NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lyndon B. Johnson Space Center

E.P.N. Number 9625

CARTOGRAPHIC RESEARCH IN E.R.E.P. PROGRAM FOR SMALL SCALE MAPPING.

June 1975.

HUNTING SURVEYS LTD.
Elstree Way
Boreham Wood
Herts.
England.

E 7.6 - 1 0.0.3 9.

NASA CR-
144478

Cartographic Research in EREP Program for Small Scale Mapping

Mr. P.G. Mott, B.A., F.I.C.E., F.R.I.C.S.
Hunting Surveys Ltd.,
Elstree Way,
Borehamwood,
Hertfordshire,
WD6 1SB,
England.

June 1975.

Final Report

Department of Trade and Industry,
1 Victoria Street,
London,
S.W.1.,
England.

Principal Investigator:

Mr. P.G. Mott, B.A., F.I.C.E., F.R.I.C.S.
Hunting Surveys Ltd.

Co-investigators:

Mr. H. Fullard, M.Sc.,
George Philip and Son Ltd.,

Mr. J.C. Bartholomew, M.A., F.R.S.E.
John Bartholomew and Son Ltd.

Mr. J.D. Leatherdale, B.A., B.Sc., A.R.I.C.S.
Hunting Surveys Ltd.

Mr. H.J. Chismon,
Hunting Surveys Ltd.

Mr. H.M. Hall
Hunting Surveys Ltd.

CONTENTS

LIST OF FIGURES

1. TECHNICAL APPROACH AND TASK DESCRIPTION

1.1 Technical Approach

To evaluate the use of EREP multispectral photographic imagery of Nepal for (1) photogrammetric control, (2) the production of original and revision mapping and (3) the interpretation of special features such as forest areas and limits of snow and ice-fields. These evaluations would include:

(a) Completeness of detail interpreted directly from the EREP imagery.

(b) Comparison of the value of different types of spectral imagery for the interpretation of various features to be mapped.

(c) Assessment of the improvement in interpretability obtained by using the EREP recovered photography compared with that of the ERTS mission.

(d) Further developments of photogrammetric techniques, image enhancement and interpretation methods as applied to small scale mapping from satellite photography.

1.2 Task Description

1.2.1 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.

1.2.2 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.

1.2.3 Supporting Studies

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

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

1.2.4 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 the tasks (a) through (d) in Section 1.1, Technical Approach.

2. HISTORY OF THE INVESTIGATION

A proposal for participation in the EREP Program in the field of cartographic research for small scale mapping was submitted to NASA jointly by Hunting Surveys Ltd., George Philip and Son Ltd. and John Bartholomew and Son Ltd. A test area was selected in Nepal since it was felt that this type of inaccessible and relatively unknown area was the kind of terrain in which EREP type photography might be used for original mapping purposes. Agreement was obtained from the Government of Nepal and the proposal was accepted and a formal agreement signed on 27th February, 1973.

Deliveries of photographic material from Skylab 4 were received progressively between July 1974 and January 1975. However sufficient material to effectively start work upon this investigation was not received until October 1974. Part of the investigation could of course, have been commenced upon the receipt of the first shipment of data, but this was considered to be a wasteful and inefficient procedure.

As soon as the first shipment of materials was received, an investigation was initiated into the availability of ground control and existing mapping and copies of relevant data were obtained.

The investigation into the cartographic uses of the photography was carried out between October 1974 and April 1975.

3. TECHNIQUES AND PROCEDURES USED

All techniques and procedures used in this investigation are those commonly in use in any photogrammetric and cartographic organisation and the equipment and instrumentation employed are all of types which one would expect to encounter in the well-equipped laboratory of such an organisation.

The use of other than standard techniques and equipment was avoided since it must be assumed that any practical cartographic use of Skylab photography would be made by an organisation using their existing facilities.

4. SUMMARY OF DATA REQUIREMENT AND DATA SUPPLIED

4.1 Skylab Operation Requirements

4.1.1 Inflight Operations

Requirements

Use EREP sensors S190A, S190B to acquire data over Nepal bounded by the following co-ordinates:

latitude $30^{\circ}30'N$, $28^{\circ}00'N$, $26^{\circ}00'N$, $28^{\circ}00'N$
longitude $81^{\circ}00'E$, $88^{\circ}00'E$, $88^{\circ}00'E$, $80^{\circ}00'E$

Supplied

See Figure 1 for area of photographic coverage.

4.1.2 Test Conditions at Test Site

	% Cloud Cover	Sun Angle	Orbital Attitude	% Snow Cover	Acquisition Time Span	Number of EREP Passes
Requirements:-						
Desired	0%	$>30^{\circ}$	ZLV	0%*	Summer	4**
Minimum	30%	$>30^{\circ}$	ZLV	20%*	Any	2***
Supplied	0%-30%	14°-18°	ZLV	0%-70%*	Winter	1

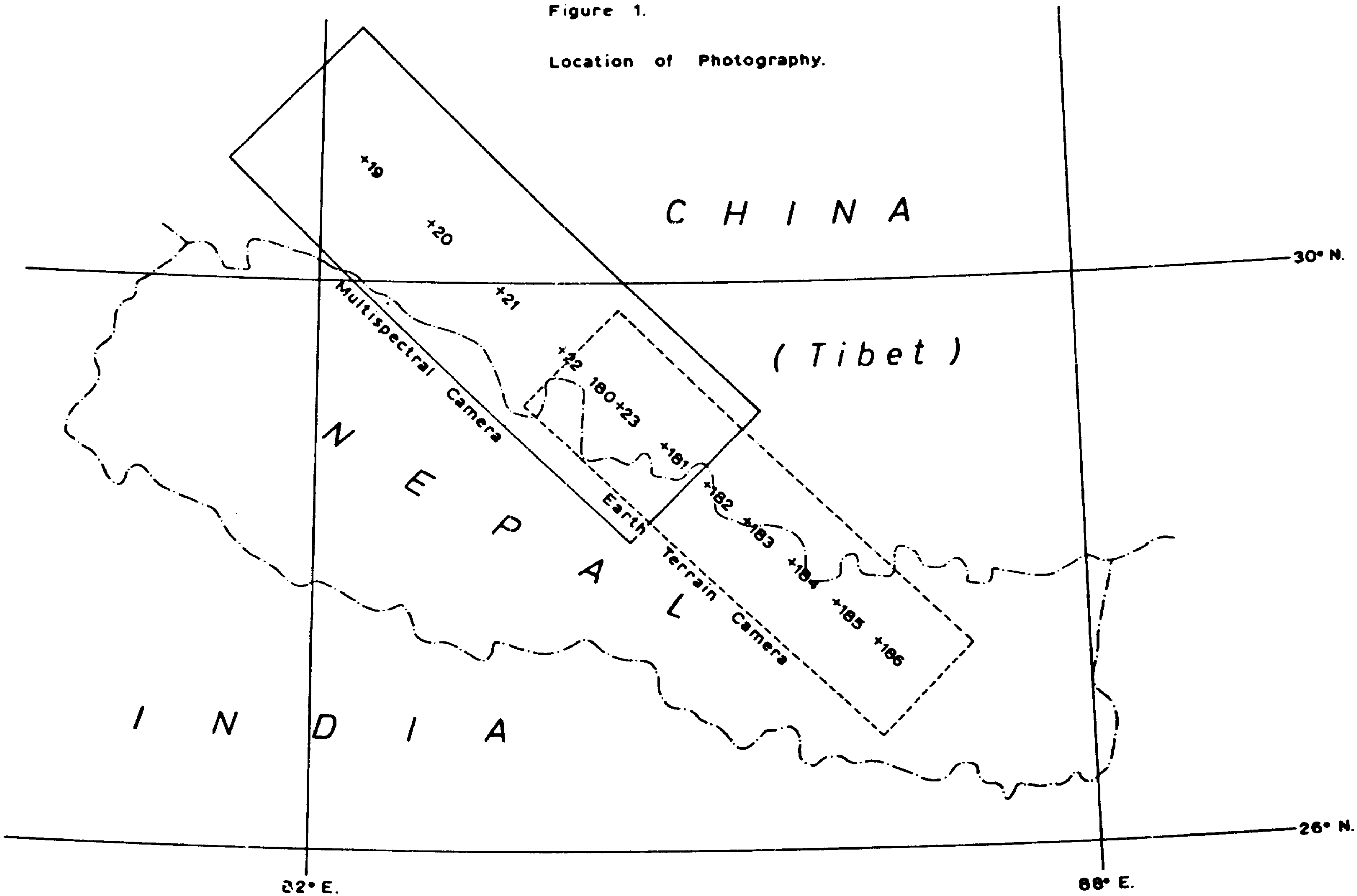
* Snow cover in lowlands. Snow cover in mountain areas is of major interest to map.

** Requires two different ascending passes and two different descending passes to cover majority of site.

*** Two separate descending passes to provide as much coverage as possible.

Figure 1.

Location of Photography.



4.2 EREP Data Requirements

4.2.1 S190A Multispectral Photographic Facility

	% Overlap	Number of frames per pass	Total Number of Frames	Film	Filters
Requirements:-					
Desired	60%	12	48	Std.	Std.
Minimum	60%	12	24	Std.	Std.
Supplied	60%	15	15	Std.	Std.

4.2.2 S190B Earth Terrain Camera

	% Overlap	Number of frames per pass	Total Number of Frames	Film	Filters
Requirements:-					
Desired	60%	18	72	B/W*	Std.
Minimum	60%	18	36	B/W*	Std.
Supplied	60%	9	9	Colour (SO-242)	Std.

* Colour film is second choice.

4.3 Data Products

4.3.1 S.190A Multispectral Photographic Facility

Requirements

Prints		Transparencies 70 mm		Precision Radiometric Processing	Other
70mm	9"	Pos.	Neg.		
	1		1	Yes	4 x enlargements desired

Material supplied as requested.

4.3.2 Earth Terrain Camera Data Products

Requirements

Prints		Transparencies			
$4\frac{1}{2} \times 4\frac{1}{2}''$	$9 \times 9''$	$4\frac{1}{2} \times 4\frac{1}{2}''$		$9 \times 9''$	
		Pos.	Neg.	Pos.	Neg.
	1		1		1

Material supplied modified because of use of second choice colour film.

4.3.3 Calibrations

Requirements

Pre-mission calibration data of the S190A and S190B systems. In-flight and post-flight data pertaining to geometric distortion, exposure accuracy, pointing and timing correlation and spatial resolution.

Data supplied as requested.

4.3.4 General Support Data (Ephemeris)

Requirements

Standard ephemeris and orbital support data.

Data supplied as required.

5. GROUND TRUTH ACTIVITIES

Copies of all available existing maps and data relevant to existing ground control were obtained. For obvious reasons of accessibility, no ground truth investigations could be carried out in the field, but the personal experience of persons cognizant with other similar areas in the Himalayas was drawn upon where possible.

The available data was more plentiful and of better quality than had been expected and greatly facilitated the subsequent work.

6. PHOTOGRAPHY

6.1 Photography Received (see Figure 1).

The original requirement was for Multispectral and Earth Terrain Camera photography to cover the whole of Nepal. This would have necessitated 48 multispectral and 72 E.T.C. frames taken on four adjacent passes, but in the event only nine E.T.C. frames and fifteen multispectral frames were received. These were partially cloud-covered and only five E.T.C. and eight multispectral frames were usable. It was expected that the two types of photography would both cover the same ground area, but the material received was all taken on one pass and the Multispectral Camera was cut-off at almost the exact moment that the Earth Terrain Camera began to function. This resulted in one strip of photography, half of which was taken with each type of camera.

6.2 Effect of Sun Angle upon the Suitability of the Photography

The photography was taken very early in the day, approximately 8 a.m. local time and doubt on the suitability of the photography was raised by NASA. The low sun angle, between about 14° and 18°, resulted in very long and dense shadows. The shadows in the bottom of the deeper valleys are in fact so dense that almost no detail is visible. On the other hand, much of the area consists of snow and ice-covered mountains and the details in this type of area are greatly enhanced by the shadows. It is considered that if this area had been photographed at a time of high sun angle, much of the detail would have been lost in the ice-glare.

6.3 Photographic Quality

The following comments are made upon the quality of the photographic materials furnished:

(a) The tone reproduction of some of the black and white materials is poor. This is discussed further in section 10.1.1

(b) There is a slight fall-off of definition in the extreme corners of the image area of the earth terrain camera photography. This is not serious enough to have any significant effect upon the value of this photography for cartographic purposes.

(c) The 4 x enlargements of the S190A photography supplied by NASA were found to be distorted and unsuitable for Photogrammetric purposes. This became apparent during the stereo-plotting instrument setting routine and alternative material was used (see 8.1.2).

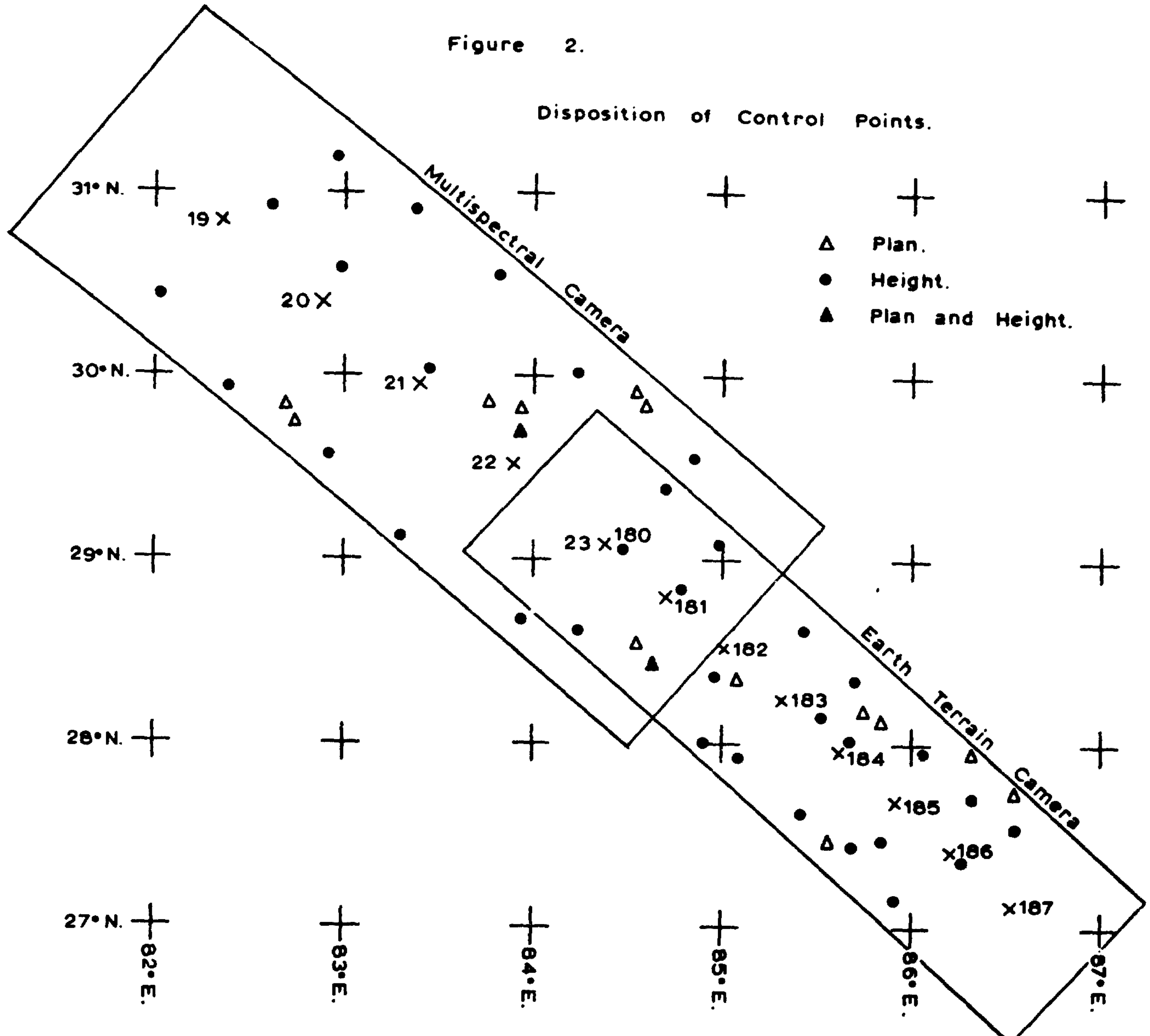
7. GROUND CONTROL (see Figure 2).

7.1 Plan Control Points

These points were all taken from stations derived from an existing triangulation network which runs along the southern face of the Himalaya Range. The actual triangulation stations are not identifiable

Figure 2.

Disposition of Control Points.



the co-ordinates of a number of prominent mountain peaks along the crest of the range and farther north in Tibet along the Brahmaputra Valley had been determined by intersection. A number of these peaks could be identified on the photography and these were used for plan control.

There must of course be a certain doubt about the accuracy of this control due to the survey methods used, the extreme length of many of the rays and the uncertainty of the identification of the exact point from widely differing view-points. However, the points were considered adequate for the purposes of this study and the results of the aero-triangulation bear this out.

The computer programs used for the block adjustment require rectangular co-ordinates for the control points. The geographical co-ordinates were therefore transformed to rectangular co-ordinates in the Universal Transverse Mercator Projection, Everest Spheroid, Zone 45.

7.2 Height Control Points

The height control points used were all taken from existing mapping. The only photo-identifiable heighted points on maps of this area are almost invariably mountain peaks and out of a total of thirty-five selected points, thirty three fall within this category. The remaining two points were both taken from the water-level of lakes.

When heights of the same point of detail were taken from different map series and the co-ordinate lists and compared one with another, considerable differences were apparent. Since there was no way of knowing which height if any was correct, it was considered advisable to take all the heights to be used from one source. They were consequently all taken from the most up-to-date 1:500,000 scale map which could be obtained since this map compared most favourably with the photography and appeared to be the most accurate.

8. AERO-TRIANGULATION

8.1 Preparation of Material

8.1.1 Earth Terrain Camera Photography

Black and white paper prints were obtained from copy negatives made from the colour positive transparencies supplied by NASA. These were used to record the positions of the selected plan and height control points. The original colour transparencies were used for observing in the photogrammetric instrument and minor control points were marked on these using a Wild PUG 4 point transfer device. This drills a 40 micron hole in the emulsion and points can be transferred very accurately from one photograph to another by means of the instrument's binocular viewing system.

The positions of the control points were not marked on the transparencies since it was considered that the correct position could best be determined when viewed in the photogrammetric instrument.

8.1.2 Multispectral Camera Photography

It was originally intended that the four times enlarged negatives supplied by NASA should be used, but they were found to be too badly distorted for any accurate photogrammetric measurements to be easily made from them. However, black and white paper prints from these enlarged negatives were used for recording the positions of the plan and height control points.

Since the enlargements could not be used, it was necessary to go back to the 70 mm negatives to obtain diapositives suitable for observing in the photogrammetric instrument. An examination of the six multispectral films available determined that the black and white film from station 5 (orange) gave the best definition of detail in this area. The 70 mm negative of this film was therefore used to make 2½ times enlarged glass diapositves. The geometric accuracy of these diapositives was checked by comparing measurements of the reseau with the published measurements. This gave an across-film error of 0 ± 15 μm compared to an along-film error of 19 ± 10 μm. This differential error appears to be present in the film negatives supplied to us.

The positions of the minor control points were marked on these diapositives using the Wild PUG 4.

8.2 Observation and Measurement

All measurements were made on a Wild Universal A7 Autograph first-order photogrammetric instrument with punch tape co-ordinate read-out. This instrument has a focal distance range of 98 to 215 mm.

The effective focal distances of the positives set in the instrument far exceed these values and it was therefore necessary to resort to an affine solution to the problem. This necessitates setting a false focal distance on the instrument which results in a vertical scale which differs from the horizontal scale, the difference being proportional to the change in focal distance.

The photography from each camera was treated independently. The overlapping pairs of photographs were set in the instrument in sequence along each strip and instrument co-ordinates at a horizontal scale of twice photograph scale were recorded for all required points.

Since the vertical and horizontal scale of each stereo model differed, a correction was applied to the z-coordinates to bring them to the same scale as the x- and y-coordinates. At the same time a correction for earth curvature was applied. This was applied graphically, a circular scale being placed over the photograph and the amount of correction read off being dependent upon the position of each individual point on the photograph.

9. STRIP ADJUSTMENT

The corrected instrument co-ordinates obtained from the aero-triangulation were used as the input for the strip adjustment. Each strip was subjected to a first order conformal fit to the planimetric control and to a second order height adjustment. The first order conformal adjustment subjects stereo-models to a scale change, change of origin and a rotation, but does not allow any individual model to be distorted to improve the fit onto the planimetric control. This type of adjustment therefore gives a very good measure of the planimetric accuracy of individual stereo-models. The second order height adjustment corrects the strip for torque and longitudinal curvature and gives a best mean fit onto the height control points. All the computations were carried out on a small 8K computer, using programmes developed by Hunting Surveys for the adjustment of blocks of aero-triangulation.

9.1 Earth Terrain Camera

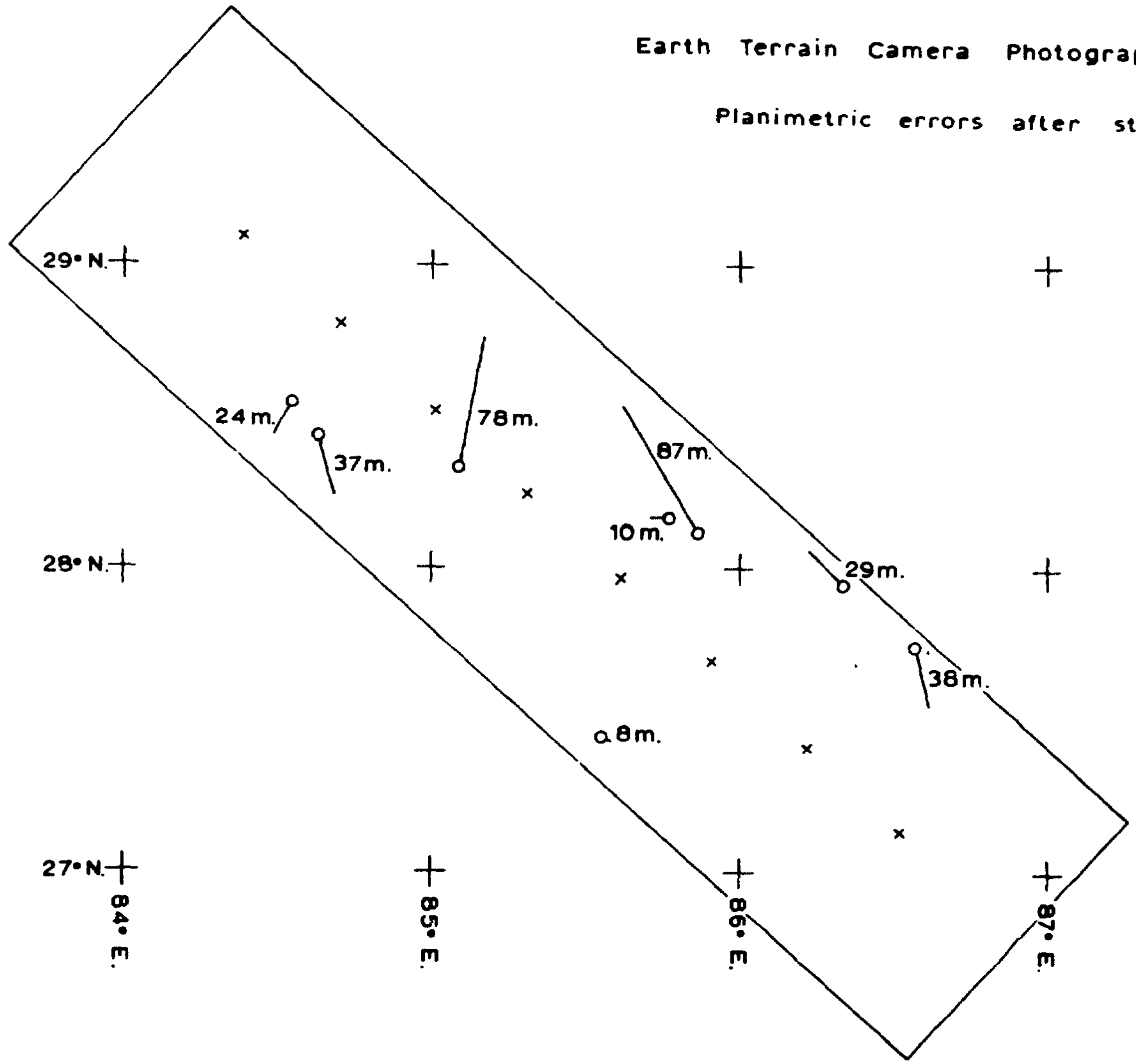
9.1.1 Planimetric Adjustment (see Figure 3).

This strip of seven stereo-models was adjusted onto a line of control points which runs along the crest of the mountain range and runs diagonally through the strip. A total of eight points were used and

Figure 3.

Earth Terrain Camera Photography.

Planimetric errors after strip adjustment.



they gave a r.m.s.e. of 47 metres with a maximum error of 87 metres.

9.1.2 Height Adjustment (see Figure 4)

The strip of photography was adjusted to fit onto a total of 20 height control points. The strip fitted well, giving a root mean square error of 111 m., with a maximum error of 241 m. Although these results were considered to be quite satisfactory it was later discovered, when attempts were made to plot contours, that the internal geometry of the earth terrain camera photography is apparently distorted and that these results are erroneous and very misleading.

It was found that when a stereo-model was set onto minor control points derived from this strip adjustment, heights read in the bottoms of valleys gave totally false values, all being much lower than was possible. In fact the floor of one very deep valley situated in an area of very high mountain peaks was apparently 2,000 metres below its true level. This type of error is consistent with that caused by a wrong focal distance setting on the plotting instrument, which results in the stereo-model having a wrong vertical scale, but this was investigated and no erroneous setting could be found. No sure explanation has been found for this phenomenon. Since it is not apparent in the results obtained from the multispectral camera photography, it must be caused by some feature peculiar to the earth terrain camera. It is not consistent with the type of error caused by the inherent inability to determine the exact location of the principal point in the E.T.C. It is therefore presumably due to the effects of the focal-plane shutter used in this type of camera, although insufficient information is available to us to prove this conclusively.

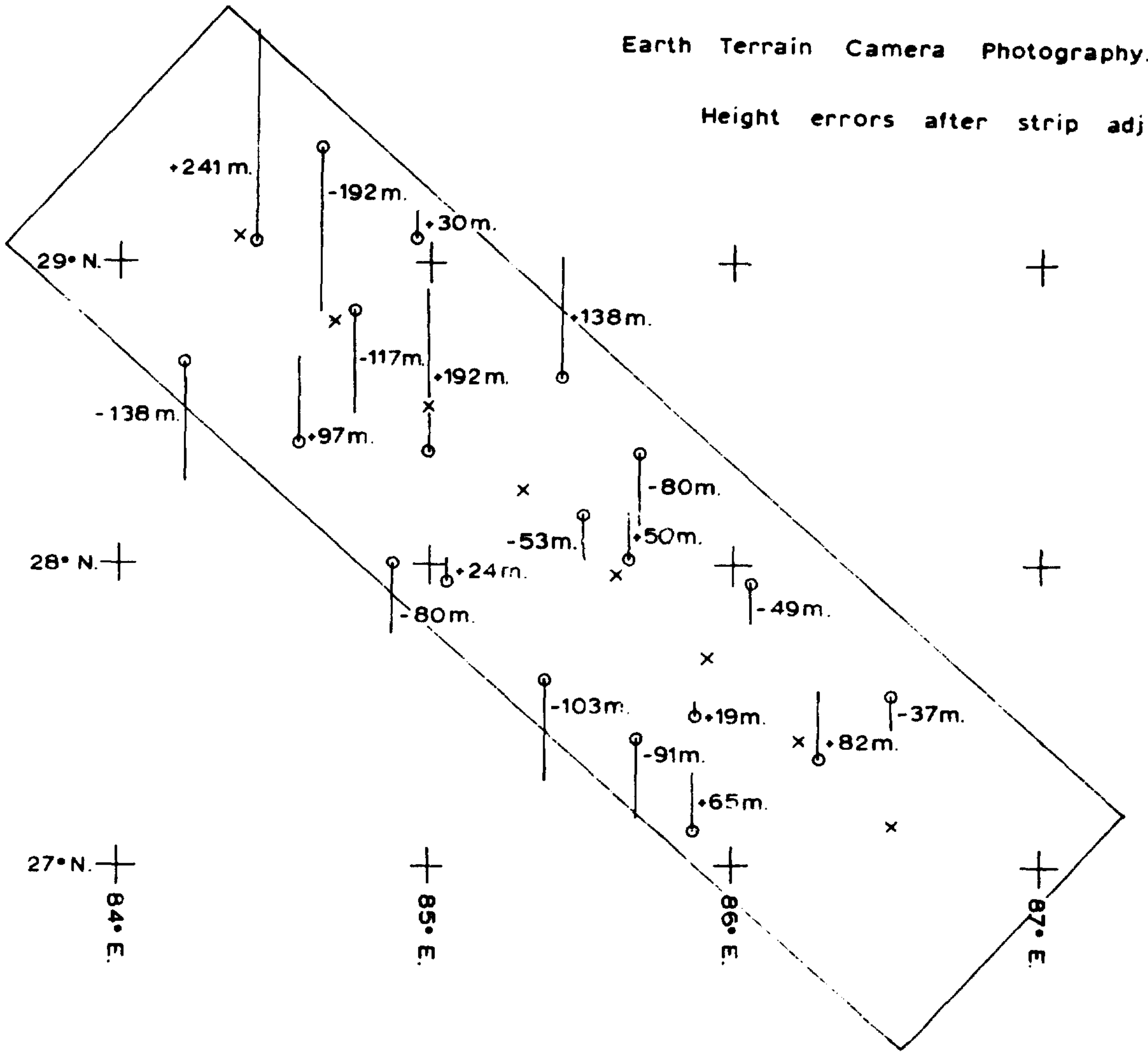
The apparently acceptable results obtained during the strip height adjustment can be explained by the nature of the terrain and the available height control. All the height control points are on mountain peaks and all of these fall on or close to a plane. This plane is not horizontal to the height datum, but the nature of the error is such that the strip can be adjusted to any set of height control points which conform to this condition.

It was found that what appeared to be acceptable height readings could be obtained by purposely reducing the principal distance set on the photogrammetric instrument by a factor of approximately 1/3, but this in no way explains the error. To study the phenomenon properly,

Figure 4.

Earth Terrain Camera Photography.

Height errors after strip adjustment.



it would be necessary to obtain earth terrain camera photography of a very mountainous area in which the ground heights are accurately known. It should be noted in passing that tests carried out during the SL2, SL3 and SL4 Pointing Accuracy Evaluation in which the photography was adjusted onto ground control were all performed in areas of relatively flat terrain and would not have shown up this error.

9.2 Multispectral Camera

9.2.1 Planimetric Adjustment (see Figure 5).

The four stereo-models adjusted onto seven plan control points which fell into three groups. The results, which were many times worse than those obtained for the earth terrain camera, gave a r.m.s.e. of 283 metres with a maximum of 383 metres. The results of NASA's investigation into the geometric accuracy of the camera/window system preclude the possibility of the errors being caused by the lens or camera window. Any film distortion sufficient to cause this magnitude of error would have been immediately apparent in the instrument settings. However, the control points used are those which are the greatest distance from the triangulation network and which are therefore the most suspect. It is not known in detail how their positions were fixed, but it seems probable that there must be several intermediate points between them and the network, all of which must have been fixed by intersection. It must therefore be concluded that these errors are in the control and not in the photography.

9.2.2. Height Adjustment (see Figure 6)

The strip was adjusted onto 16 height control points which resulted in a r.m.s.e. of 117 m. with a maximum error of 270 m. This result could have been improved if two points had been eliminated from the adjustment on the assumption that the ground heights were in error. However, there was no real basis to assume this and they were therefore left in the adjustment.

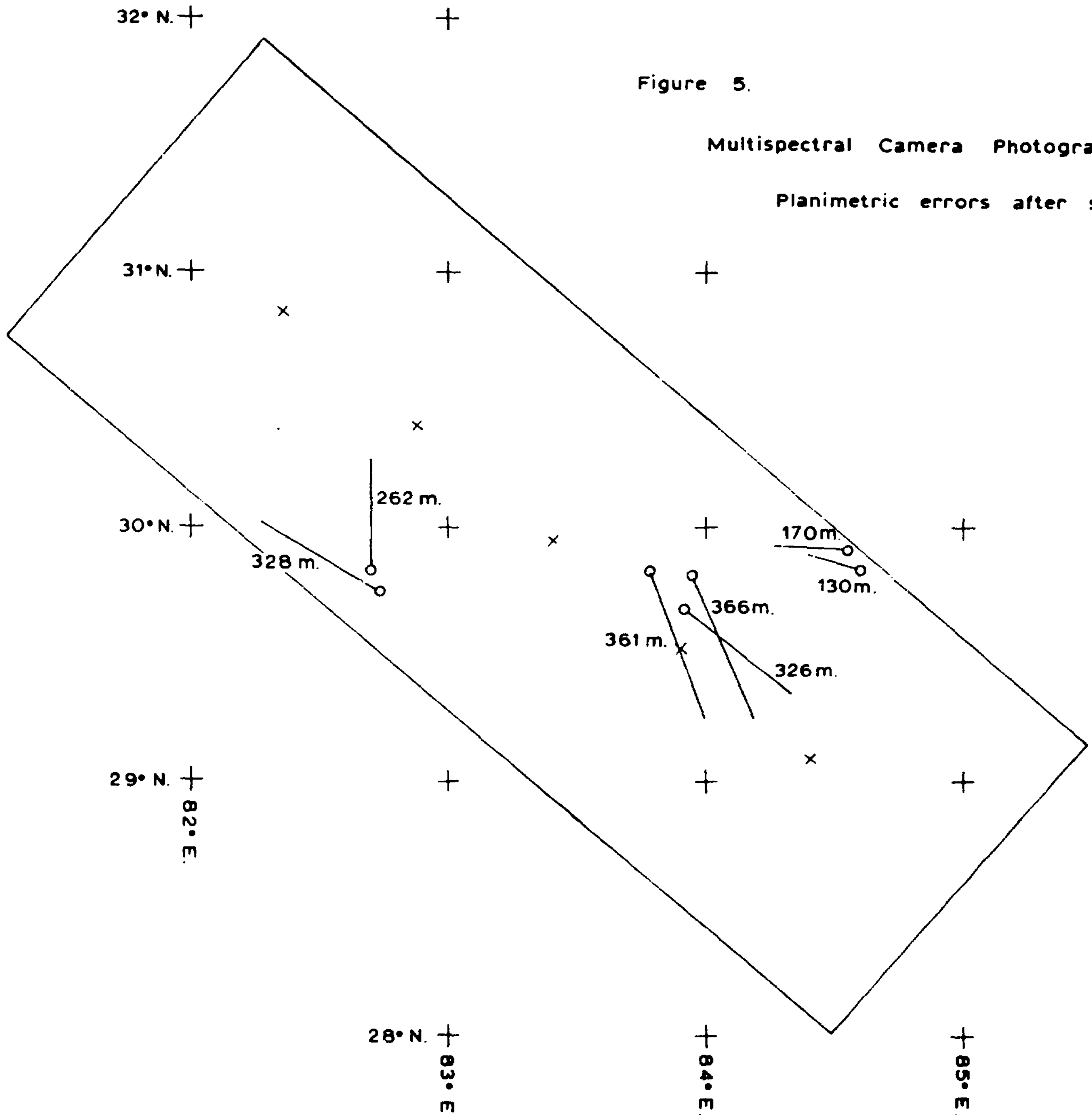
10. DETAIL INTERPRETATION AND PLOTTING

Under normal photogrammetric techniques, the interpretation and plotting of detail are carried out simultaneously, but for convenience they are discussed separately here.

Figure 5.

Multispectral Camera Photography.

Planimetric errors after strip adjustment.



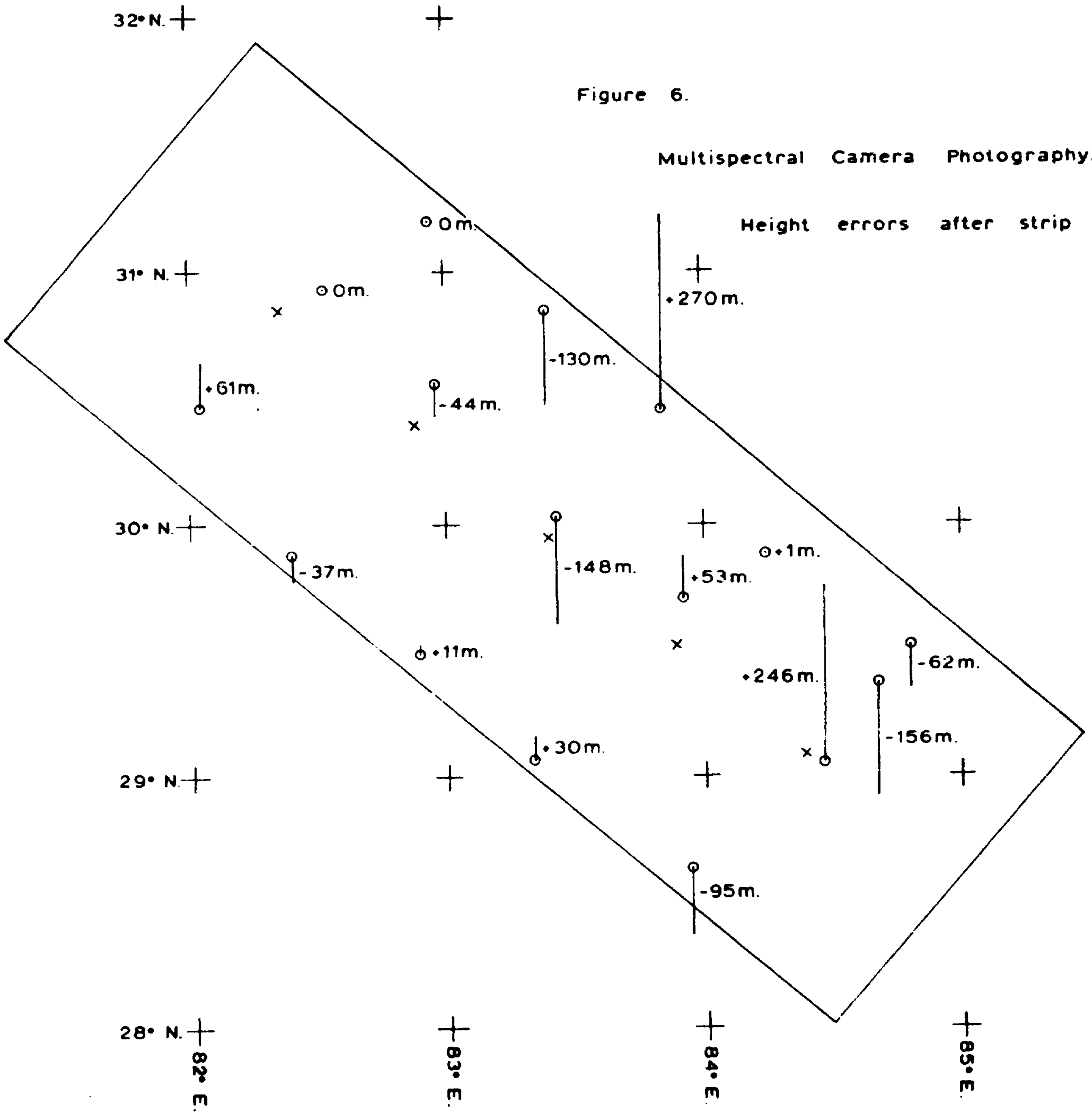


Figure 6.

Multispectral Camera Photography.

Height errors after strip adjustment.

10.1 Multispectral Camera Photography

One stereo-model was selected as the test area on the basis of minimum snow and cloud cover. The area chosen measures approximately 75 by 114 kms and is centred on a point with geographical co-ordinates of 29°20'N. and 84°20'E. This area was plotted at a scale of 1:500,000 with contours at 250 metre vertical interval. In addition to this, a small part of the test area measuring 9,400 by 14,200 metres was plotted at a scale of 1:62,500, this being the maximum enlargement possible on the stereo-plotter, again with contours at 250 metre vertical interval.(Roll No.60. Exp. Nos. 022-23).

10.1.1. Detail Interpretation

There was of course photography available from the six different camera stations to aid the interpretation, but it was found in practice that it was only necessary to use the photography from station 5 (600-700 nanometres bandpass, SO-022 Panatomic-X black and white film) and from station 4 (400-700 nanometres bandpass, SO-356 hi-resolution colour film). It is believed that this is due to a combination of three factors, namely the tone-reproduction characteristics of the photographic system employed, the nature of the terrain and the climatic conditions of the test area.

In the black and white photographic material supplied by NASA the tone-reproduction becomes progressively less satisfactory as the average wavelength of the band used increases. This may be partly explained by the EK2424 film used for the two infra-red camera stations. However, since the progressive deterioration in tone reproduction also continues through station 5 and 6 (film SO-022) and stations 1 and 2 (film EK 2424), it must be assumed to be caused by some other factor. Given the apparent lack of atmospheric effects upon this photography, it would appear to be probably due to the relationship between the spectral reflectance of the ground and the effective spectral sensitivity of the photographic system.

Under normal conditions, one would expect the shorter wave-length photography to be seriously affected by atmospheric haze, but this is not so in this case. It seems probable that the thin atmosphere in the test area is intensely cold at this season of the year, the been frozen out. This almost completely dust and water-free air then approaches the light scattering conditions of a 'Rayleigh' atmosphere, which would then be likely to have better light transmission performance at the shorter wave-lengths than a more polluted atmosphere. At the same time, the shortest wavelength record is also most influenced by the blue sky-light, giving better illumination in the shadows without excessive light scatter due to the absence of haze.

The net result of this is that the film from camera station 5 shows the most fine detail, both in the dark areas of bare rock and in the snow and that in this particular case, the photography obtained from this station is considerably better for cartographic purposes than that obtained from the other three stations using black and white film.

Purely from an interpreters viewpoint the natural colour photography from station 4 is noticeably better than the black and white photography from station 5. However, as previously stated, the enlarged colour photography was found to be geometrically inaccurate and the technique adopted was to plot using the band 5 photography in the photogrammetric instrument assisted by the use of the colour photography to aid the interpretation.

10.1.2 Detail Shown

The following details were shown on the instrument plot.

(a) Rivers. With the exception of the Brahmaputra and its larger tributaries, it is often not possible to see the actual courses of the rivers and streams because of the dense shadows in the valley bottoms. Watercourses have therefore been depicted wherever the shape of the terrain indicates that one may logically be expected to exist. On the 1:500,000 scale plot, the drainage pattern has had to be considerably simplified, but at a scale of 1:62,500 it is possible to plot every small stream.

(b) Glaciers. These are not always easy to distinguish since they are heavily snow covered at this season of the year. They must therefore be assumed to exist in those valleys which have a characteristic U-shaped cross section in their upper reaches.

(c) Tracks. Where these run over unbroken bare ground they are clearly visible. They are of course, completely obscured in the snow covered areas and also cannot be seen when they run into broken country.

(d) Marsh. There are considerable areas along the course of the Brahmaputra where numerous small pools of water and meandering watercourses indicate a liability to flood. These areas are presumably marshy, at least at some seasons of the year.

10.1.3 Details Not Visible on Photography

(a) Villages. It is known from existing mapping that some villages occur in the test area. Despite the fact that their locations could be accurately identified by comparison with local topography, the villages themselves could not be seen. This is due to their small size, their scattered nature and the lack of contrast between the roofs of the buildings and the surrounding ground surface.

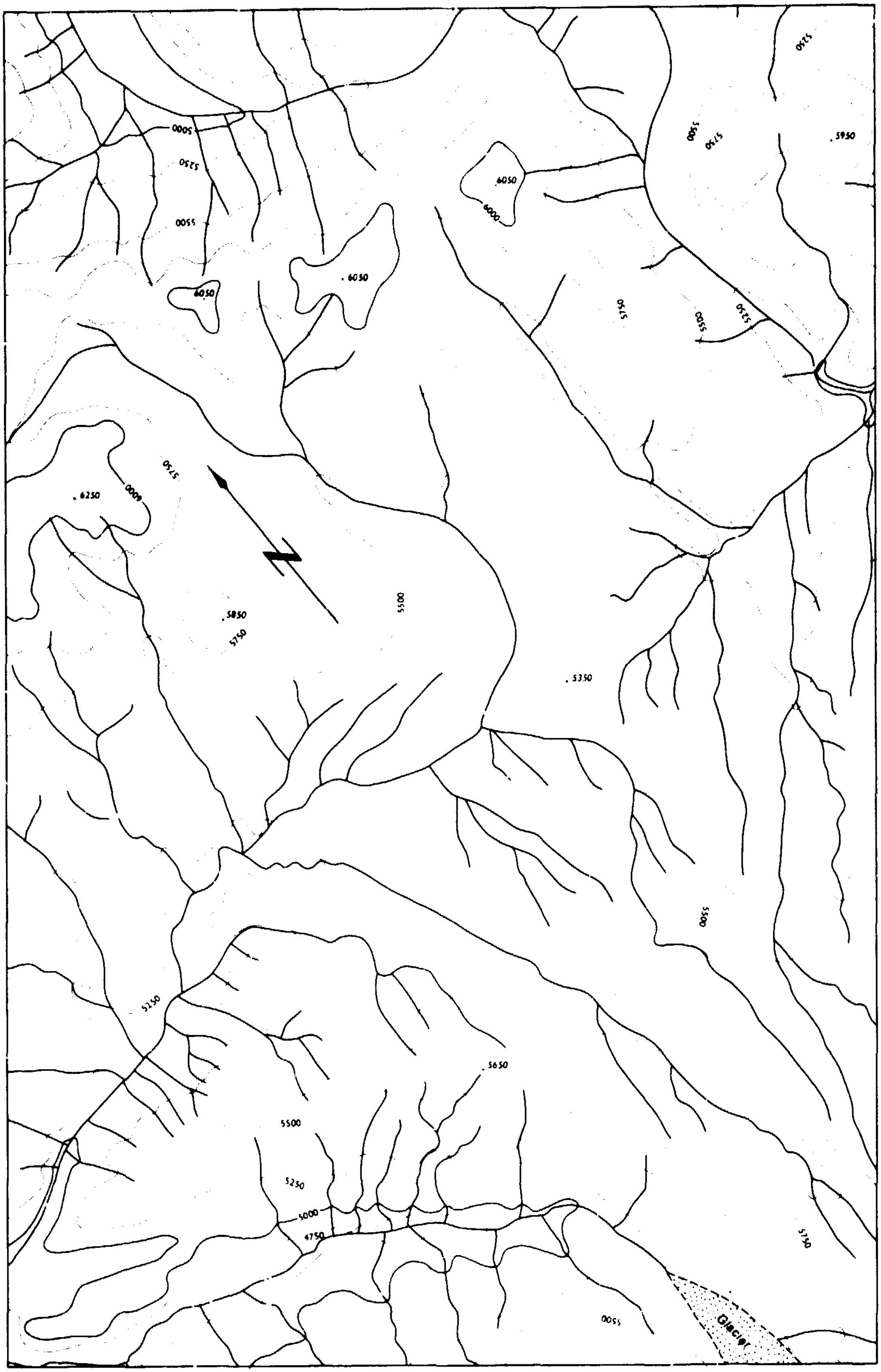
(b) Vegetation. No sign whatever of green vegetation can be detected in the test area. Little or no vegetation would be expected on the high mountains at any time of the year, but this is probably a seasonal condition in the Brahmaputra valley. Areas of cultivation are too small to be identified.

10.1.4 Plotting (see Figure 7 and 8)

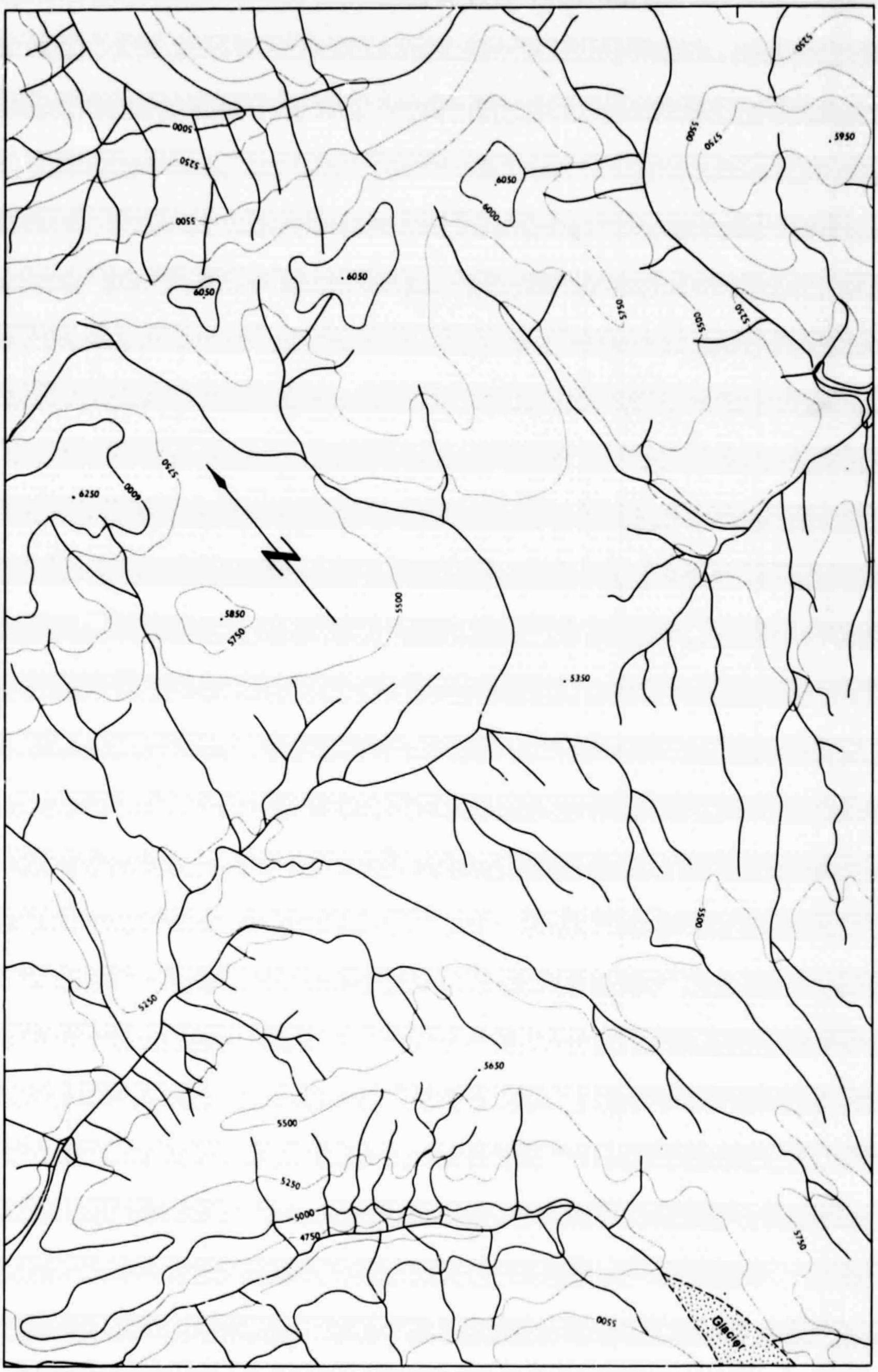
All plotting was carried out on a first order photogrammetric stereo-plotting instrument. Because enlarged diapositives were used, the effective focal distance was outside the range of adjustment of the instrument. A false value was therefore used, resulting in a vertical scale which differed from the horizontal scale by a known amount. A correction was then applied to all heights read on the instrument.

Corrections had to be made during the plotting of the contours to compensate for the effects of earth curvature. To allow for this, a network of fifteen evenly displaced minor control points were selected during the aero-triangulation and the heights of these points were corrected for earth curvature during the adjustment procedure. The stereo-model was levelled and contours plotted in eight separate sections, each section being sufficiently small that the effects within it of earth curvature could be considered negligible.

Figure 7. Photogrammetric map plotted from multispectral camera photography at a scale of 1:500,000 with contours at 250m. V.I.



F. ure 8. Photogrammetric map plotted from multispectral camera photography at a scale of 1:62,500 with contours at 250m. V.I.



F. ure 8. Photogrammetric map plotted from multispectral camera photography at a scale of 1:62,500 with contours at 250m. V.I.

One complete stereo-model (Roll 60, Exp. Nos. 022-023) was plotted at a scale of 1:500,000 with contours at a vertical interval of 250 metres. In addition to this, a small part of this model was plotted at a scale of 1:62,500 (the maximum enlargement obtainable on the stereo-plotting instrument used), again with contours at 250 metres vertical interval.

10.2 Earth Terrain Camera

As previously stated in section 9.1.2 of this report, the attempts at stereo-plotting contours from this photography were not successful. Any attempt at mapping from this photography was therefore abandoned. It could have been satisfactorily used for plotting detail only, but it was felt that taking into consideration the very mountainous nature of the terrain and the lack of visible cultural features, this would serve no real purpose without accompanying height data.

10.2.1 Detail Interpretation

An investigation of this photography was undertaken under a stereocope to determine what detail is visible. Because of the lack of simultaneous operation of the two cameras, it is only possible to make a co-parison between the two types of photography in a very limited area.

Despite the fact that the earth terrain camera photography has twice the resolution of the multispectral photography, given the same film in both cases, the increase in the amount of detail visible on the E.T.C. photography is not very great. This must be due in part to the nature of the terrain. The significant natural features of the area are all of sufficient size that they are visible, even with the reduced resolution of the multispectral photography. On the other hand, the cultural features with a few exceptions are all too small and scattered to be seen, even with the resolution of the E.T.C. photography. The resolution of the earth terrain camera photography would have to be very considerably increased before a significant improvement over the multispectral camera photography would become apparent in this type of terrain.

Unfortunately, Katmandu which is the only sizeable town on this photography is covered by early morning mist and the runway of the airport is the only part of the town which is visible. The only other cultural features which can be clearly seen, are some tracks at the northern end of the strip and areas of cultivation in the southern foothills of the Himalayas. One village and its associated pattern of tracks and terraced cultivation were tentatively identified, but they were on the very limits of resolution and would certainly never have been discovered if their position had not been previously known.

11. PRACTICAL CARTOGRAPHIC USES OF SKYLAB PHOTOGRAPHY

The current practical cartographic uses of Skylab photography are severely limited by the amount of available photographic coverage. Whilst the United States are fairly well covered, the total coverage of the remainder of the world is very small and piecemeal and seldom gives adequate photographic data for any particular project area. These comments must therefore presuppose the ready availability of photography at nominal cost.

11.1 Original Mapping

The photography has a very practical role to play in the production of original mapping of the less developed areas of the world. A large proportion of the earth's land surface is inadequately mapped, even at small scales. Adequate funds are not available for mapping these areas by conventional methods and will probably not become so in the foreseeable future, so that any technique which can introduce substantial economies should be readily received.

It must be emphasised however, that this photography, in common with all very small scale photography and imagery, cannot be used to supply all the detail needed on a small scale map. The importance for cartographic purposes of most natural features is directly related to their size and the resolution of this photography is entirely adequate for the interpretation of such features for maps at scales up to 1:100,000 or even larger. However, the situation regarding cultural features is very different. Most cultural features in undeveloped areas are very small and even if they are visible on the photography, they will probably not be identifiable without further information on their exact positions. Cultural features are shown on small-scale maps because of their potential value to map-users and this has little if any relationship to their size. For example, in the more arid areas of the world, a well may be of vital importance to travellers but can only be detected on very large scale photography. Skylab coverage is necessarily limited to the supply of the majority of natural features and occasional cultural features upon which further details extracted from a variety of existing sources may be 'hung'.

It is not possible to arrive at an absolute map positional accuracy figure from the tests performed on this photography because of the lack of precise plan control. However, it is our considered opinion that the absolute plan error of detail plotted from the multispectral camera photography should not exceed the stated resolution figure of 40-46m. This photography is therefore suitable for the production of planimetric maps at a scale of 1:100,000 to the U.S. National Map Accuracy Standards which call for a planimetric accuracy of 50 metres at this scale.

Because of the small base-height ratio which is inherent in all space photography, it is not practical to plot contours to an accuracy commensurate with this scale. A vertical interval of 250 metres appears to be a practical minimum and whilst this may be adequate in areas of excessive relief such as the Himalayas, it is totally inadequate in most other parts of the world. It is however possible to plot form-lines which, while they are completely inadequate for the purposes for which contours are normally intended, may be used to supply the information needed for the general depiction of relief by conventional cartographic techniques of hill-shading and layer-tinting.

Because of its shortcomings for height measurement, it is not considered that the earth terrain camera photography is suitable as base material for original mapping. However in some circumstances it may be of use in aiding the interpretation of simultaneous multispectral camera photography.

It has been assumed throughout this discussion that the photography will only be used for the production of original maps of undeveloped areas since small scale maps of developed areas are almost always derived from larger scale surveys.

11.2 Map Revision

For this purpose, it is considered that the earth terrain camera photography should be used in preference to the multispectral photography. Map revision will seldom involve natural features since these normally undergo little change. On the other hand, cultural features are subject to constant change and a map is almost invariably out of date by the time it is published. Since the earth terrain camera photography has a resolution of 20 metres compared to the 40 metre resolution of the multispectral photography, the former is obviously of more use for interpreting cultural features. These features are often accentuated by their contrast with the surrounding vegetation and it would be advantageous to take the photography at the period of maximum green-growth in order to obtain most advantage from this contrast.

This photography is suitable for the revision of maps at a scale of 1:100,000 or smaller. At scales larger than this, it will not supply the detail necessary to revise urban areas but it may still be adequate for areas of more open country. It can also be used to define areas of urban development which may then be revised by more conventional methods.

11.3 Uses for Photogrammetric Control

Skylab coverage can be considered as a possible source of photogrammetric plan control in area where existing control is very widely spaced. In this context, resolution must limit its uses to those areas which contain identifiable detail of a type suitable for use as control points. Where additional field control is necessary to supplement existing data, the use of Skylab aero-triangulation and block adjustment can result in far fewer new control points being provided than would otherwise be necessary. This factor is of special importance if doppler/satellite equipment is employed, thus eliminating the need for long traverses measured by electronic methods or for long trilateration networks.

11.4 Thematic Mapping

The synoptic view obtained with this photography has obvious advantages in the field of thematic mapping. The two themes which are immediately apparent within the test area are snow cover and forest.

11.4.1 Snow Cover (see Figure 9)

The extent of the snow cover is easily defined on the photography from both cameras. The natural colour film is most satisfactory for the interpretation of snow details. It is possible to divide the area of snow cover into two classes, namely thin snow cover where some bare rock can be seen showing through and thick cover which completely blankets the landscape. It is not possible to differentiate between snow and ice or, with the exception of glaciers, to define areas of permanent snow and ice.

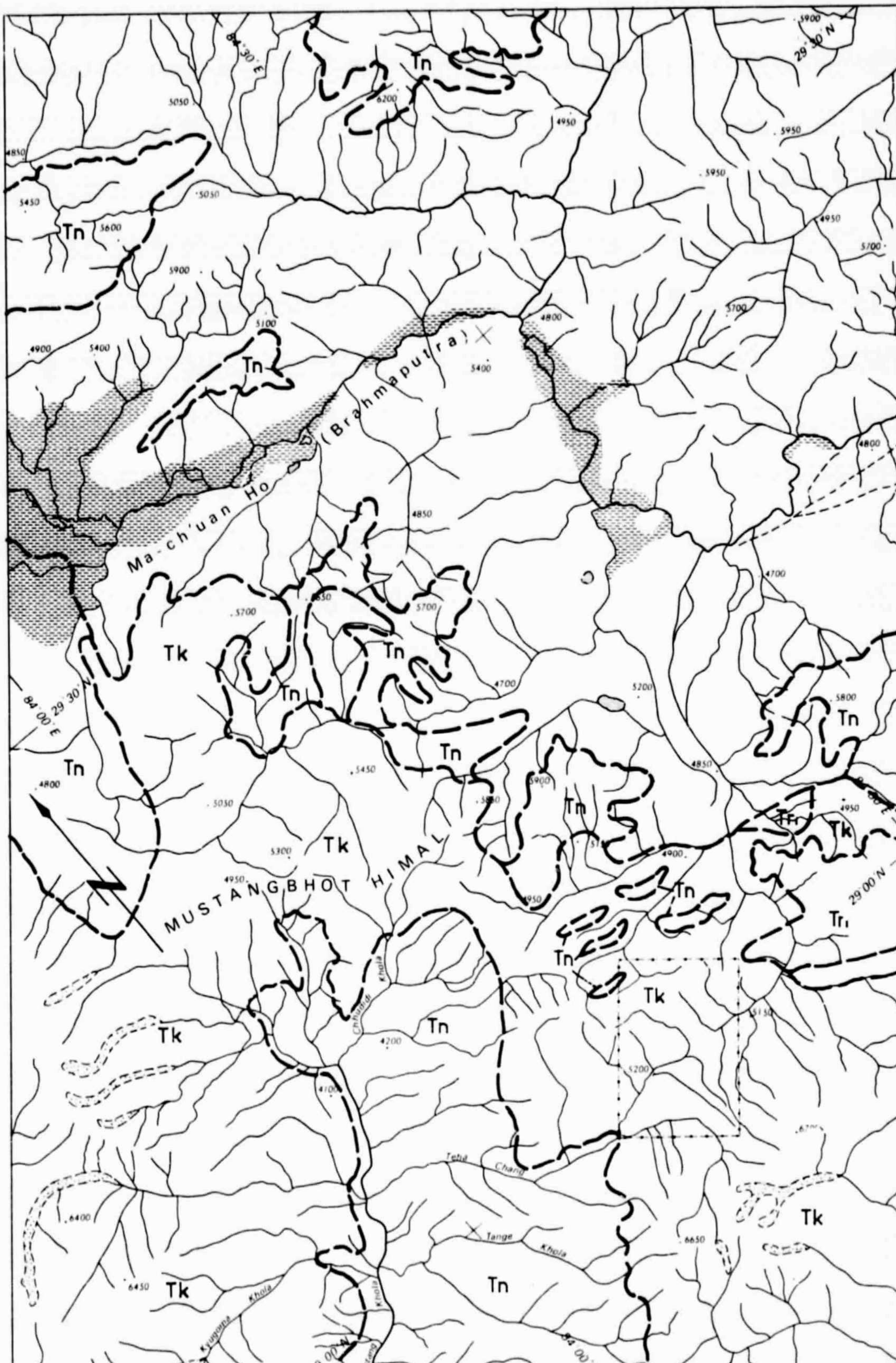


Figure 9. Extent of snow cover (December 1973) on area mapped at 1:500,000. Tk = thick snow cover. Tn = thin snow cover.

11.4.2 Forest (see Figure 10)

The multispectral camera photography could not be examined for its potential usefulness for this theme since there does not appear to be any forest in the area of photocover. The natural colour photography from the earth terrain camera does however cover considerable areas of forest in the south of Nepal and the limits of the areas covered by the different types of forest can be clearly differentiated. The classification of these various types must obviously rely heavily upon knowledge of the forestry of the area. It is possible to identify areas of dense forest of a minimum size of about 1 km square in the mountains and about 700 m square in the flatter regions where the forest contrasts strongly with the surrounding areas.

12. COMPARISON BETWEEN SKYLAB PHOTOGRAPHY AND LANDSAT MULTISPECTRAL IMAGERY

12.1 Availability of Cover

Landsat imagery gives world-wide coverage, it is sequential, readily accessible and new imagery is constantly being recorded on a world basis. Skylab photography is very limited in coverage outside the United States and only covers selected test sites.

12.2 Ground Resolution

The best ground resolution obtainable from Skylab photography is 30 metres with the multispectral camera (camera station 5, wavelength 600 to 700 nanometres, SO-022 Panatomic-X black and white film) and 17 metres with the earth terrain camera (EK 3414 hi-definition black and white film). This is much superior to the Landsat minimum ground resolution of 80m. However it is planned that the return beam vidicon camera to be used in Landsat-C which is tentatively scheduled for launch in late 1977, will have a ground resolution of 40 metres.

12.3 Image Quality

Skylab photography is of much better image quality than Landsat imagery since it does not suffer from the defects of a scanned picture which are inherent in all Landsat imagery. These defects include mis-placed and faulty scan-lines and the detail-masking effect of the scan-lines.

12.4 Stereoscopic Capabilities

For all practical purposes, there is no stereoscopic capability with the Landsat imagery. Although there is some lateral overlap

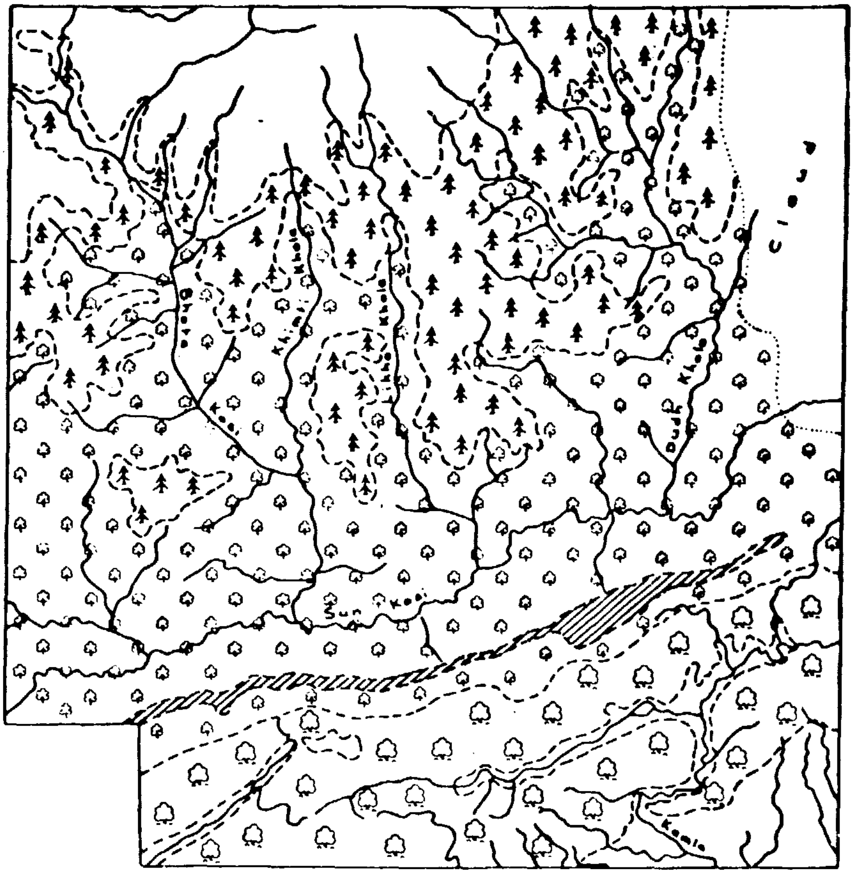


Figure 10. Interpretation of Areas of Forest.

Forest Classification:

Tropical moist deciduous forest containing Sal (Shorea robusta). Confined to the southern foothills from 1000-3000 ft. altitude. Completely covers the terrain, except where it has been cleared along the river bottoms.

Tropical evergreen forest, possibly including Deodar (Cedrus deodara). Confined to the ridge of the Siwalik Hills along the southern side of the Sun Kosi valley at altitudes above 4000 ft.

Upland coniferous evergreen forest. Confined to the higher regions from about 6000 ft. up to the tree-line at about 10,000 ft.

Mixed deciduous forest.
Covers the hill-sides below 6,000 ft. Locally dense in sheltered valleys and occasionally on the northern faces of the hills, but otherwise scattered.

Earth Terrain Camera photography.
Roll No. 91. Exp. No. 186.
Hi-resolution colour film (SO 242).
Centre point. Lat. 86°13'E. Long. 27°25'N.

between images, the height displacement of detail is so small that there is little apparent stereoscopic relief except in extremely mountainous areas. On the other hand, Skylab photography is fully stereoscopic and whilst it is not adequate for plotting contours to normally acceptable standards, the stereo-relief makes the interpretation of drainage features very much easier and more accurate.

12.5 Geometric Accuracy of Imagery

The Skylab photography, being produced through lenses of known characteristics, has known and measurable deformations. The Landsat multispectral scanner imagery suffers from random deformations due to displacement of individual scan-lines which are inherent in any scanned imagery.

12.6 Conclusions on the Comparison

Until Skylab photography is readily available as and when it is required, Landsat imagery has one overwhelming advantage in that it provides world-wide coverage available to all. There is no real clash between the two types of imagery, they complement rather than compete with one another. Landsat imagery is satisfactory for initial mapping of remote areas with little if any ground control at 1:1,000,000, or at larger scales up to 1:250,000 with reduced accuracy. Skylab photography is more suitable for second-stage follow-up mapping of selected sites at scales up to 1:100,000.

13. RECOMMENDATIONS FOR CHANGES TO THE PHOTOGRAPHIC SYSTEM

13.1 Earth Curvature

To become commercially viable for mapping purposes, space photography must be suitable for use in the types of photogrammetric instruments commonly employed. These instruments cannot easily cope with the correction of the degree of earth curvature present in photography taken from an altitude of 430 kms. There are analytical plotters in which this correction is no problem, but they are little used commercially. This correction must be made if height measurements of acceptable accuracy are to be obtained. From a photogrammetric user's viewpoint, it is preferable that the photography supplied has already been corrected. This may be done by printing the photographs through a correction plate designed simultaneously to correct for earth curvature and lens distortion.

13.2 Earth Terrain Camera

It is unfortunate that the Earth Terrain Camera was only designed to provide high resolution photographs to aid the interpretation of data gathered by the other sensors. This camera has a potential for photogrammetric mapping at least equal to that of the multispectral camera, but this is completely negated by the use of a focal plane shutter which produces unacceptable distortions in the photography. For precise photogrammetric measurement the camera should have a between-lens rotary shutter.

It is a sound principal that photography should always be of the best possible quality and not just adequate for the job in hand. It has repeatedly been found in practice that photography intended for one use is eventually required for other and often more demanding purposes.

14. CONCLUSIONS

Film-recoverable space photography such as that produced by Skylab has a definite use in cartography. It must however be able to compete economically and in availability with conventional small-scale aerial photography. It is unlikely to become as widely available as Landsat imagery, but it is hoped that further photography will be obtained of selected target areas for cartographic purposes.

The photography is suitable for producing planimetric maps with graphical representation of land-form at scales up to 1:100,000. It cannot supply all the detail necessary for maps at this scale, but it may be used to produce a sound framework which can be completed by detail from other sources. It's principal cartographic use would be for original mapping of undeveloped areas of the world, but it would also be useful for the revision of existing maps and for monitoring extensive urban changes.

In addition to these uses, the synoptic view provided by the photography in conjunction with its resolution and stereoscopic coverage should prove to be of value for thematic mapping of earth resources and land utilisation.