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Using photogrammetry to study subsidence caused by gypsum dissolution around Ripon

Urban Geoscience & Geological Hazards Programme

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BRITISH GEOLOGICAL SURVEY

URBAN GEOSCIENCE & GEOLOGICAL HAZARDS PROGRAMME

INTERNAL REPORT IR/03/155

Using photogrammetry to study subsidence caused by gypsum dissolution around Ripon

P Turner

Contributor/editor

A H Cooper

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British Geological Survey offices

Keyworth, Nottingham NG12 5GG
☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.geologyshop.com

Murchison House, West Mains Road, Edinburgh EH9 3LA
☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE
☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU
☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast, BT9 5BF
☎ 028-9038 8462 Fax 028-9038 8461

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB
☎ 01491-838800 Fax 01491-692345

Sophia House, 28 Cathedral Road, Cardiff, CF11 9LJ
☎ 029–2066 0147 Fax 029–2066 0159

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU
☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

Gypsum (hydrated Calcium Sulphate $CaSO_4.2H_2O$, the raw material for plaster) is widespread throughout the world, but it dissolves so rapidly that it poses a threat to any development that encounters it. More than one metre of gypsum per annum can be easily dissolved by moderate river action on natural exposures. Where this dissolution occurs underground at similar rates, caves can develop, expand rapidly and suddenly collapse. Such caves occur in the Permian rocks beneath Ripon, North Yorkshire

Until March 2005 the Environment and Hazards Directorate of the BGS under its Urban Geoscience and Geological Hazards programme studied karst geohazards in Britain.

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Summary

This report describes the work undertaken in the Remote Sensing photogrammetry section of BGS to produce digital stereo models, digital elevation models (DEMs), orthophotos and associated products covering an area around Ripon.

This report details how photogrammetry techniques were used to remotely identify known, unknown and potential gypsum subsidence features around Ripon from two dates of aerial photographs.

Initially it was hoped that the DEMs for 1986 and 2003 could be compared to create a difference map. When the two data sets were compared there were errors and it is believed the reasons for this included one or more of the following:

1. The 1986 camera calibration certificate did not have the full details required to set up the ImageStation project.
2. The 2003 photos were scanned from prints. Stretch can occur in prints and cause errors.
3. It was hoped to use the same control points to create fixed points in both projects. Control positions from the 1986 project were either obscured or the ground had been altered in the 2003 photos. The 2003 project also covered a larger area and extra control points were required that fell outside the 1986 project area.
4. The bulk orient process was run on the final models. This creates a DEM for each stereo pair and does not use the overall solution to create the DEM. Errors can occur where models overlap.
5. There was insufficient sidelap on the two 2003 runs. Tie points were created manually.
6. The smoothing in the elevation points creation process was different in each project as some models did not run at the lower setting.

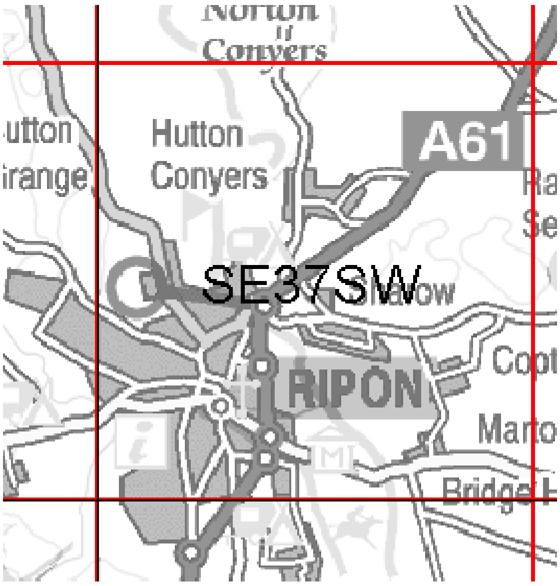


Figure 1 Ripon location map

1 Photogrammetry production

Digital photogrammetry techniques offer a rapid and efficient method for processing aerial photographs accurately and in high volumes. Products such as stereo models, orthophotos and Digital Elevation Models (DEMs) are suitable for a range of applications including groundwater vulnerability mapping or hydrological modelling. In combination with traditional field methods, digital stereo model interpretation offers the functionality to digitise line work directly in its correct three-dimensional geographic space. If created, orthophotos with map overlays can be taken into the field to assist field-based interpretations and the use of image drapes over elevation models provides a useful visualisation technique.

For this project stereo-models, DEMs and orthophotos were created. The ZI Imaging ImageStation products ImageStation Auto Triangulation (ISAT) and OrthoPro, Intergraph's Terrain Analyst software and ERDAS Imagine were used.

Stereo models and images draped over the created DEMs were used to interpret the position of unknown subsidence hollows and to check the positions of those already surveyed.

For a guide to ImageStation photogrammetric production routines refer to HALL, M. AND TURNER, P, 2004. Photogrammetry production using ImageStation. *British Geological Survey Internal Report*, in prep.

1.1 1986 PHOTOGRAPHY

1.1.1 1986 Photos

For the first part of the project some 1986 black and white photos were available. In total there were 6 photos in 1 strip covering the area. The scale was approximately 1:4400. The monochrome photographs were taken in May 1986 by NERC, the images being stored on film negative in the NERC film archive held at BGS Keyworth. They were scanned at Infoterra at a resolution of 21 microns (µm). This means each pixel is 0.0021mm square and is equivalent to a resolution of 1200 dpi or 47.25dpmm.

The flight line has a South-North orientation. Overlap of photos was 60%.

Strip	**Photos**	**Date of photos**	**No. of photos**
1	3472-3476	13-5-86	6

Table 1 1986 photo details

1.1.2 Camera calibration

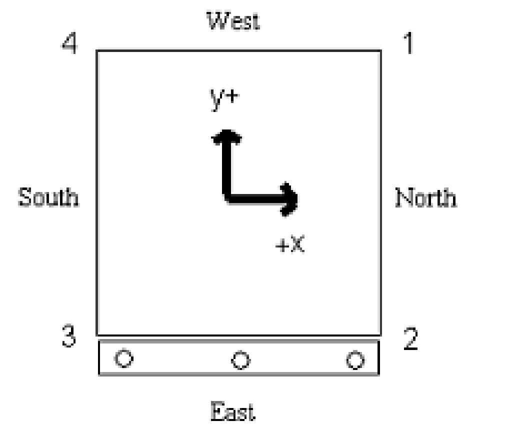
The camera calibration certificate was purchased from Simmons Aerofilms. See Appendix 1 for the scanned certificate. The table below shows the main details of the camera.

Lens type	Wild Aviogon
Serial number	15 AG 38
Calibration Date	8.4.86
Calibration Number	HSC/15 AG 38/9
Principle distance	152.6mm

Table 2 1986 photos - camera details

1.1.3 Orientations

The usual procedure in aerial photos is for the camera dials to be at either the leading or trailing edge of the camera and perpendicular to the direction of flight. ImageStation software expects the positive x-axis for the fiducial measurements to be perpendicular to the dials and parallel to the direction of flight. The Ripon photos have their dials parallel to the direction of flight i.e. from South to North. The fiducial positions had to be calculated based on the x-axis being parallel to the dials with the positive in the direction of flight. The orientations and fiducial numbers of the photos are shown below.
ImageStation requires the fiducial coordinates to be based on an x-y axis. The certificate provided only gave the length of the diagonals and the fiducial positions relative to each other. MicroStation was used to calculate x-y coordinates for the fiducials using the South to North axis as the positive x-axis.
A simple way to check that the photo co-ordinate system is correct after the strip has been set up and the interior orientations measured is to note that the Kappa value should be equal to the clockwise rotation needed to point the positive X-axis to the East in the ground co-ordinate system.



Fiducials:

	X	Y
1 =	105.993	105.995
2 =	105.993	-105.999
3 =	-106.006	-106.008
4 =	-106.001	105.996

Model set up direction was 0° →

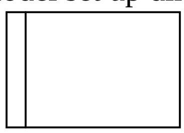


Figure 2 Fiducial positions for 1986 Ripon photos

1.1.4 Image format

Using the Intergraph Raster Utilities (ISRU) software the TIF images provided were converted to the Intergraph JPG format required for image processing. This was done using a batch file; see Appendix 2. Overviews were created to allow faster access to the images when zooming in and out.

Colour/greyscale	Greyscale
Scanned internally/externally	Externally
Scanning resolution	1200 (21 μm)
Format	TIF
Converted to	JPG
Overview format	Averaged
Number of overviews	9

Table 3 1986 photos - image format

1.2 2003 PHOTOGRAPHY

1.2.1 2003 Photos

For the second part of the project the NERC Airborne Remote Sensing Facility (ARSF) were commissioned to take photos of the same area as the 1986 study. In total there were 14 photos in 2 strips covering the area. The scale was approximately 1:5250. The colour photographs were taken in April 2003 by ARSF. ARSF use the Cambridge Unit for Landscape Modelling to scan the negatives but unfortunately their scanner was out of use when the negatives were available. In order to complete the work in 2003-2004 ARSF provided photographic prints and these were scanned at Infoterra at a resolution of 21 microns (μm). This means each pixel is 0.0021mm square and is equivalent to a resolution of 1200 dpi or 47.25dpmm.

The flight line has a South-North orientation. Overlap of photos was 60%.

Strip	Photos	Date of photos	No. of photos
1	1837-1831	8-4-03	7
2	1808-1814	8-4-03	7

Table 4 2003 photo details

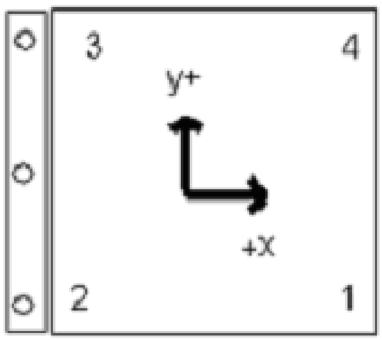
1.2.2 Camera calibration

The camera calibration certificate was provided by ARSF. The table below shows the main details of the camera. There is no scanned version of the certificate but this is held by the Remote Sensing section.

Lens type	Wild Universal Aviogon
Serial number	15 UAGII 3103
Calibration Date	28.03.01
Calibration Number	AF/15UAGII3103/5
Principle distance	153.435

Table 5 2003 photos - camera details

1.2.3 Orientations



Fiducials:

	X	Y
1 =	106.003	-106.003
2 =	-106	-105.99
3 =	-105.999	105.993
4 =	-105.996	106

Model set up for strip 1 was 0° →

Model set up for strip 2 was 180° ←

Figure 3 Fiducial positions for 2003 Ripon photos

1.2.4 Image format

Using the Intergraph Raster Utilities (ISRU) software the TIF images provided were converted to the Intergraph JPG format required for image processing. This was done using a batch file; see

Appendix 2. Overviews were created to allow faster access to the images when zooming in and out.

Colour/greyscale	Colour
Scanned internally/externally	Externally
Scanning resolution	1200 (21 µm)
Format	TIF
Converted to	JPG
Overview format	Averaged
Number of overviews	9

Table 6 2003 photos - image format

2 Workflow

The ImageStation and Terrain Analyst software modules allow a full workflow for photogrammetric work. ImageStation Automatic Triangulation (ISAT) provides the triangulation tools and ImageStation Stereo Display (ISSD) allows viewing of stereo pairs and digitising into MicroStation design (DGN) files. ImageStation OrthoPro (ISOP) is used to create orthophoto products.

2.1 IMAGESTATION AUTOMATIC TRIANGULATION (ISAT)

2.1.1 ISPM/ISAT project set up

ImageStation Project Manager or ImageStation Automatic Triangulation can be used for setting up the project parameters.

Project name and location		ripon and ripon2003 on ImageStation KWPG86	
Parameter Settings		Projection	Transverse Mercator, British National Grid, OSGB 1936
		Origin of projection	49°N, 2°W
		False origin	-100000m North 400000m East
		Standard deviation of measurement	11µm (86 & 03)
		Flying height	2240m (86) 780m (03)
		Average ground elevation	150m (86) 30m (03)
		Atmospheric refraction	✓
		Ground curvature	✓
User settings	Acceptable IO limits	Max sigma	10µm (86 & 03)
		Max residual	10µm (86 & 03)
	Acceptable RO limits	Max sigma	10µm (86 & 03)
		Max y parallax	10µm (86 & 03)
	Acceptable AO /Bundle adjustment	Max sigma	10µm (86 & 03)
		Max RMS X, Y and Z	2, 2, 0.2 (86) 10, 10, 1 (03)

Project name and location		ripon and ripon2003 on ImageStation KWPG86	
	limits	Max residual X, Y and Z	4, 4, 0.5 (86) 20, 20, 2 (03)
Default user points		5	

Table 7 ISPM/ISAT project parameters for 1986 and 2003

2.1.2 Ground control point collection

Ground control points were taken from the Ordnance Survey contour and spot height data set held on the BGS server. 17 points were required for the 1986 photos. Some of these were also used on the 2003 photos but as the 2003 photos covered a larger area 23 control points were used.

2.1.3 Ground control point measurement

Control points were located and once a successful solution was produced the automatic triangulation was used to create tie points in a sub-project. Further editing was made to refine tie points or control points. After refinement tie points were densified into control points. The bulk orientation tool was used to check that the Relative Orientation and Absolute Orientation values for each model were acceptable. The results are shown in Appendix 3.

Separate stereo models were created for the 1986 project. For the 2003 project separate models were not made as the software had been upgraded to allow models to be viewed “on the fly”.

A problem occurred with the 2003 photos as the ARSF had not flown them with sufficient sidelap between the runs. A 25% sidelap is required for the ImageStation software to create tie points but the Ripon photos had a sidelap of less than 15%. Manual tie points had to be created.

2.2 IMAGESTATION AUTOMATIC ELEVATIONS (ISAE)

ISAE was used to extract elevation points into MicroStation 3D design (DGN) files. A separate design file is created for each stereo model. The points are created in the design files using different levels and colours to show the levels of accuracy. To achieve this the DGN file is created and a stereo model assigned to that file.

Elevation collection parameters	Terrain type		Hilly
	Grid width		4m
	Smoothing		1.1 (86) 1.5 (03)
	Hold grid to multiples of grid width		Yes
	Adaptive grid		No
	Adaptive matching		Yes
	Adaptive parallax		Yes
	Output area		Entire model
Output parameters	Output points to output design file		Yes
	Output surfaces	Raw	Yes
		Que	Yes
		TTN	Yes
DTM quality checks	User defined		Yes
	Accuracy threshold		default
Job processing	Create feature pyramids		Yes

	Perform DTM extraction	Yes
	Create output surfaces	Yes
	Delete Surface Files	No

Table 8 ISAE parameters for 1986 and 2003

Elevation points were generated into DGN files called dtm***_***.dgn. Points around the outer edge of the model were removed using ISSD and MicroStation and the edited files saved as edi***_***.dgn.

There was insufficient time to do thorough checking and correction of the DEM points created in either project. A lower smoothing setting would have created a more accurate DEM.

Areas along the River Ure in the 1986 project have uncorrected height errors due to the software not being able to match areas of great contrast caused by light reflecting off water.

2.3 TERRAIN ANALYST

Terrain Analyst is used to triangulate the points in the DGN files to create triangulation files (TTN) for each model. The maximum triangle side length was set to 8m. These were then used to create a grid file (GRD) with a spacing of 2 metres. For the 1986 project another grid with a spacing of 4 metres was also created. The grid files were merged to create the final grids. Examples of the batch files used in these processes can be found in Appendix 2.

In Terrain Analyst the DEM can be viewed as shaded relief, smooth or rough contours and slope vectors. Rough and smooth contours can also be output to a DGN file. These files can be very large. For the 1986 project test files of smooth contours at 0.1m vertical intervals were output to three separate files for the eastern, centre and western thirds of the project area. The contours were colour coded to repeat every 1m. Another file covering the whole project area was produced with 0.5m vertical intervals. It was found that creating a colour coded DEM was a better way of outputting the data so these files were deleted.

Screen saves can be made of the shaded relief images but these are only low resolution. To create better resolution images Terrain Analyst can create a high resolution shaded relief image. The options for output are the same as for the screen display; sun angle, azimuth and intensity can be set and the image can be coloured in bands to show differing heights. Both grey scale and colour images were produced, the colour images with a colour change every 0.1m. These images can be georeferenced to allow the interpretation of the position of subsidence.

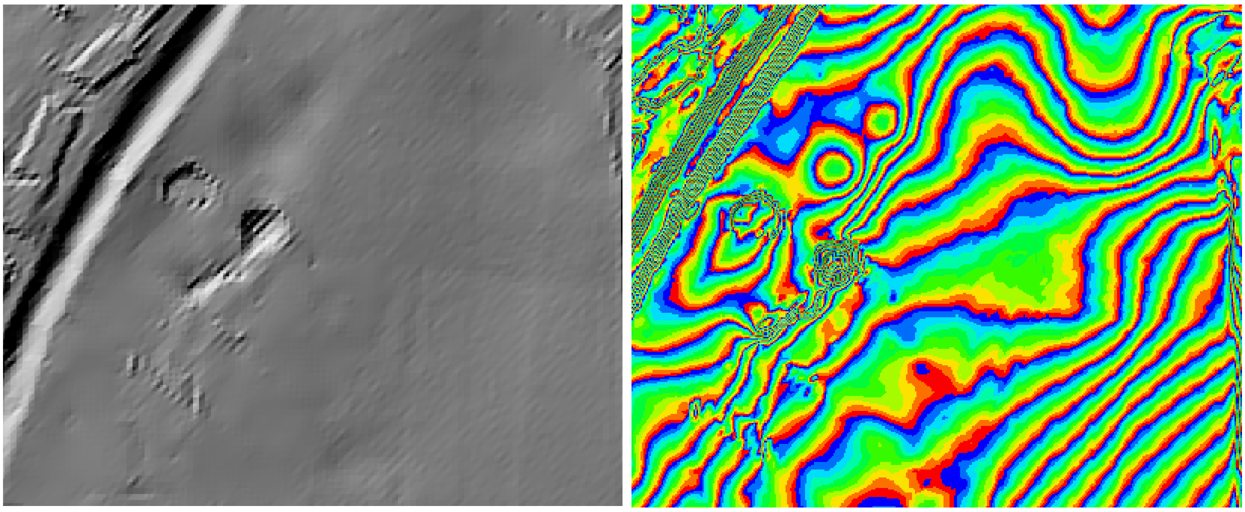


Figure 4 Comparison of grey scale and colour banded shaded relief of an area north of Ripon showing solution hollows

The above images were only created for the 1986 project.

The DEMs for 1986 and 2003 were exported to USGS DEM format. See the remote sensing report IntergraphGridToUSGSDEM.doc for information about changing the format of the DEM to USGS DEM and IMG format using MTA and ERDAS Imagine.

The final IMG files can be used in their native format in ESRI ArcGIS projects.

2.4 IMAGESTATION BASE RECTIFIER (ISBR)

This software is used to create orthophotos. An orthophoto is created for each of the original JPG images. To create the orthophotos the final project settings and the final grid are required.

Input options	Project	ripon and ripon2003
	Grid size	2m
	Clipping image	Inside Fiducials
	No. of overviews	Full set, averaged
	Pixel size	0.1m
	Output type	Same as input (JPG)
	Tile size	Same as input (JPG)
	Format	Same as input (JPG)
Rectification options	Cubic convolution	
DTM options	Grid file	Ripon_finalgrid_2m.grd and ripon2003all_2m.grd

Table 9 ISBR parameters for 1986 and 2003

2.5 ORTHOPRO (ISOP)

OrthoPro is a collection of programs designed to speed the process of creating mosaics of orthophotos. The processes use Intergraph's GeoMedia GIS software to create what is called a Geoworkspace. The photos are manipulated in an OrthoPro project. The photos are 'dodged', mosaicked and finally made into products to match the areas required. The dodging process is designed to lighten dark areas and darken light areas to compensate for uneven lighting conditions. Mosaicking is the joining together of the orthophotos so that products can be made. Products are usually made to match Ordnance Survey grid sheets.

2.5.1 Dodging orthophotos

Using the Project Planning dialog box the Minimum Bounding Rectangle (MBR) of the project was set to the limit of the orthophotos and the pixel size set to 0.1m.

Using the Dodge dialog box all the Orthophotos were selected and their properties edited as in the table below. The dodged photos are saved with a CMP file extension.

Properties	Kernel	15
	Intensity range	Min 5, Max 250
	Darken maximum	25
	Brighten maximum	25
	Destination	H:\images\ripon\dodged
	File format	JPG
	Q factor	15
	No. of overviews	Full set

Table 10 ISOP dodging parameters

2.5.2 Creating orthophoto products

To create a mosaic the software requires the ISAT (or ISPM) project parameters, as the position of the original photos is required in order to create the seam lines. The final GRD file is required for elevation data.

To define the position of the products the OrthoPro User Defined Product Editor (UDPE) is used. A TXT file is created, which holds the XY coordinates of the corners of the product areas required. To create the text file there is a spreadsheet with macros so that when a National Grid sheet number is entered its four corner coordinates are automatically generated. This spreadsheet can be exported as a tab delimited ASCII file and imported into the OrthoPro database.

Using the OrthoPro Project Planning dialog the ISPM and elevation data sources are chosen. Seamlines are created automatically from the Generate Seamlines button. The project area is chosen and the photos mosaicked.

Format	TIFF (World File)
Orientation	Row Major
Compression	None
Overviews	Full set – averaged
Tile	None
Tone Matching	All products

Table 11 ISOP product parameters

The final products for the 1986 Ripon project were created to fit a grid covering the DEM area as shown in Figure 3. The lower left corner of the grid is at 431000,471000 and the upper right at 432700,473430.

Figure 5 Orthophoto product locations

Each 500m square has 0.1m pixels (5000 x 5000 pixels).

To get the best results from the BGS plotters images should be plotted at 150 dpi (6dpmm). The 0.1m resolution images could therefore be plotted acceptably at a scale of 1:600. As this scale is unlikely to be used lower resolution files were made using ISRU at 0.4m and 1.6m pixel size and these give a resolution of 150dpi when plotted at 1:2500 and 1:10000 scale respectively.

For the 2003 photos a grid of 1km squares was used covering an expanded area north and east of the 1986 photos. The final products were made at 0.4m resolution pixels.

2.6 INTERPRETATION

Using ImageStation Stereo Display (ISSD) the stereo models were used to interpret the position of gypsum solution hollows. Earlier interpretations from surveys by BGS and Travers Morgan were used to overlay the stereo models.

Features were digitised into a 3D MicroStation file as one of three types;

- Obvious features
- Features recorded in the earlier surveys but not obvious from the stereo images
- Features that could be caused by subsidence.

The DGN files were translated into an ArcView project and saved as SHP files.

3 Conclusion

The use of photogrammetry allows high quality images and stereo models to be created. In the 1986 project this allowed the position of hollows recorded in earlier surveys to be better located and to record the position of hollows not previously recorded.

The photogrammetry does not replace ground checking. Some hollows recorded in earlier surveys were not visible on the stereo images because they have been infilled, are in urban areas where they are only visible when properties start to subside, or are where crops or other ground features make it difficult to interpret their positions.

High resolution shaded relief images can be useful in recording subtle changes in heights not visible from the original photography.

Orthophotos have been created from the original photography and these can be used in a GIS to aid interpretation.

The data created can be exported to other software if required.

Appendix 1 Camera Calibration Certificate

HUNTING SURVEYS & CONSULTANTS LTD.
ELSTREE WAY, BOREHAM WOOD
HERTFORDSHIRE. WD6 1SB.

CAMERA CALIBRATION

LENS : 15 AG   NO.: 38   CALIBRATION DATE 8/4/86

ex Aerofilms   21

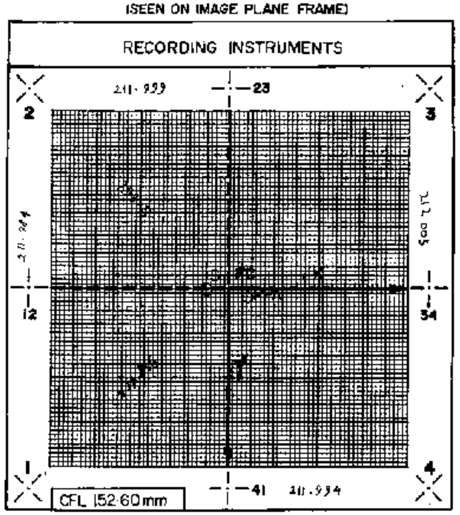
POINT	X MM	Y MM	X	Y
FC	0·000	0·000	0	0
S	-0·005	0·000	0	-0·005
PPA	0·004	0·002	0·002	0·004

1 - 2 = 211·984   1 - 3 = 299·816
2 - 3 = 211·999   2 - 4 = 299·800
3 - 4 = 212·005
4 - 1 = 211·994

DISTANCES BETWEEN FIDUCIAL MARKS IN MM. MEASURED ON 8/4/86

FC : FIDUCIAL CENTRE
S : POINT OF BEST SYMMETRY
PPA : PRINCIPAL POINT OF AUTOCOLLIMATION

(SEEN ON IMAGE PLANE FRAME)



← ODF

SCALE 1000 : 1

HSC/15AG38/9   9/4/86

CALIBRATION No. HSC/15 AG 38/9   DATE OF CALIBRATION 8.4.86.

LENS TYPE: Wild Aviogon   Serial No.: 15 AG 38

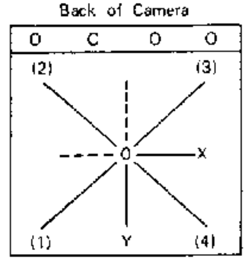
FILTER TYPE: None fitted   Serial No.:

ORIGIN OF MEASUREMENTS O: The point of Symmetry

SIGN CONVENTION : Distortion is positive if away from origin

CALIBRATED AT A TEMPERATURE OF 20°C

CALIBRATION PERFORMED BY: K. Rirsch



MEASUREMENTS

CALIBRATED PRINCIPAL DISTANCE: 152.60 mm

COORDINATES OF POINT OF SYMMETRY
x = -0.005 mm   y = 0.000 mm

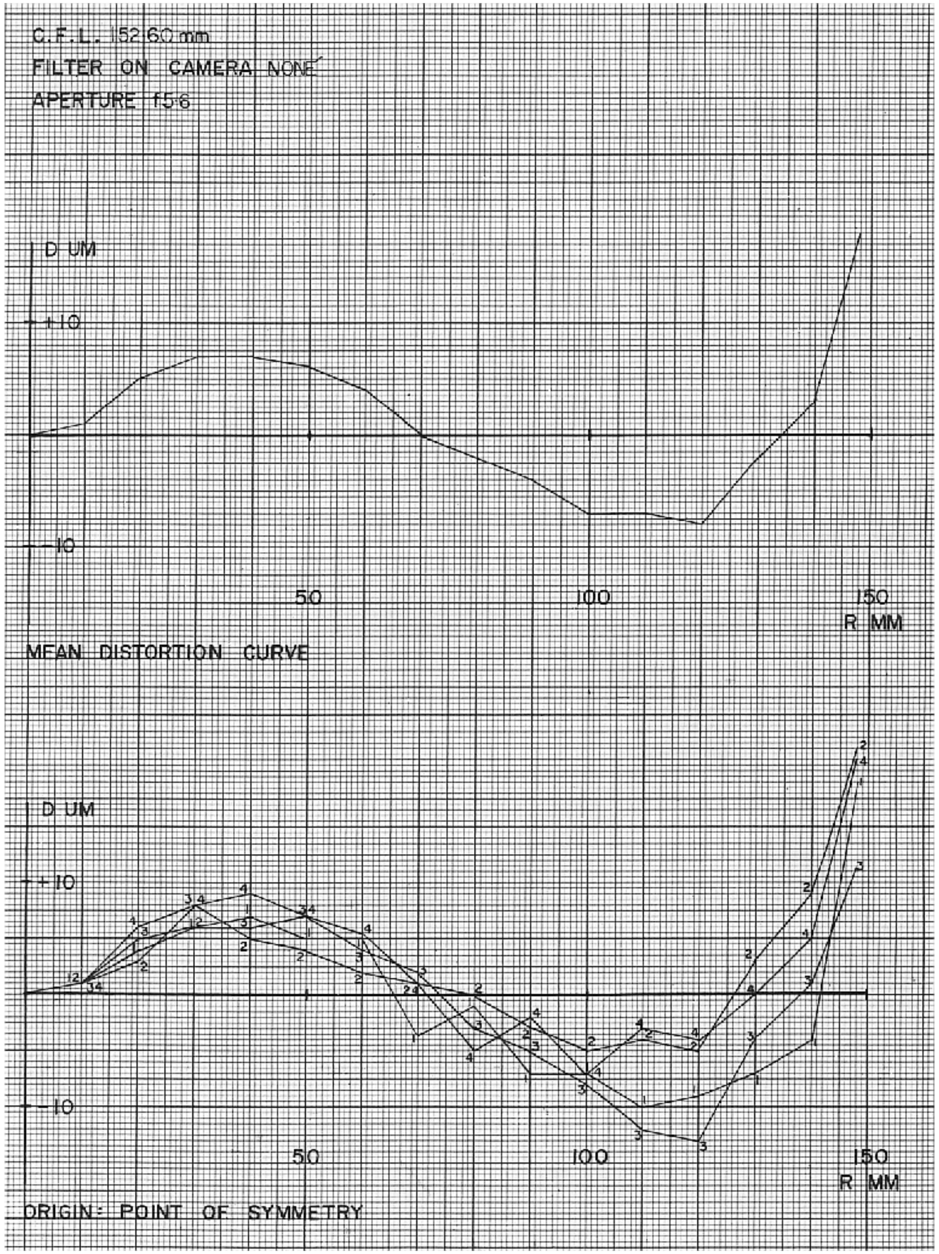
COORDINATES OF PRINCIPAL POINT OF AUTOCOLLIMATION
x = 0.004 mm   y = 0.002 mm

RADIAL DISTORTION IN MILLIMETRES:

Radius (mm)	20	40	60	80	100	120	140
Semi diagonal (1) (ex 4)	0.004	0.007	0.005	-0.001	-0.007	-0.009	-0.004
Semi diagonal (2) (ex 3)	0.003	0.005	0.002	0.000	-0.005	-0.005	0.009
Semi diagonal (3) (ex 2)	0.005	0.006	0.004	-0.003	-0.008	-0.013	0.001
Semi diagonal (4) (ex 1)	0.006	0.009	0.006	-0.005	-0.007	-0.004	0.005
Mean	0.005	0.007	0.004	-0.002	-0.007	-0.008	0.003

BEFORE CALIBRATION THE OPTICAL UNIT WAS CHECKED AND FOUND TO BE IN A SERVICEABLE CONDITION.

APPROVED BY: ....



CALIBRATION No. HSC/15 AG 38/9

DATE OF CALIBRATION 8.4.86

RESOLUTION

LENS TYPE: Wild Aviogon

SERIAL No.: 15AG 38

FOCAL LENGTH: 152.60 mm

APERTURE f5.6

FILM TYPE: agfapan 25 professional

HIGH CONTRAST TEST CHART

DEGREES OFF AXIS	RESOLUTION	
	Radial	Tangential
0	53	53
5	53	53
10	52	51
15	51	49
20	55	47
25	53	49
30	51	44
35	49	40
40	26	35
45	8	27
50	-	-
55	-	-
60	-	-

Measured by: Wild 1.8.74.

Approved by:

Appendix 2 Batch files

TRANSLATING THE ORIGINAL TIFF TO INTERGRAPH JPG

The images were provided in TIF format and required translating to JPG format with overviews adding. This was done using the Intergraph Raster Files Utilities program, Many to Raw file converter.

```
mr_file -i 1 -Cj -Q13 H:\images\ripon\2472.tif H:\images\ripon\2472.jpg
mkov -n 9 -g 2 -g 4 -g 8 -g 16 -g 32 -g 64 -g 128 -g 256 -g 512 H:\images\ripon\2472.jpg
```

-i is the number of input images; -C specifies the output image is not in Raw format ; j specifies the output to be JPEG format, -Q is the compression factor; -n is the number of overviews to create; -g is the overview fraction.

CREATING THE DIGITAL ELEVATION MODEL

The elevation points created in ISAE are used to create a TIN model. This is converted to a grid file and finally the individual models are merged to create a final grid. All these processes use the Terrain Analyst program. For these projects grid files were created with 2 metre and 4 metre spacing. The examples given below are for the 1986 project.

Design files to TIN models

```
dgntin -v -D E:\ripon\dgn\edit3472_3473 -O E:\ripon\mta\ttn\3472_3473 -l 5-7 -p E:\ripon\mta -z 1000 -f regular -m 8 -T
```

-D is the input design file with full path; -O is the output TTN file which is created in the \ttn folder; -z is the multiplication factor for the Design File positional units to make them the same as the master unit, in this case MU:PU = m:mm = 1:1000; -m is the maximum size of triangles and needs to be larger than the elevation point grid distance.

TIN models to grid files

```
tingrid -v -T E:\ripon\mta\ttn\3472_3473 -O E:\ripon\mta\grd\3472_3473 -D E:\ripon\dgn\edit3472_3473 -p E:\ripon\mta -x "2.0 m" -y "2.0 m"

tingrid -v -T E:\ripon\mta\ttn\3472_3473 -O E:\ripon\mta\grd\3472_3473 -D E:\ripon\dgn\edit3472_3473 -p E:\ripon\mta -x "4.0 m" -y "4.0 m"
```

-T is the TTN input file; -O is the output GRD file which is created in the \grd folder; -D is a DGN file to use for working units information; -x and –y are the column and row spacing in ground units (master units). The gridding method is by default planar.

Grid merge

```
grdmerge -v -p E:\ripon\mta -F e:\ripon\mta\grd\3472_3473 -S e:\ripon\mta\grd\3472_3473 -m a -O e:\ripon\mta\grd\run1_1_2m
grdmerge -v -p E:\ripon\mta -F e:\ripon\mta\grd\run1_1_2m -S e:\ripon\mta\grd\3473_3474 -m a -O e:\ripon\mta\grd\run1_2_2m
grdmerge -v -p E:\ripon\mta -F e:\ripon\mta\grd\run1_2_2m -S e:\ripon\mta\grd\3474_3475 -m a -O e:\ripon\mta\grd\run1_3_2m
grdmerge -v -p E:\ripon\mta -F e:\ripon\mta\grd\run1_3_2m -S e:\ripon\mta\grd\3475_3476 -m a -O e:\ripon\mta\grd\run1_4_2m
grdmerge -v -p E:\ripon\mta -F e:\ripon\mta\grd\run1_4_2m -S e:\ripon\mta\grd\3476_3477 -m a -O e:\ripon\mta\grd\ripon_finalgrid_2m
```

-F is the first input grid file; -S is the second input grid; -m is the merge method and averaged (a) is used; -O is the output grid.

Appendix 3 Triangulation Report Files

1986 project

```
Computing RO solutions.
    Sigma is in microns.

Model Id: 1~3472+1~3473, Iters: 4, Dof: 23, Sigma: 3.70, Num Pts: 29
Model Id: 1~3473+1~3474, Iters: 4, Dof: 22, Sigma: 4.86, Num Pts: 29
Model Id: 1~3474+1~3475, Iters: 4, Dof: 23, Sigma: 5.96, Num Pts: 32
Model Id: 1~3475+1~3476, Iters: 4, Dof: 12, Sigma: 3.11, Num Pts: 17
Model Id: 1~3476+1~3477, Iters: 4, Dof: 15, Sigma: 4.83, Num Pts: 21
5 RO Solutions computed.

Computing AO solutions.
    RMS is in meters.

Model Id: 1~3472+1~3473, Iters: 2, Dof: 77, Sigma: 6.56, Num Pts: 29, RMS (X: 0.405, Y: 0.511, Z: 0.084, XY: 0.461)
Model Id: 1~3473+1~3474, Iters: 2, Dof: 74, Sigma: 7.44, Num Pts: 29, RMS (X: 0.258, Y: 0.267, Z: 0.102, XY: 0.262)
Model Id: 1~3474+1~3475, Iters: 2, Dof: 77, Sigma: 5.28, Num Pts: 32, RMS (X: 0.596, Y: 0.526, Z: 0.090, XY: 0.562)
Model Id: 1~3475+1~3476, Iters: 2, Dof: 44, Sigma: 2.78, Num Pts: 17, RMS (X: 0.666, Y: 0.612, Z: 0.085, XY: 0.639)
Model Id: 1~3476+1~3477, Iters: 2, Dof: 53, Sigma: 1.97, Num Pts: 21, RMS (X: 0.038, Y: 0.075, Z: 0.036, XY: 0.059)
5 AO Solutions computed.
```

2003 project
Computing RO solutions.
Sigma is in microns.

Model Id: 1~1837+1~1836, Iters: 3, Dof: 29, Sigma: 16.31, Num Pts: 34
Model Id: 1~1836+1~1835, Iters: 3, Dof: 30, Sigma: 13.62, Num Pts: 35
Model Id: 1~1835+1~1834, Iters: 3, Dof: 35, Sigma: 13.22, Num Pts: 40
Model Id: 1~1834+1~1833, Iters: 3, Dof: 33, Sigma: 15.69, Num Pts: 38
Model Id: 1~1833+1~1832, Iters: 3, Dof: 26, Sigma: 13.47, Num Pts: 31
Model Id: 1~1832+1~1831, Iters: 3, Dof: 29, Sigma: 12.83, Num Pts: 34
Model Id: 2~1808+2~1809, Iters: 3, Dof: 27, Sigma: 14.68, Num Pts: 32
Model Id: 2~1809+2~1810, Iters: 3, Dof: 40, Sigma: 13.51, Num Pts: 45
Model Id: 2~1810+2~1811, Iters: 3, Dof: 38, Sigma: 12.45, Num Pts: 43
Model Id: 2~1811+2~1812, Iters: 3, Dof: 27, Sigma: 10.18, Num Pts: 32
Model Id: 2~1812+2~1813, Iters: 3, Dof: 28, Sigma: 13.58, Num Pts: 33
Model Id: 2~1813+2~1814, Iters: 3, Dof: 37, Sigma: 15.02, Num Pts: 42

12 RO Solutions computed.

Computing AO solutions.
RMS is in meters.

Model Id: 1~1837+1~1836, Iters: 2, Dof: 95, Sigma: 13.10, Num Pts: 34, RMS (X: 0.180, Y: 0.099, Z: 0.449, XY: 0.145)
Model Id: 1~1836+1~1835, Iters: 2, Dof: 98, Sigma: 23.68, Num Pts: 35, RMS (X: 0.254, Y: 0.216, Z: 0.627, XY: 0.236)
Model Id: 1~1835+1~1834, Iters: 2, Dof: 113, Sigma: 25.27, Num Pts: 40, RMS (X: 0.251, Y: 0.202, Z: 0.604, XY: 0.228)
Model Id: 1~1834+1~1833, Iters: 2, Dof: 107, Sigma: 20.90, Num Pts: 38, RMS (X: 0.239, Y: 0.220, Z: 0.514, XY: 0.229)
Model Id: 1~1833+1~1832, Iters: 2, Dof: 86, Sigma: 18.45, Num Pts: 31, RMS (X: 0.254, Y: 0.185, Z: 0.573, XY: 0.222)
Model Id: 1~1832+1~1831, Iters: 2, Dof: 94, Sigma: 18.28, Num Pts: 34, RMS (X: 0.264, Y: 0.205, Z: 0.494, XY: 0.236)
Model Id: 2~1808+2~1809, Iters: 2, Dof: 88, Sigma: 17.96, Num Pts: 32, RMS (X: 0.208, Y: 0.182, Z: 0.561, XY: 0.195)
Model Id: 2~1809+2~1810, Iters: 2, Dof: 127, Sigma: 19.60, Num Pts: 45, RMS (X: 0.241, Y: 0.202, Z: 0.575, XY: 0.222)
Model Id: 2~1810+2~1811, Iters: 2, Dof: 122, Sigma: 18.78, Num Pts: 43, RMS (X: 0.190, Y: 0.192, Z: 0.549, XY: 0.191)
Model Id: 2~1811+2~1812, Iters: 2, Dof: 89, Sigma: 15.62, Num Pts: 32, RMS (X: 0.181, Y: 0.163, Z: 0.501, XY: 0.172)
Model Id: 2~1812+2~1813, Iters: 2, Dof: 92, Sigma: 14.75, Num Pts: 33, RMS (X: 0.206, Y: 0.141, Z: 0.444, XY: 0.176)
Model Id: 2~1813+2~1814, Iters: 2, Dof: 119, Sigma: 25.33, Num Pts: 42, RMS (X: 0.321, Y: 0.173, Z: 0.700, XY: 0.258)

12 AO Solutions computed.

Appendix 4 Data Backup Record

The data for the projects are backed up on 8mm tapes or CDs. These are stored By SNS and are annotated as in the table below. This is an extract from the remote sensing spreadsheet of archived data.

Number	Format	Date	Contents
K12306	8mm	24/05/02	Ripon 2002. All project files for 1986 photos: JPGs, stereo models, DGNs with DEM points , GRD and TTN files
K12307	CD	24/05/02	Ripon 2002. All project files for 1986 photos: JPGs, stereo models, DGNs with DEM points , GRD and TTN files
K12308	CD	24/05/02	Ripon 2002. 1986 NERC B/W photos 3472 to 3474 scanned at Infoterra in TIF format.
K12309	CD	24/05/02	Ripon 2002. 1986 NERC B/W photos 3475 to 3477 scanned at Infoterra in TIF format.
K12941	CD	03/07/03	Ripon - Ordnance Survey data - 10k Landform contours, 10k Spot heights, 2.5k Landline data
K12942	8mm	03/07/03	Ripon - Tape 1 of 2 (see 14296), data for 86 and 03: ISPM projects, grids, JPGs, orthophotos, vector data. 6/4/05
K14113	DVD	23/04/04	Ripon - Colour TIFs @ 1200dpi from ARSF photos 1808-1814. Scanned by Infoterra.
K14114	DVD	23/04/04	Ripon - Colour TIFs @ 1200dpi from ARSF photos 1831-1837. Scanned by Infoterra.
K14296	8mm	08/04/05	Ripon - Tape 2 of 2 (see 12942), data for 86 and 03: ISPM projects, grids, JPGs, orthophotos, vector data. 6/4/05

Glossary

ARSF	Airborne Remote Sensing Facility
DEM	Digital Elevation Model
DGN	MicroStation design file
ISAE	ImageStation Automatic Elevations
ISAT	ImageStation Automatic Triangulation
ISBR	ImageStation Base Rectifier
ISDC	ImageStation DTM Collection
ISOP	ImageStation OrthoPro
ISPM	ImageStation Photogrammetric Manager
ISRU	ImageStation Raster Utilities
ISSD	ImageStation Stereo Display
NERC	Natural Environment Research Council
SHP	ArcView shape file
UDPE	OrthoPro User Defined Product Editor