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THE USE OF ULTRA-SMALL SCALE AERIAL
PHOTOGRAPHY IN MEDIUM SCALE MAPPING AND REVISION

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ABSTRACT

The applications of high-flown, super-wide angle aerial photography within the scale range 1:140 000 - 1:160 000 to both initial medium scale mapping and subsequent revision procedures in South Africa are described. Aerial triangulation, the production of 1:50 000 orthophoto maps as well as their later use in the various related cartographic processes are discussed. The work thus far undertaken has yielded very promising results especially in economy and accuracy as well as in the improved depiction of extensive areas of bush, sanddunes and desert.

INTRODUCTION

At the International Symposium in Ottawa, K J Lester (1) indicated that the main problem area facing the national mapping agency in the Republic of South Africa was the revision and metrication of the 1:50 000 series. This series comprises 1916 sheets of which approximately half have been metricated and carry 20 metre contours, the remainder being in imperial units. There remains a considerable task therefore to complete the metrication together with the continuing revision of the series according to a predetermined cycle. The standard procedure as described in the paper referred to above is to use 1:50 000 photography for metrication. With this photography an average of 20 stereomodels are required to cover a standard 15' x 15' 1:50 000 sheet. Using ultra-small scale photography at 1:150 000 only 2 stereomodels are required to cover the same sheet area and the saving in time spent on photogrammetric procedures is impressive. Investigations into the feasibility of using the 1:150 000 photography in a dual role to plot 20 metre contours as well as to produce 1:50 000 orthophotos for detail revision have recently been completed and the results are reported below as well as other advantages arising from the use of orthophotos.

AERIAL PHOTOGRAPHY

Experimental work commenced during 1977 with the flying of ultra-small scale super wide angle photography at scales of 1:150 000 - 1:170 000. The aircraft used was a Lear Jet to which various modifications had been made, to enable the aircraft to fly at the extreme limit of its ceiling while carrying maximum fuel load and undertaking photographic sorties. The camera used was a Zeiss RMK A 8,5/23 in conjunction with a standard type D yellow filter and panchromatic film. The specifications demanded a minimum fore and aft overlap of 90% with either east-west or north-south flight lines following the centres of the standard 1:50 000 published maps. Ten percent coverage beyond each sheet boundary is required with a maximum deviation in the flight line position determined according to photo scale, direction of flight, and sheet size at that particular latitude and longitude.

In South African latitudes a north-south direction of flight would be desirable to give a greater tolerance in navigation along the centre line, but experience has shown that the jet streams encountered at the required flight altitude tend to flow in an easterly direction making north-south flight lines more difficult to maintain accurately. The majority of the ultra-small scale photography undertaken thus far has therefore been flown in an east-west direction although exceptions are made where the configuration of the area clearly indicates more economy in north-south photography. Other problems of a practical nature that were encountered during photography were the inability of the aircraft to undertake flat turns due to the provision of a "yaw-damper". This meant that any change of direction had to be effected by banking, causing significant omega tilts in the photography at times. Icing problems on the navigation and camera ports were also encountered and in featureless desert and bush areas conventional navigation proved difficult, but this problem would be common to all scales of photography.

An analysis of the phi and omega tilts in grades encountered on two photographic tasks gave the following results:

(1) K J Lester : Map Revision in South Africa. Commission IV of ISP Ottawa 1978.

Task	phi			omega		
	minimum	maximum	mean	minimum	maximum	mean
A	0,1	4,9	1,4	0,1	4,4	1,9
B	0,1	1,5	0,7	0,1	4,4	1,3

Task A was the first experimental task flown and there is a noticeable improvement in phi in the later task B as the aircrew gained experience. The more or less constant results for omega are directly related to the problems in changing direction of the flight line discussed above.

The heights of the camera stations determined during aerial triangulation indicate that the flight paths have remained constant with average deviations of the order of 0,4% H. Likewise the average planimetric deviation of the flight line is of the order of 300 metres. These results indicate that, notwithstanding the fact that the aircraft is operating at maximum ceiling, the stringent photographic specifications can be met without difficulty. Provided the photography is only flown during optimum weather conditions, the resolution of detail and general photographic quality are excellent and eminently suited for orthophoto production at enlargement factors of 3-3,5 or even greater.

AERIAL TRIANGULATION

Although 90% overlap photography is available, appropriate 60% overlap exposures are selected for the aerial triangulation and subsequent photogrammetric procedures. To provide the necessary control for the acquisition of terrain data required for the production of orthophoto maps and contouring, aerial triangulation procedures were employed. Initially the observations were made on a Zeiss PSK Stereocomparator and calculated using standard analytical procedures. These procedures included inter alia the application of a clean-up programme to the observations, based on the assumption that the photography was vertical or near-vertical. This clean-up programme corrected the raw observations for the effects of earth curvature, refraction and lens distortion. Subsequent experience indicated that at times significant tilts were present and that as a result erroneous corrections were being applied to the observations. The use of observations made on a Wild A 10, incorporating earth curvature corrections etc mechanically, followed by the strip formation of independent models and subsequent block adjustment on to the national geodetic system was then resorted to. Although this method gave results which were adequate for all practical purposes (see table below), it was apparent that the effects of earth curvature were not being completely eliminated. The latest aerial triangulation is being undertaken on the stereocomparator, with a clean-up programme which excludes corrections for earth curvature, followed by model and strip formation in model co-ordinates, strip adjustment to a space co-ordinate system and then transformation to the geodetic system for the final block adjustment.

Control and check points for the aerial triangulation were obtained by stereoscopic transfer of ground and photogrammetric control points from previous mapping tasks at photoscales varying between 1:36 000 and 1:60 000 and as a result a comparatively dense pattern of control was used. The following table indicates typical aerial triangulation results:

Method*	Number of Models	No of Control Points	Standard Error in metres	
			Position	Height
I	59	46	7,7	3,1
I	56	32	6,9	2,9
II	18	32	4,9	2,1

* I Independent model triangulation on Wild A 10

* II Observation on stereocomparator plus clean-up programme omitting earth curvature adjustment on space co-ordinate system and final transformation to geodetic system

Results of this order of accuracy are more than acceptable for accurate orthophoto production using either the Wild ORI or the Zeiss-Gigas systems. The encouraging results achieved especially with a control density of 2 or more points per model and the use of space co-ordinates to eliminate the effects of earth curvature have led to further experimental work with a view to the possible use of 1:150 000 photography to produce 20 metre contours.

CONTOURING

As mentioned in the introduction, the greatest task facing this organisation is the metrication of about one thousand sheets of the 1:50 000 series. A careful estimate indicates that at least 90% of these sheets fall in the flatter areas of South Africa away from the more mountainous regions. The accuracy specification of the published 1:50 000 map with a 20 metre contour interval requires that 90% of the elevations tested be within one-half a contour interval and the remaining 10% within one half and one contour interval. To ascertain the accuracies obtainable under production conditions a comprehensive investigation similar to (2) and (3) below was undertaken. A test area 50 square kilometres in extent, comprising flat, medium and steep terrain was selected and 20 metre contours were plotted from 1:36 000 photography to serve as a standard against which the spot heights and contours determined from the 1:50 000 photography could be tested. The terrain slopes varied from $1^{\circ}45'$ to $38^{\circ}40'$ with a mean of $6^{\circ}15'$, and the photogrammetric plotting of the 1:150 000 photography was done on both a Kern PG 2 and Wild A 10 stereoplotter, with mechanical compensation for the effects of earth curvature. The plotting scale was 1:50 000.

Preliminary tests gave the following results. The actual photo scale was 1:160 000.

Instrument	Model Scale	Repeatability of a Height Reading	Mean fit on controls
Kern PG 2	1:138 888	1,7 m	3,5 m
Wild A 10	1: 62 000	1,3 m	3 m

To analyse the contours, the "true" 20 metre contours and those plotted from the ultra-small scale photography were accurately enlarged to 1:10 000 to facilitate the

(2) G H Lindig : Neue Methoden der Schichtlinienprüfung-Z Vermessung (1956) 7 & 8

(3) T J Blachut: Compendium of Photogrammetric Contouring. Working Group IV/3 1964

measurement of differences in plan position of the contours under investigation. Differences were measured at some 700 points at 10 mm intervals falling on 13 contour lines selected at random. The slope of the ground α was determined at each point using adjacent contour positions and the vertical errors were separated into systematic and random components. The standard horizontal and vertical errors of a contour are expressed as : $m_{\text{horizontal}} = \pm(A + B) \cot \alpha$ and $m_{\text{elevation}} = \pm(B + A \tan \alpha)$.

The results below followed from the investigation.

Instrument	Systematic error metres	B		A		Standard error $m_{\text{elevation}}$	
		metres	%H	metres	mm at 1:50 000	metres	%H
Kern PG 2	-4,5	1,9	0,014	28,5	0,57	5,0	0,035
Wild A 10	-0,7	3,1	0,022	10,7	0,21	4,3	0,030

The standard errors in elevation were as expected, the large value of A for the Kern PG 2 being closely related to the pantograph-tilting table combination used on this instrument for positional enlargement. The result for B on the Kern PG 2 viz 1,9 metres is considered to be on the low side as one would expect this constant to be of the order of 3 metres or more for such high flown photography and it is felt that a value of 2,5 metres would be more appropriate. Taking the standard errors of a control point determined by aerial triangulation as 2,5 metres in elevation and 6,5 metres in position into account the standard error for a contour on the Kern PG 2 could be expressed as $m_{\text{elevation}} = (3,5 + 29 \tan \alpha)$ metres and if a further allowance of 0,5 mm is made for positional errors in the contours resulting from the cartographic process, the final contour on a published map should have a standard error of $(3,5 + 30 \tan \alpha)$ metres. It can be inferred that for an average slope of 5° , the standard error would then be 6,1 metres (0,043%H) and assuming a normal distribution, it could be expected that 90% of points tested would fall within 10 metres, which on a published map would comply with specification. Problems would be encountered in steeper terrain and here larger scale photography must be resorted to. By similar deduction were a Wild A 10 to be used the final contour on a published map should have a standard error of $(3,9 + 12,8 \tan \alpha)$ metres. In this case average slopes up to just under 10° could be contoured, and the resulting map still comply with specification.

Machine time on each instrument for an area of 650 square kilometres was as follows:

Instrument	Photo Scale	Models	Machine Time
Kern PG 2	1: 36 000	44	101,5 hours
Kern PG 2	1:160 000	2	17,5 hours
Wild A 10	1:160 000	2	22,0 hours

It must be stressed that the 1:150 000 photography is primarily intended for 1:50 000 orthophoto production without mosaicking so no advantage would accrue were photography at a scale of say 1:100 000 or 1:125 000 to be flown simply to increase contouring accuracy, as such photograph would be unsuitable for orthophoto production.

PRODUCTION OF 1:50 000 ORTHOPHOTOS

Initially 1:50 000 Orthophotos were produced on the Zeiss Planimat-GZ 1 system, but present production has been concentrated on the more versatile Wild ORI system. The latter system can accommodate greater tilts as these are compensated for analytically rather than mechanically. Normally the two models whose common diapositive forms the scanning diapositive, are relatively and absolutely oriented on Kern PG 2 plotters which have been modified for the acquisition of digital terrain data on magnetic tape. This digital terrain data may be acquired either during a process of contouring or if contours are not required, by scanning the model in a regular pattern. Problems have arisen in a few instances where severe photographic tilts beyond the range of the plotting equipment preclude absolute orientation. In these cases the digital terrain data was obtained from the model after relative orientation and the absolute orientation achieved analytically. Direct plotting of contours was of course not possible in this instance. Another practical solution to the tilt problem has been to use an adjacent diapositive which more often than not has acceptable tilts. At present the contours as plotted directly on the plotting machine are used although experimental work in the automated plotting of contours from the DTM data is proceeding. In one instance where the terrain was very flat and bush-covered, controlled 20 metre form lines were interpolated from a close grid of heights plotted from the DTM data. Positional accuracy tests were made by comparing identical points of detail on the 1:50 000 orthophoto against:

a photogrammetric plot on the A 10 using 1:150 000 scale photography;
 the original manuscript used for the production of the existing 1:50 000 published map;
 the existing standing cartographic material on a stable base; and
 the published map.

The standard errors in position expressed in millimetres at map scale were:

Orthophoto compared to	Standard Error mm
Photogrammetric Plot	0,30
Original Manuscript	0,38
Existing Standing Material	0,39
Existing Published Sheet	0,44

These results confirm expectations, but as there is no definite direct standard against which to compare them, it would be incorrect to make any far-reaching statistical assumptions. The original manuscript has not been tested on the ground for positional accuracy and no larger scale maps are available. The slight degeneration in accuracy at each subsequent stage is to be expected, and indeed when the many steps of the cartographic process are considered, it is gratifying that the degeneration amounts to but 0,06 mm.

REVISION OF STANDING MATERIAL

For revision purposes it is intended to update and improve where necessary the detail appearing on the existing standing material by direct tracing from the orthophoto. The standard error of 0,39 mm between orthophoto and standing material confirms that no deterioration in accuracy standards would occur. In fact the experiment has shown for instance that a considerable improvement in the accuracy of

depiction of the drainage pattern and other natural features would result. It will be noted that the positional accuracy standard for the published 1:50 000 map series requires that 95% of all well defined points of detail be within 0,75 mm of their true position on the ground.

Prior to editing on the ground a composite of the standing material of each sheet is compared with a bromide print of the equivalent orthophoto. During this examination it is generally easy to recognise changes of detail as well as inaccurate compilation and to effect the necessary amendments by direct tracing. In the farming areas cultivation shows up extremely well on the orthophoto so that the method is particularly suited to the depiction and revision of this important feature of the landscape. Realignments of roads and railways, new roads and extensions to townships are quickly detected and can be accurately added.

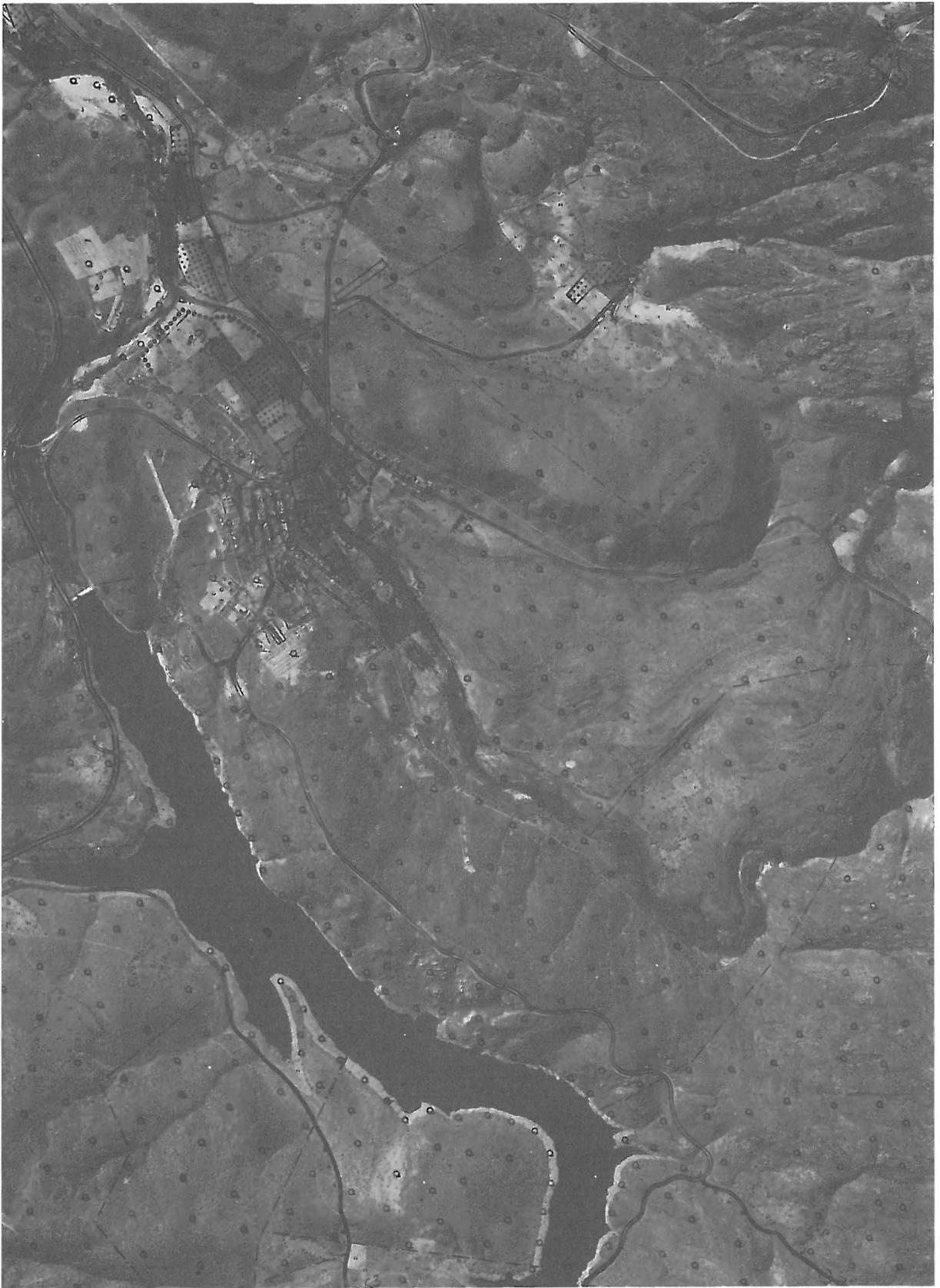
The final editing consists mainly of checking the amended data against the ground and recording the results. No matter how intricate and extensive new developments are they can be accurately added by direct tracing. The 1:50 000 orthophoto has revolutionised the techniques of revising the series. They make it possible to do a rapid revision of all the man-made features of a sheet in a far shorter time and with a greater accuracy than ever before. In fact it has been found that when revision is urgently required or maps of inaccessible areas are needed they can be produced with little or no field work.

There are limitations in that fences, telephone lines and power lines are not always visible on the orthophoto. The fences can often be deduced where there is a difference in the degree of grazing or in the state of cultivation. Moreover co-ordinates on the national system are readily available for fences running along cadastral boundaries as well as for all major power lines.

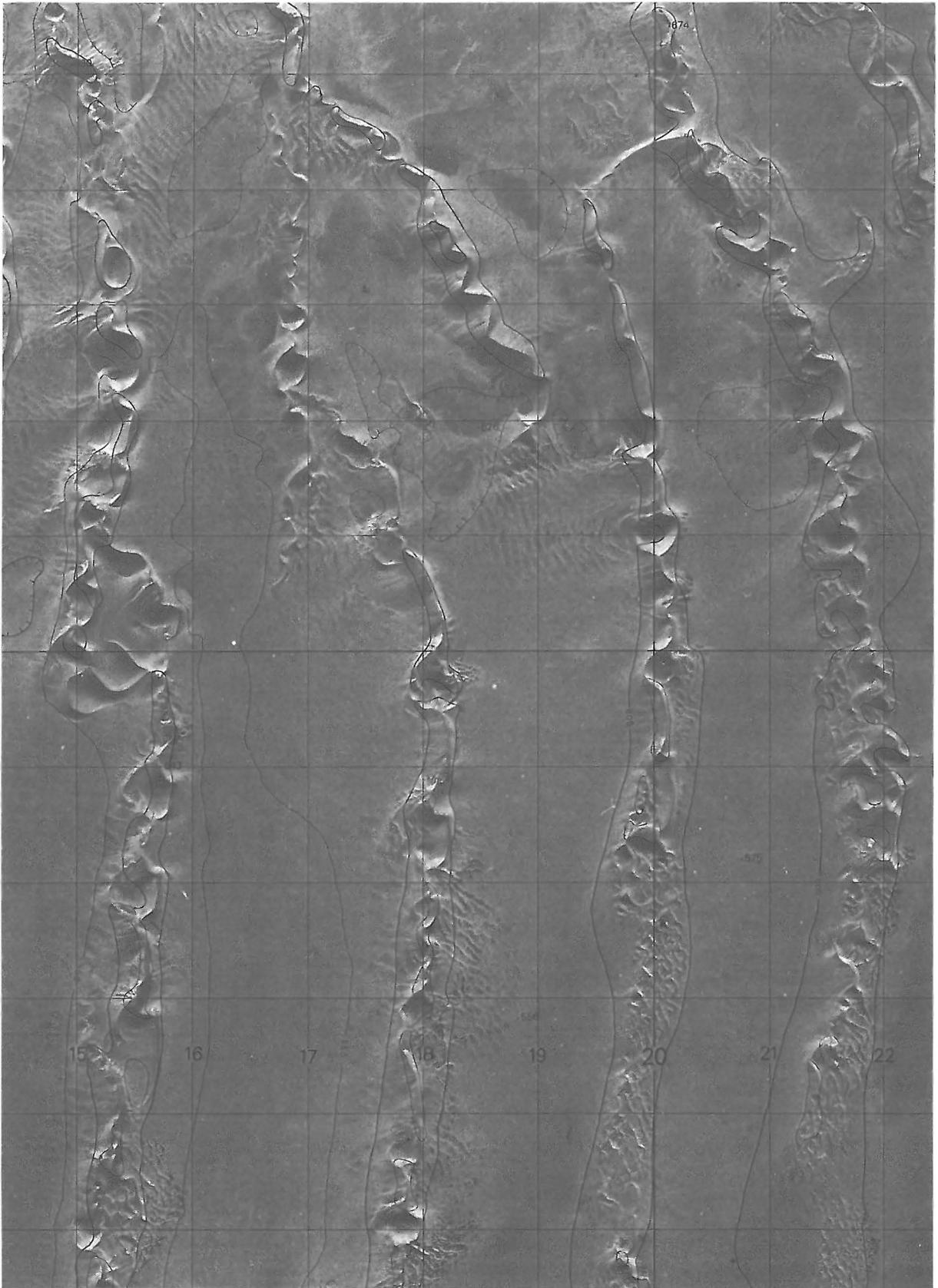
The precision depicting of other finer detail not visible on the orthophoto is not attempted and it is in fact debatable whether this is either necessary or desirable on a 1:50 000 map.

MAPPING OF PROBLEM AREAS

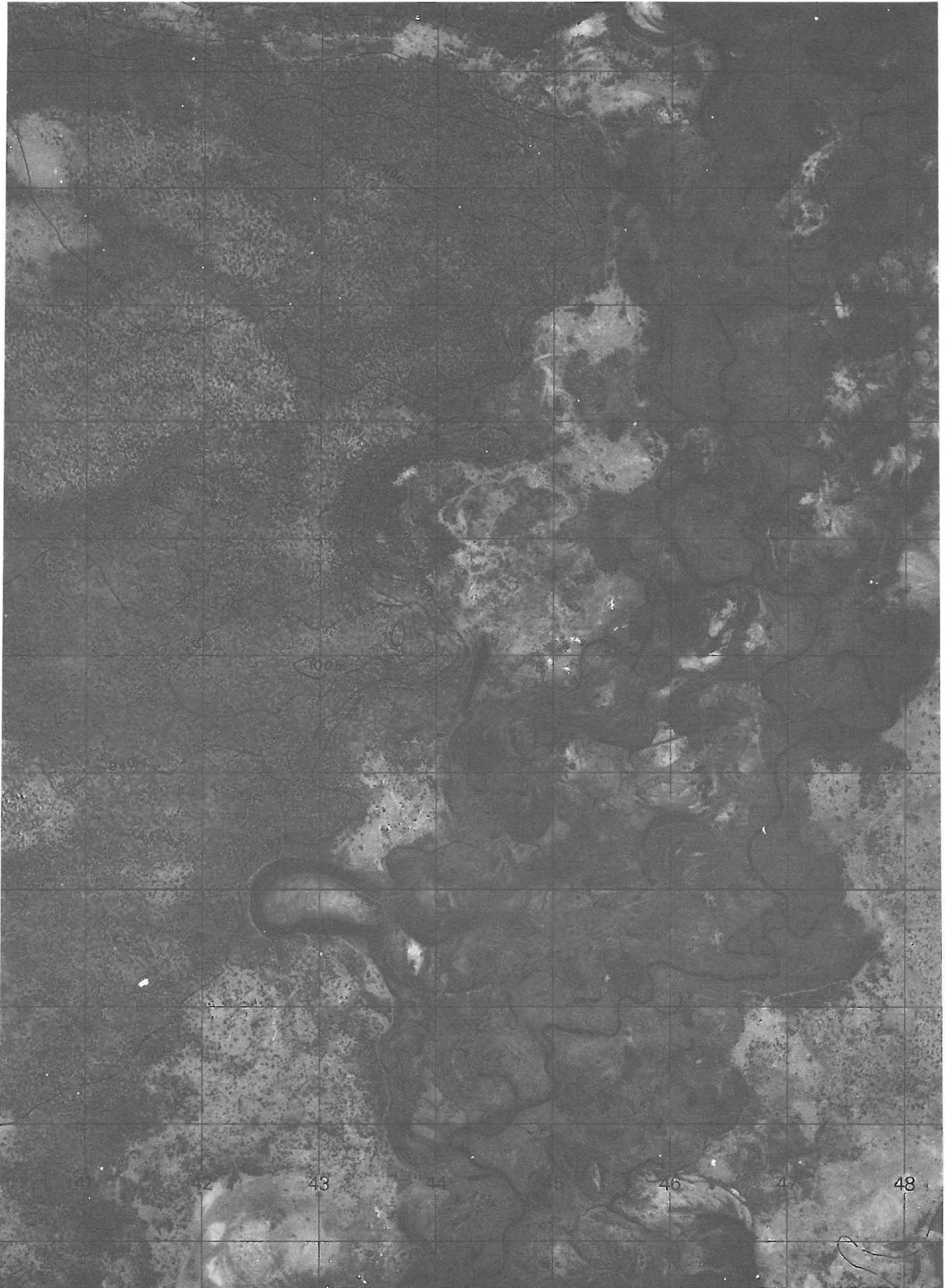
In South Africa and in South West Africa/Namibia there are vast arid semi-desert and desert regions, some devoid of vegetation, others tree-covered, while sand-dunes of all shapes, patterns and orientations, some windblown and shifting, others of monstrous size but relatively stable, cover thousands of square kilometres. Such terrain offers to the map-maker a challenge which may be unique. The combination of orthophoto map with conventional line map symbols is the best means yet devised of depicting this kind of country, and has been adopted with success in South Africa. It is generally conceded in the philosophy of cartography that a topographical map should seek to convey to the user as authentic a suggestion as possible of the intrinsic nature of the country it represents. When the dominant features of the visible landscape are such as almost to defy conventional symbolisation, it has proved to be as good a solution as any (and a more economical one than most) to use line-map techniques for those elements of the topography that lend themselves to it, or might otherwise be lost, and to overprint these on reproduction films of the orthophoto negative which have been combined with masks to allow the printing of various aspects of the photographic imagery in selected colour tones. In earlier editions of this kind of map, a photographic mosaic formed a background to the symbolised detail. While this was a considerable improvement over a conventional line map, it suffered from the defect that identifiable photographic detail could be considerably displaced. The current techniques ensure that the new maps are superior in all respects.



Part of 1:50 000 Orthophoto Map with data from existing published map superimposed



Portion of 1:50 000 Orthophoto Map showing sand-dunes overprinted with contours and spot heights.



Portion of 1:50 000 Orthophoto Map showing intricate drainage pattern and vegetation varying from open grassland to high forest.