAPHY USED IN THE MAP REVISION POTENTIAL STUDY OF INVESTIGATION V



SKYLAB S190B 3.3X Enlargement

1:250 000

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SKYLAB S190A 12X Enlargement

1:250 000

APPENDIX G

TO

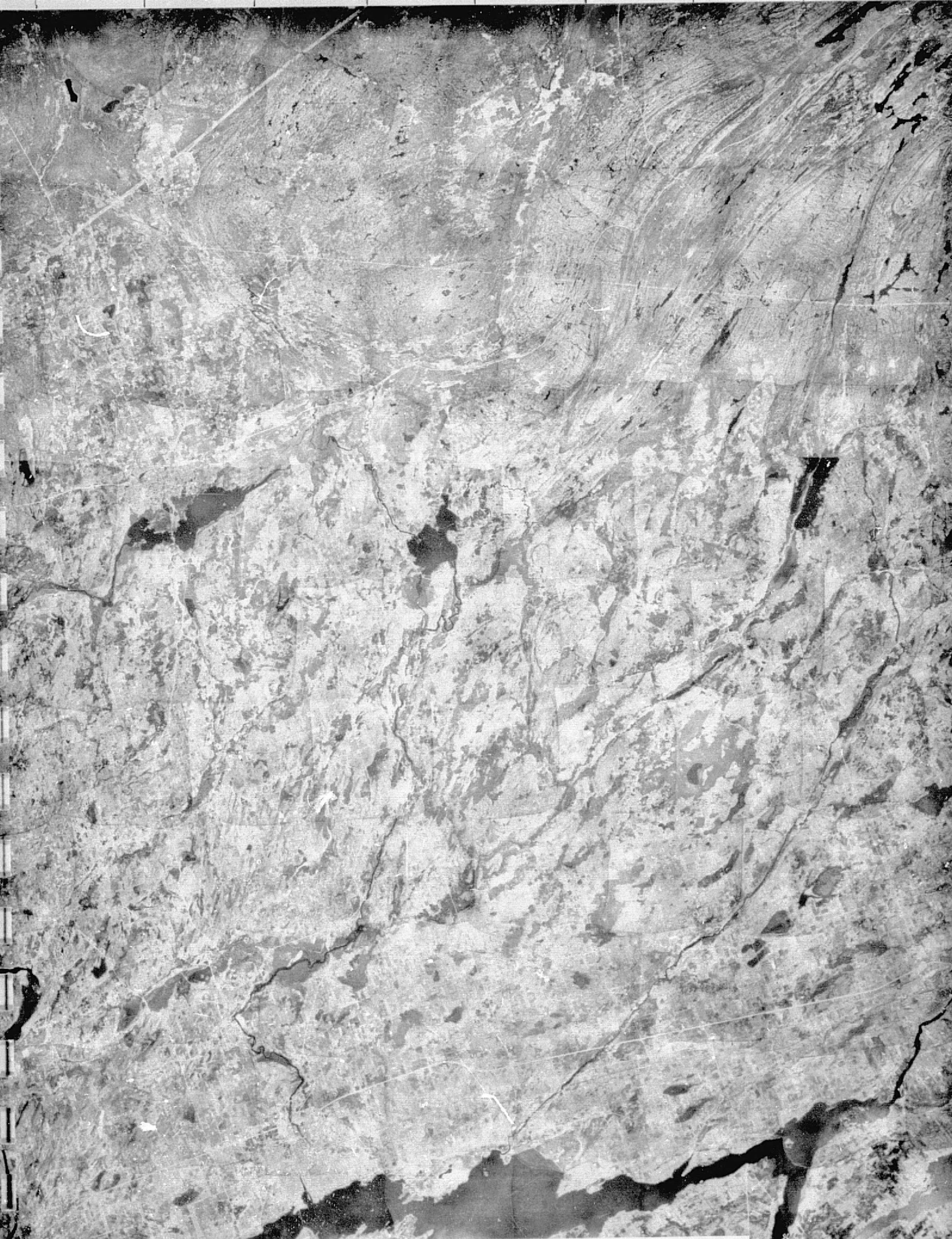
"INVESTIGATION OF SELECTED IMAGERY FROM SKYLAB/EREP S190 PHOTOGRAPHIC SYSTEM"

EXAMPLE RECTIFIED PHOTOGRAPHY

USED IN

INVESTIGATION VI

TOPOGRAPHICAL SURVEY DIRECTORATE
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA



AERIAL PHOTO MOSAIC