EXPERIENCES PRODUCING SMALL SCALE LINE MAPPING FROM SPOT IMAGERY.

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ABSTRACT

The Ordnance Survey of Great Britain is currently engaged in a project to produce 1/100,000 line mapping of the eastern YAR (Yemen Arab Republic). Preliminary tests employing SPOT imagery of Europe suggested that 1/100,000 mapping specifications could easily be met and SPOT panchromatic imagery of eastern YAR was acquired.

To date , the project has encountered repeated difficulties in the identification of ground control points owing to the open rugged nature of the YAR terrain. The landscape contains few of the topographical features which are readily available in highly developed countries as small scale mapping control points. An increase in control point provision has been necessary in some cases to overcome these obstacles. Tests have shown that 1/100,000 line mapping specifications are attainable.

The project has already demonstrated that SPOT has given the photogrammetrist another data source which may be utilised , given the prerequisite resources , to produce small scale line mapping quickly and efficiently.

Ordnance Survey is interested in developing SPOT related applications further by investigating procedures to generate height information by DTM generation , correlation techniques etc. to maximise the potential of this and similar types of imagery.

AIM OF THE PROJECT

The aim of this project is to determine the technical and economic feasibility of producing small scale line mapping from SPOT imagery.

INTRODUCTION and BACKGROUND

OS (Ordnance Survey , Great Britain) is currently involved in a task to supply small scale line mapping to the YAR (Yemen Arab Republic). The project is being funded by the ODA (Overseas Development Administration) in a joint YAR / UK initiative.

Part of the project involves producing approximately 25,000 sq. Km. of line mapping (12 sheets) in eastern YAR at 1/100,000 scale.

In late 1986 attempts to acquire aerial photography for the 1/100,000 mapping project failed when flight clearance could not be obtained for the area where the international boundary is poorly defined. Part of the area of interest is covered by existing 1/40,000 scale RAF photography (flown in 1973) but this has proven to be unsatisfactory for photogrammetric adjustment purposes.

OS already had an interest in SPOT as a data source and now had an immediate project to which , if tests proved successful , the imagery could be applied. Four panchromatic stereo scenes were therefore ordered in December 1986

(149-321,322 and 150-321,322) and the imagery was acquired in January 1987.

In April 1987 an evaluation of SPOT imagery and Kern SPOT software was undertaken using the Kern DSR-1 at UCL (University College London). The imagery under test covered one of the test sites in southern France surrounding Aix en Provence. The results of these tests were very encouraging and the Kern SPOT software suite , developed at UCL , was subsequently purchased.

On receipt of the software further tests were undertaken at OS using the SPOT imagery of YAR acquired in January 1987. One model covered an area previously mapped at 1/50,000 scale for which 1/80,000 scale aerial photography was available. These tests were designed to evaluate the ease of model restitution, control point identification and plotting activities and to determine the precision of the final product.

The tests encountered difficulties with control point identification . However , the results suggested 1/100,000 scale line mapping with a 40 m VI would be feasible using SPOT imagery and further imagery was ordered to cover the remainder of eastern YAR (14 models). The project entered full production on 1st April 1988.

This paper will describe the resources required to undertake this project such as hardware , software , imagery and ground control requirements. Experiences encountered in developing production procedures including model restitution and map compilation are also included.

RESOURCES

PHOTOGRAMMETRIC HARDWARE

All work at OS has been undertaken using a Kern DSR-11 analytical plotting instrument supported by a Kern GP1 flat-bed plotting table. The instrument is hosted by a DEC PDP Micro-11/73 processor. The DSR range benefits from distributed processing and the initial tests at UCL confirmed the inadequate cycling time of the standard LSI 11/23 processor which is dedicated to maintaining collinearity (the 'plate processor'). There was a small but noticeable delay from operator positioning in the model to stage plate response. This is caused by the ten fold increase in the number of computations required by this particular processsor when processing SPOT geometry (Gugan , 1987) compared with conventional geometry.

Kern were able to demonstrate that the normal 50 Hz cycling time could be recovered by replacing the 11/23 processor by the LSI 11/73. With some local processor redistribution at OS this was permanently achieved , though some mechanical adjustment to the DSR-11 and the replacment of conventional geometry software was required to counteract the higher performance of the 11/73 processor.

At the time of writing the host computer has just been upgraded to a DEC MicroVax II and the delivery of SPOT VMS software is awaited.

SOFTWARE

The Kern SPOT software interfaces with the standard Kern MAPS200 software suite. Project definition and inner orientation is followed by plate co-ordinate measurement prior to computing a space resection/bundle adjustment where the unknowns are four orbital parameters , the three satellite rotations and three linear rates of change of those rotations (Gugan , 1987). The model may be restored using as few as two ground control points and the first four of the ten parameters but significant parallax should be expected. To minimise parallax throughout the model it is necessary to utilise all ten parameters

Once the model has been satisfactorily restored , the map compilation program may be entered in the normal way and data collection may be output in UTM , geocentric or geographical form.

IMAGERY

The SPOT imagery of the eastern Yemen has been acquired in two phases which correspond to the two blocks of work which make up this project.

IMAGERY PHASE I (SE YAR) :

Stereo Panchromatic Level 1A data was acquired in January 1987 for models 149-321,322 and 150-321,322. CCTs were purchased by OS and prior to film writing at NRSC (National Remote Sensing Centre , Farnborough) some limited image processing was undertaken. This included some Gaussian contrast stretching in shadow areas and the application of a 5 x 5 pixel high pass convolution filter to provide some image edge enhancement.

There were problems with early attempts at film writing, and following recommendations by OS, diapositives to an acceptable standard were produced. Pixels were written at 30 um giving an image size of 180 mm x 180 mm and a diapositive image scale of approximately 1/330,000.

It was noticed that, while full stereo cover had been attained , there was a narrow gap between paths 149 and 150 (see Figure 1. over). While this narrow model may be restored using the software the necessity of doing so will increase model setting time by at least 50 % and, owing to the small amount of overlap and lack of ground control along the periphery of the scenes, residual parallax may be uncomfortable at map compilation stage.

IMAGERY PHASE II (NE YAR) :

Further stereo panchromatic data (with a preference for Level 1P) was ordered for the remaining part of north east YAR (14 models - see Table 1 over). All data was acquired by late 1987. Level 1A data was supplied. Nine of these models were film written by SPOT Image and the remainder were purchased in CCT form. The latter scenes are currently being processed by NRSC using similar guidelines as for Phase I with the exception that the convolution filter has been reduced to 3 x 3 pixel size.

One model is being produced without edge enhancement to determine if this process has any benefits or penalties to control point identification and the interpretation of topographical features in this type of terrain.

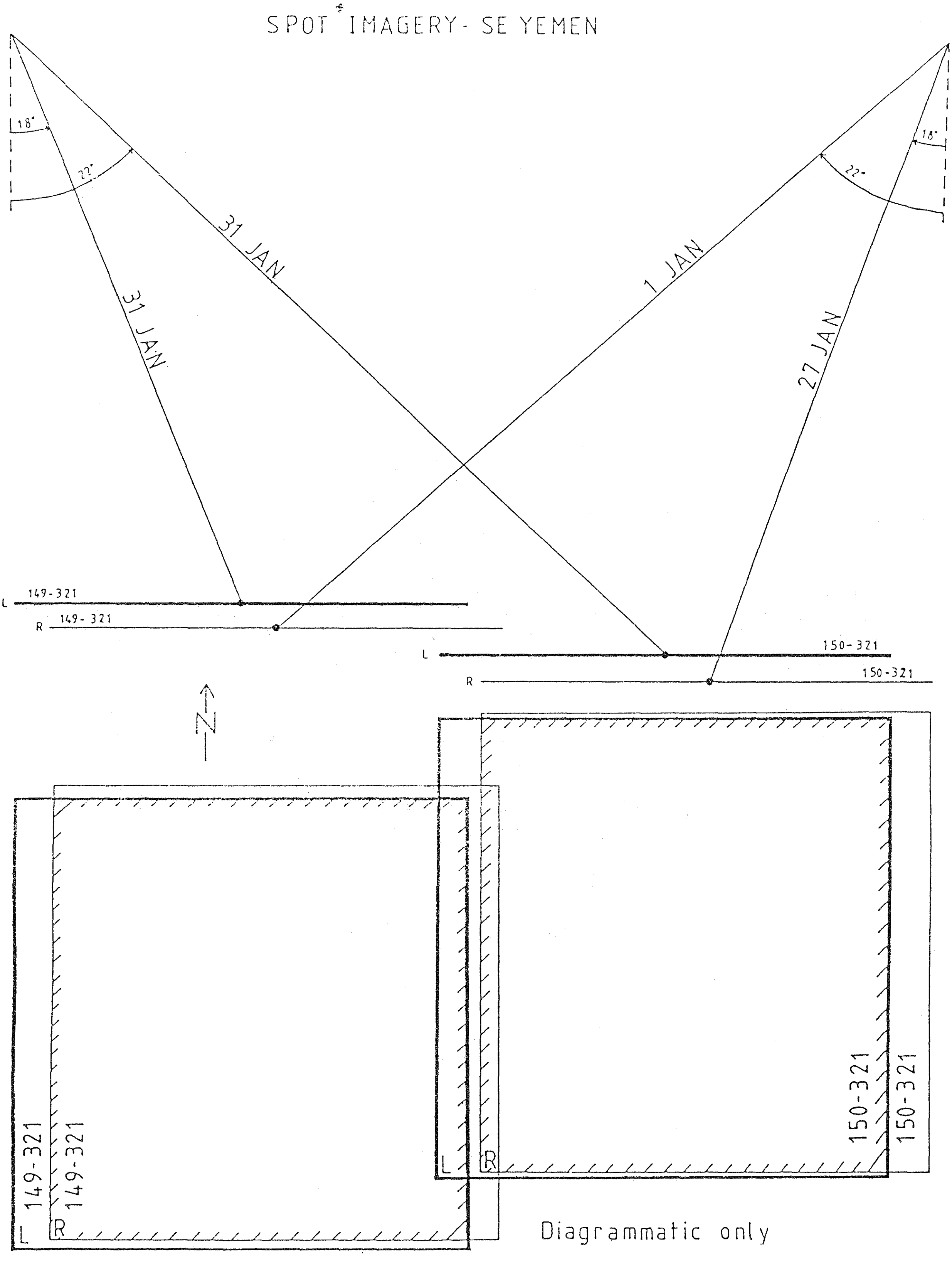

Figure 1. SPOT Scene configuration for part of of Phase I of the project - note the gap between western and eastern stereo paths.

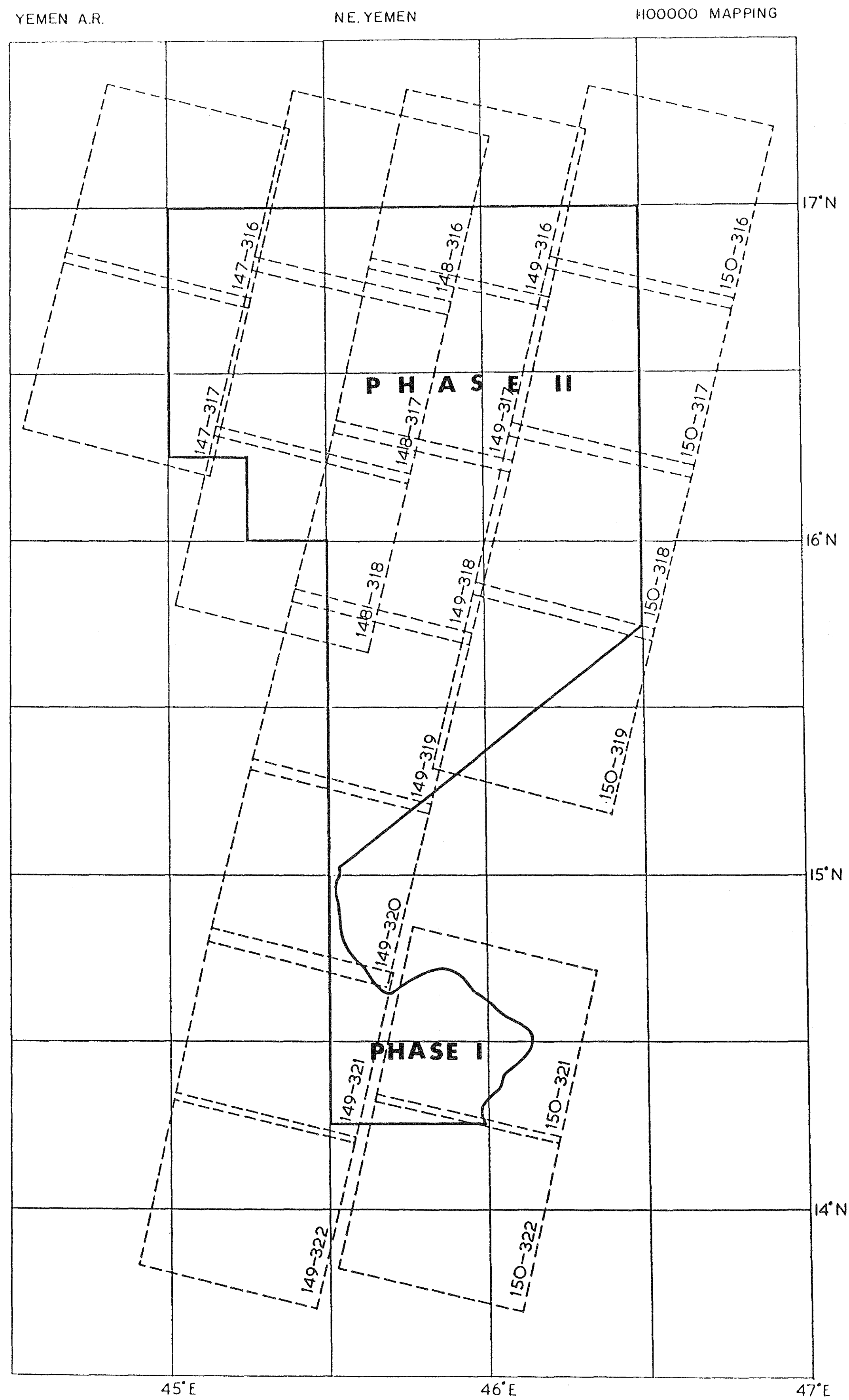

Figure 2. Distribution of all SPOT scenes eastern Yemen Arab Republic.

	Model	Product	Left (East Look) HRV	Date	Mirr.(deg)	Right (West Look) HRV	Date	Mirr.(deg)	B/H
1	147-316	CCT	1	27-SEP	-17.8	1	14-NOV	+22.3	0.8
2	147-317	CCT	1	27-SEP	-17.8	1	14-NOV	+22.3	0.8
3	148-316	Diap.	2	27-SEP	-21.7	2	14-NOV	+18.4	0.8
4	148-317	CCT	2	27-SEP	-21.7	2	14-NOV	+18.4	0.8
5	148-318	CCT	2	27-SEP	-21.7	2	14-NOV	+18.4	0.8
6	149-316	Diap.	1	22-SEP	-17.8	1	09-NOV	+22.3	0.8
7	149-317	Diap.	1	22-SEP	-17.8	1	09-NOV	+22.3	0.8
8	149-318	Diap.	1	22-SEP	-17.8	1	09-NOV	+22.3	0.8
9	149-319	Diap.	1	22-SEP	-17.8	1	09-NOV	+22.3	0.8
10	149-320	CCT	1	22-SEP	-17.8	1	09-NOV	+21.7	0.8
11	149-321	CCT	1	31-JAN	-17.8	2	01-JAN	+22.3	0.8
12	149-322	CCT	1	31-JAN	-17.8	2	01-JAN	+22.3	0.8
13	150-316	Diap.	2	22-SEP	-21.7	2	09-NOV	+18.4	0.8
14	150-317	Diap.	2	22-SEP	-21.7	2	09-NOV	+18.4	0.8
15	150-318	Diap.	2	22-SEP	-21.7	2	09-NOV	+18.4	0.8
16	150-319	Diap.	2	22-SEP	-21.7	2	09-NOV	+18.4	0.8
17	150-321	CCT	2	31-JAN	-21.7	2	27-JAN	+18.4	0.8
18	150-322	CCT	2	31-JAN	-21.7	2	27-JAN	+18.4	0.8
19	150(321)- 149(321)**	CCT	2	31-JAN	-21.7	2	01-JAN	+22.3	0.8
20	150(322)- 149(321)**	CCT	2	31-JAN	-21.7	2	01-JAN	+22.3	0.8

Table 1. SPOT Imagery : Acquisition of Yemen Data

All data is Level 1A Panchromatic acquired in 1987.

** : Narrow model restored to fill gap between full stereo paths.

GROUND CONTROL REQUIREMENTS

GROUND CONTROL PHASE I:

The majority of the control for the YAR project had been fixed by triangulation , traversing or by doppler in preparation for aerial triangulation block adjustment. To compute a full parameter SPOT solution, at least five three-dimensional control points are required per model and seven to eight will provide some redundancy to monitor the quality of the restoration.

For the initial SPOT YAR tests, control values were derived from the existing underlying 1/80,000 scale aerial photography in scene 149-322. Selected models were fully restored using either a Wild A10 or Kern PG2 analogue workstation utilising control generated by a previous PAT-M block adjustment. Points in the aerial photogrammetric model which were also identifiable on the SPOT contact print or a 3x SPOT enlargement were co-ordinated using the Kern analogue absolute orientation program. It was estimated that the precision of the output UTM co-ordinates was in the order of 1-2 m in each of x , y and z, relative to the local PAT-M control.

In those scenes or areas where adjusted aerial photography is not available the SPOT model restitution will rely on the base control (ie. doppler fixations, triangulation stations , photo. points etc) only.

GROUND CONTROL PHASE II:

Since most of the ground control for the NE YAR was established in preparation for the aborted aerial photography the distribution is not necessarily suited to SPOT model setting. It will be necessary to supplement the control from further existing aerial triangulation PAT-M blocks in some areas such as along the western periphery of the new mapping.

The field location of some of the later doppler control points was aided by the use of approximately scaled TM (Thematic Mapper) imagery is an attempt to overcome identification problems.

In addition a short strip of the RAF photography is being observed to bridge controls and provide some extra points in the central eastern section where ground control is sparse. This will be adjusted using the PAT-M package and will yield UTM co-ordinates directly. The Kern software package does not yet include a space block adjustment for SPOT imagery.

SPOT MODEL RESTITUTION

To date three SPOT models have been restored , two for test purposes (Aix en Provence and Yemen 149-322) and the third for map compilation purposes (Yemen 149-321).

RESTORATION OF THE AIX MODEL:

The Aix model was restored (with the exception of one control point) in one round of observations. The control was easy to identify in most cases and model setting time was approximately 80 minutes. There was little residual parallax and the resolution was sufficient to detect the z element in large structures such as farms and major buildings in towns.

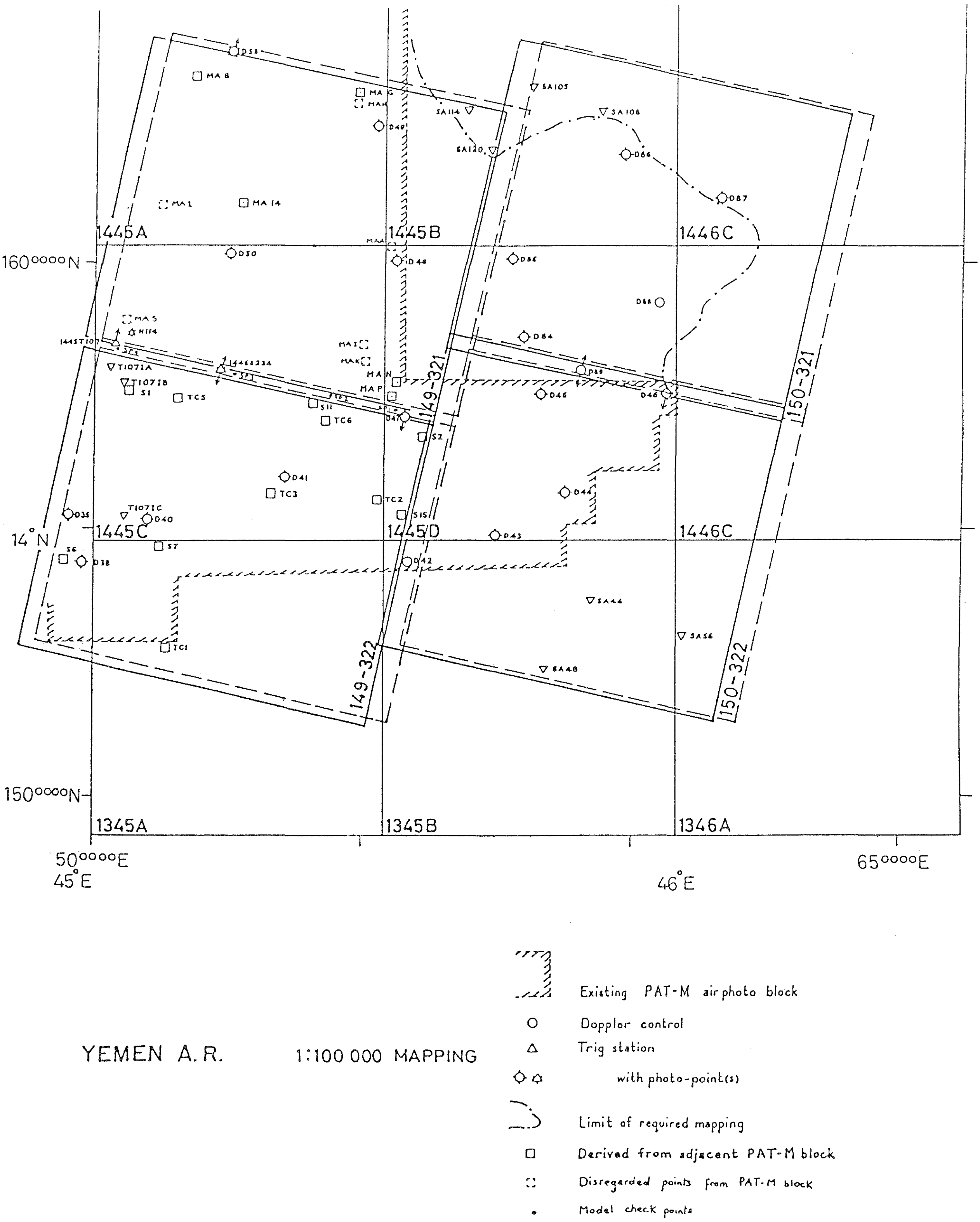

Figure 3. SPOT model configuration and control distribution for Phase I of the Project.

RESTORATION OF THE YAR TEST MODEL 149-322:

Eight controls were co-ordinated for the first attempt to restore model 149-322. It was immediately noticeable that the quality of the image was significantly inferior to that of the Aix test model. The fit to the controls , few of which could be precisely identified , exhibited large residuals. The combination of a very steep and rugged terrain with little local contrast at many of the control points and the poor resolution small scale imagery were considered to be the chief reasons for the poor results.

Consequently, additional controls were co-ordinated. With increased experience, there was now a strong emphasis on the type of control point to be selected. In addition NRSC were given specific instructions regarding film writing. While a some SPOT images had been film written for various users by NRSC, this was the first photogrammetric task to be under- taken and a change to the standard film writing technique was necessary. New diapositives of improved resolution were received in which the pixel structure could now be detected.

Using the new images and only clearly identifiable controls, the model was reset. The results , although still below expectation , were much improved. Some controls , such as track/road junctions , did not always resolve so clearly as anticipated and as a consequence it was necessary to disregard some of the controls exhibiting very high residuals. Eleven of the set of 24 controls were applied in the final restoration

A small sample of seven points from the national control system were utilised as check points (see table 2). The rmse vector was 28 m , which was disappointing but did confirm that the system would produce mapping to 1/100,000 standards. Some residual parallax did remain in the model , usually no more than 2 pixels except in the south eastern corner where control was non-existent , here the parallax extended to 4-5 pixels in some areas.

Four points on the northern periphery of the model were co-ordinated to monitor the sympathy from one model to the next (from model 149-322 to 149-321).

CONTOURING PRECISION:

The majority of the task would be devoted to contouring and the comparative test was located in an area of three contiguous models from the aerial triangulation PAT-M block. These models were chosen because they ranged from very steep rugged terrain and very little cultivation to a more gentle sloping area.

Contour precision was assessed by applying a grid of 1000m squares to the graphic contours and heighting one contour close to the centre of each grid square. The contour was intersected with the GP1 table microscope and the value was obtained from the restored 1/80,000 scale photographic model in the DSR-11.

The results , which were relative to the local PAT-M control (see table 3), did not fully meet early predictions but were encouraging. The values did not support the heighting accuracy suggested by the small sample of check points but it was felt that a contouring vertical interval of 40 m was justifiable.

Model	Control: No.Points Avail.	Used	RMSE (m) xy	z	Check Points: No.Points Avail.	Used	RMSE (m) xy	z	System.(m) xy	z
1. Aix en Provence Test	19	19	8.2	5.8	Not Tested					
2. Yemen 149-322 Test	24	11	15.4	14.1	7	7	27.7	29.1	14.2	-2.3
CONTOUR COMPARISONS										
1.Significant Relief :					50	48	-	14.7	-	-1.2
2.Mixed Relief :					38	37	-	11.8	-	-1.8
3.Minimal Relief :					28	28	-	6.8	-	-1.1
All points (3 models) :					116	110	-	10.8	-	-0.5
Spot Heights :					5	5	-	8.6	-	-6.6
3. Yemen 149-321 Prodn.	20	10	17.8	10.2	Not Tested					

Table 2. Restoration of SPOT Models and results of contouring precision. Rmse is expressed in Local Vertical Cartesian Co-ordinates.

RESTORATION OF THE YAR PRODUCTION MODEL 149-321:

The restoration of this model provided a similar experience to the test model where some points were difficult to identify or in some cases the feature had changed since the date of photography. Again, on occasion, a well defined point would exhibit high residuals. A satisfactory solution was obtained and the four peripheral points co-ordinated in model 149-322 were re-observed with the following results :

Point	Differences: Easting	Northing	Vector	Height
SP1	-20.0	-4.0	20.0	0.0
SP2	-19.0	8.0	20.6	1.0
SP3	10.0	17.0	19.7	1.0
SP4*	72.0	16.0	73.8	-2.0

Table 3. Co-ordinate value differences observed in adjacent models. (* : One pixel of parallax existed at this point in model 149-321).

This model contains a mix of higher order (eg. doppler) control and points derived from local aerial photography. There is no facility to vary the weight of control points when the bundle adjustment is processed within the Kern software.

GROUND CONTROL POINTS - IDENTIFICATION:

One of the major obstacles during the course of the tests was the identification problems associated with the selected control points. Whereas the controls in the Aix test model were very easy to observe, positive identification of many points in eastern YAR was not always possible. The controls in the Aix model benefited from local contrast and linear features; for example, a white road junction would provide an excellent target against a dark background such as forestry or pasture. The YAR SPOT imagery does not exhibit the same contrasting change owing to the nature of the terrain. There is little evidence of habitation in many areas and few linear features which make good targets. Rivers tend to flow in narrow ravines with unclear courses and it quite possible to lose single features such as clumps of trees due to the nature of the SPOT sampling process.

It is also important to quantify to what extent , if any , the effects of image processing/resampling processes ie contrast stretching and edge enhancement are having on control point identification.

Table 4 compares the successful type of control point used by OS to date and the adaption to differing topographies.

	AIX EN PROVENCE	SE YAR	
		149-322	149-321
Bridge Rd/R'r/Canal	3	3	0
Building	1	0	2
Mountain Peak	0	2	0
Natural Feature	0	0	1
Road/Tk.Angle	2	0	0
Road/Tk. Junc	13	0	0
River Junc.	0	3	2
River Angle	0	0	0
Tree/Bush/Clump	0	2	4
Cnr. Woodland	0	1	0
Other	0	0	1
Total :	19	11	10
Model Setting Time (approx.) :	- 2 hours	3 hours	5 hours
Source of pts. :	Digitised from IGN 1/25,000	Air Photog.	Doppler/ Air Pho.
Co-ord. system :	Lambert	UTM	
Spheroid :	Clarke 1880	WGS72	

Table 4. Comparison of SPOT model control point types.

STRIP MODEL FORMATION:

Since each SPOT image is composed of 6000 sub-scenes , each one pixel wide , then it follows that the photogrammetric model is not necessarily confined to the extent of the distributed diapositive media. The Kern software utilises orbital parameters to restore the model it is therefore conceivable that only the first and last of n contiguous scenes may be observed to restore a model extending from

Array 1 , ... Array 6000 x n

where n is the number of SPOT sub-scenes.

However the usefulness of this approach may be tempered by the changing orientation of the sensor. Where the changes are rapid or tend to oscillate then clearly sufficient ground control will be required to model those changes. In addition , the computed unknowns must also include parameters to accomodate non-linear rates of change.

Savings in the required number of ground control points are likely if the rotations are minimal or have been accounted for. A minor obstacle to the procedure is related to the overlap provided with adjacent scenes. It is necessary to determine the extent of this overlap prior to performing the initial inner orientations. OS intends to restore a strip model on completion of Phase I of this project.

NARROW MODEL RESTITUTION FOR ADJACENT PATHS 149 and 150:

It will be necessary to restore two models (see Figure 1 and Table 1.) to fill the narrow swath which varies from five Kilometres to three Kilometres between paths 149 and 150. Left scenes from path 150 and the right scene from path 149 will be utilised to complete this part of the task. The software fortunately allows for single plate observations. In this case, points will be co-ordinated along the eastern and western edges, prior to setting these models to monitor sympathy.

MAP COMPILATION

Map compilation at 1/100,000 scale is proceeding. The line mapping is being plotted directly in ballpoint pen onto scribecoat material. Separate overlays are prepared for topographic detail and contours and the mapping will be manually scribed on completion.

The data is also being digitally recorded for future use in an evaluation of automated processes applied to small scale mapping.

Part of the project abuts onto existing 1/50,000 sheets which have been photographically reduced to 1/100,000 scale. To date, in most cases, the edge matching has been demonstrated to be very good.

FUTURE INVESTIGATION

During the course of this project it is expected that it will be possible to evaluate the usefulness of digital photogrammetric superimposition with respect to new small scale mapping projects.

In anticipation of future projects some development work will be undertaken using the captured digital data. This will include processing the data through the well established OS photogrammetric digital map production procedures and will involve cleaning the data on graphic workstations prior to automated graphic output.

OS is also interested in evaluating methods of generating height data to compare conventional contouring procedures with DTMs etc (Toomey , 1986) and correlation techniques.

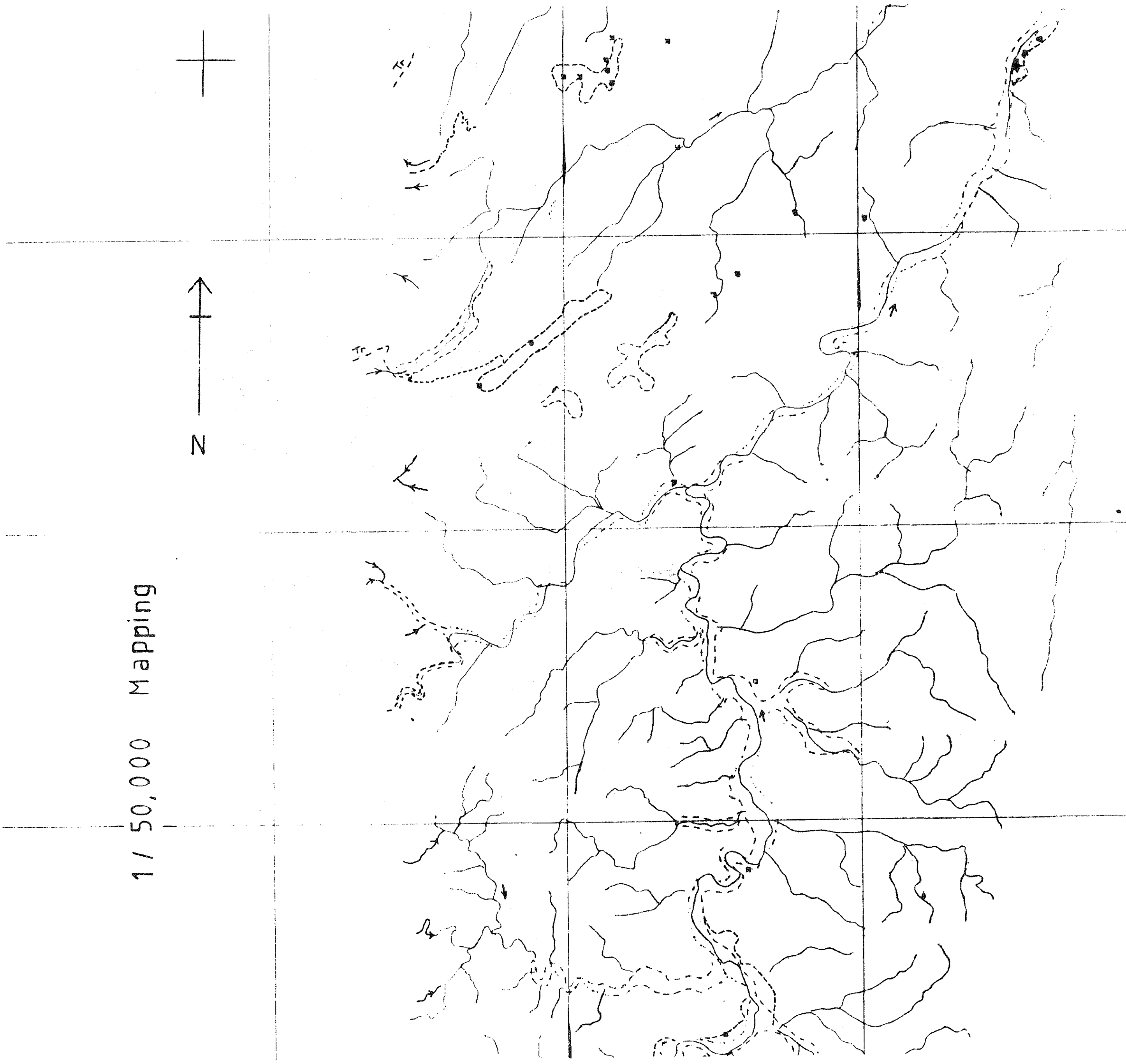

Figure 4. Sample of topographic detail taken from the YAR Project from SPOT imagery.

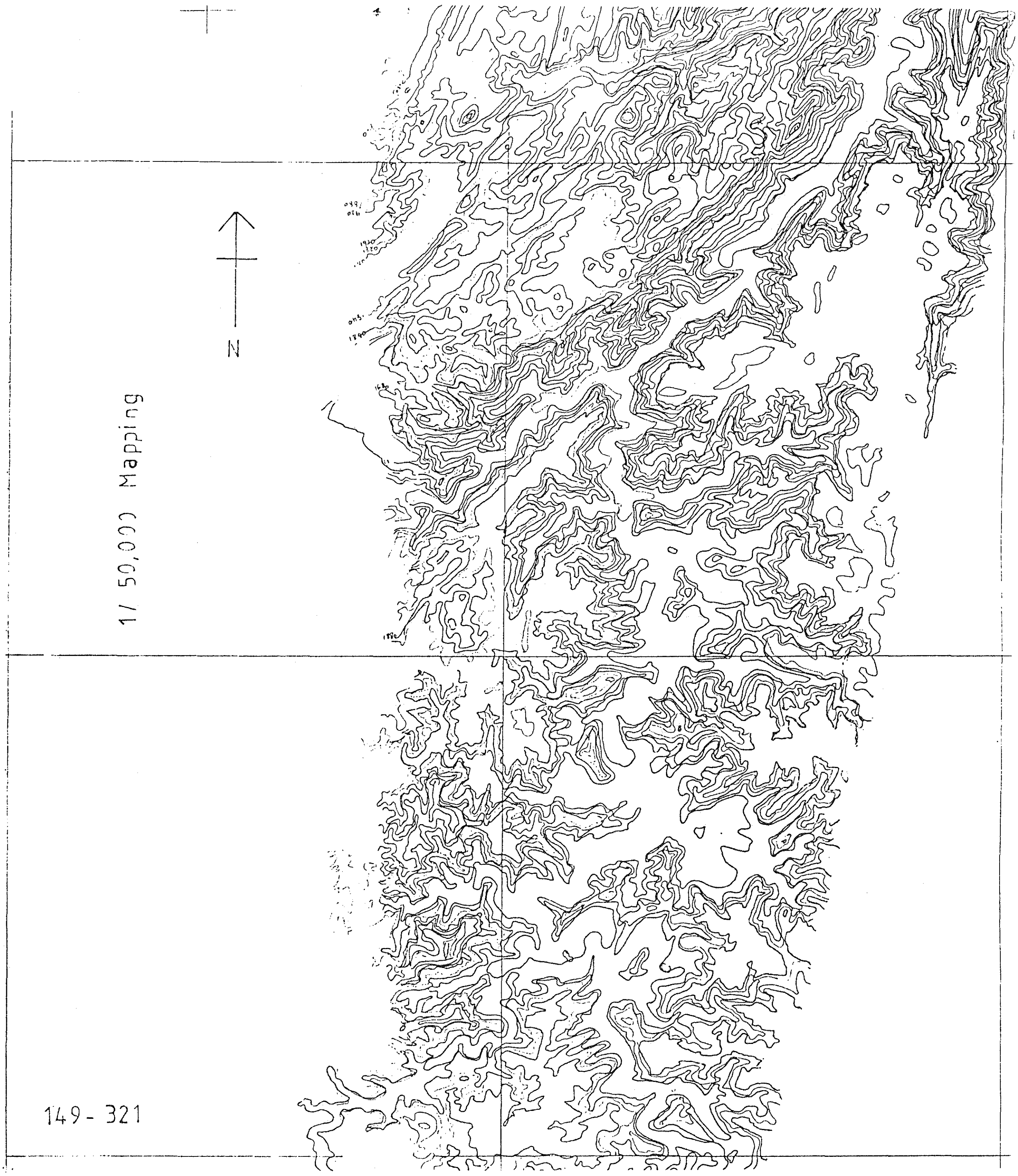

Figure 5. Sample of Contouring taken from the YAR Project from SPOT imagery. VI : 40 m [Incomplete]

SUMMARY

The concept has been proven. The tests have shown that the application of SPOT imagery to line mapping is technically feasible at the 1/100,000 product scale.

The results compare unfavourably with the findings of other users to date (Ducher, 1988; Rodriguez et al, 1987) but have been determined in the type of environment in which SPOT has a major role to play. To date this project has shown that there is no reason to dispute these claims; but control point selection and identification is considerably more difficult in open rugged terrain such as YAR than in developed areas such as Western Europe.

Project co-ordination and selection of control points should be made with great care to ensure a successful conclusion. Ideally it may be necessary for the ground surveyor to have 10x enlargements of the SPOT image of the selected control location sites but clearly this will not always be possible and other alternatives such as TM scenes may be of use.

A slight increase in ground control may be required in areas such as YAR. However, ground control is an expensive element in small scale mapping projects, particularly overseas, and the development of a SPOT space block adjustment package would enhance the Kern/UCL software. In addition the facility to assign weights to control points during single scene processing would be welcomed. The software developed by UCL, is easy to use and integrates well with the existing Kern suite of model restitution and map compilation programs.

Care should be taken when ordering or receiving imagery to avoid the gaps evident in Phase I of this project since any extra model setting time will clearly add to the project costs.

ACKNOWLEDGEMENTS

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