

# MAPPING WITH SPOT IMAGERY AND INTEGRATED DATA SETS

by

R. Simard, G. Rochon and A. Leclerc  
DIGIM INC., 1100, René Lévesque Blvd. West,  
Montréal, Canada H3B 4P3

## ABSTRACT

This paper addresses the characteristics and performance of the semi-automated CARTOSPOT system developed at Digim for the production of 1:50 000 and smaller-scale topographical maps from stereoscopic SPOT imagery and a very limited number of ground control points. The system components and the main information processing stages involved are described. The quality of the produced maps and DTMs (Digital Terrain Models) is also evaluated. Finally, geological applications of DTMs derived from SPOT data are investigated.

## 1. INTRODUCTION

The successful technical performance of the SPOT satellite system has initiated a broad spectrum of demonstration applications throughout the world. Among those, one of the most attractive applications is definitely the topographical mapping and integration of base map information with multi-source data sets. DIGIM has developed a sophisticated digital system for automatic production of topographical maps at scales of 1:50 000 and smaller. The system, called CARTOSPOT, is based on an image-processing package developed to process stereoscopic as well as monoscopic SPOT images. The system handles raster-format data for the production of DEMs (Digital Elevation Models), ortho-images and thematic map products. This highly performing system has been developed for ultimate accuracy achievement in order to satisfy as much as possible stringent topographical mapping standards. As a result, not only very precise results are achievable, but also application of the system for a wide range of environment is now effective.

Transfer of raster data to vector format is currently performed on an Intergraph mapping system for topographical map compilation, edition and plotting. Also, vector-to-raster data conversion is applicable inversely for multi-source data integration. From the DEM, ortho-image and base-map data, spatio-maps and perspective views with graphic overlays as well as synthetic terrain views generated with artificial parallax or lighting can be produced.

## 2. TOPOGRAPHICAL MAPPING

### 2.1 THE CARTOSPOT SYSTEM

This section will describe the main steps involved in the creation of DEMs, ortho-images and topographical maps from SPOT images (Rochon et al., 1987). The input data consist of both stereoscopic panchromatic and multiband geometrically raw SPOT images. Ephemeris and attitude data are also used to model the spacecraft-sensor image acquisition geometry. A set of GCPs (Ground Control Points) is also necessary. The geometric modelling is based on a theoretical model developed by Guichard (1985) and Toutin (1986). Its principal characteristic is that the SPOT sensor viewing geometry and satellite motion effect have been integrated into a physical model. As a result, very few ground control

points (at least 3 in XYZ) are required for the modelling. Figure 1 shows the main processing steps involved in the production of DEMs, ortho-images and topographical maps.

2.1.1 Main Processing Steps The input data are first preprocessed. The preprocessing of images includes basic contrast enhancement and filtering depending on the quality of raw data. The terrain coordinates of GCPs are collected and their positions in the images are measured as well as the position of other homologous points (for which the ground coordinates are unknown). The geometric modelling of the SPOT scenes is then performed simultaneously using the whole set of control points and the ancillary data such as ephemeris and attitude files.

The orbit file contains six (6) orbital parameters for every minute: the three components of the position and of the velocity of the satellite in an earth-centred system. These parameters are transformed into six osculatory parameters which describe the geometry of the orbit more physically. These parameters are: earth centre-satellite distance, orbit-plane inclination, satellite argument, longitude of the ascending node, etc. From the attitude file a computation is made of:

- the variations of attitude (roll, yaw and pitch) with respect to the scene centre;
- the linear part of these variations by least-squares computation;
- the non-linear part of these variations;
- the ground effect of the non-linear part of the attitude variations for every 250 pixels (10 m), which are computed with a sliding mean.

The two stereoscopic images, which are acquired with the largest B/H (base-to-height ratio) possible, are used with the geometric model parameters to produce a raw DEM. Once the DEM has been derived, a multiband input image is processed along with this DEM and the geometric model parameters to produce an ortho-image. The multiband ortho-image is classified to obtain the location of the lakes and this information is used to refine the DEM: elevation values over a lake are all set to the most probable level of the lake. Using the refined DEM, the topographical contours are drawn automatically.

If panchromatic SPOT data are used, a panchromatic raw SPOT image is also rectified using the refined DEM. The panchromatic and the multiband ortho-image can be integrated, producing a colour ortho-image with a resolution of 10 metres. Some part of the extraction of the cartographic features can be made through classification of the ortho-image but human interpretation is always needed. Therefore, the ortho-image is further enhanced to improve visual perception of details. These enhancements include the production of stereomates for 3-D perception (synthetic stereoscopic images containing only x parallaxes and produced by use of a DEM) and edge enhancement.

Since the final map must be in vector format and the stereomates and the DEM produced are in raster format, they have to be transferred to a graphics station which allows display of both types of data for the subsequent steps. Planimetric details are drawn in vector format by visually interpreting the stereomates displayed in background. All vector data are edited and prepared for automatic drawing. Masks are produced for surface elements and place names are added as well as legend, frame, grid and coordinates. Finally, from the DEM, ortho-image and final cartographic overlays, other products can be derived, such as spatio-maps, digital terrain models and perspective views.

Some complementary information will now be given concerning the production of the raw DEM.

**2.1.2 Production of Raw DEM** Once the geometric model is determined, stereo-reduction can be achieved if needed. The stereo-reduction is a preprocessing step in the case of images having large B/H and high variations of altitude. It is the parallax present in the stereo images which allows height values of the DEM to be derived: the larger the B/H, the more precise the DEM can be. But, since parallax measurement is performed using a correlation-based algorithm, large geometric distortions due to the relief within the correlation window can affect the image-matching performance.

DEM processing is done at low resolution prior to final (high) resolution. Spatially reduced images containing less relief distortion (in a relative sense) are used to produce a first coarse DEM (see Figure 2). After, the coarse DEM is used to reduce the amount of parallax in the full-resolution stereo images. The stereo-reduced images (containing only residual parallaxes) are used to derive a relative DEM which gives altitude variations in relation to the coarse DEM (see Figure 3). By adding the relative DEM to the coarse DEM, a raw DEM is obtained. (The DEM is called raw because it still needs to be refined). In the case of stereo images containing a smaller amount of relief-induced parallax, where stereo-reduction is not required, low-resolution processing and combination of relative and coarse DEM can be skipped. The changes in the high-resolution processing are then very minor (see Figure 3).

In more detail, the steps involved in low-resolution processing are the following. First, the preprocessed images are spatially reduced (for example at 50 metres). Using the geometric model, the images are resampled in the MIS (Mean Intermediate System), a reference coordinate system different from the map coordinate system. The purpose of using the intermediate system is to decrease the amount of y parallax present in the stereo images in order to facilitate their matching.

The stereo-image-matching process is area-based correlation and its implementation done on a FPS-5420 multiple processor system. Emphasis was placed on the design of efficient processing structures on the multi-processor system to speed up computation of the correlation function. The speed advantage is largely obtained with fast floating point operations, concurrent operations on serial data ("pipelining"), and a systematic data structure. The matching of the stereo images produces parallax files which are filtered in order to remove gross errors. Through the process called space intersection, which uses the parameters of the geometric model, parallax measurements are transformed into elevation values which, once interpolated, form the coarse DEM. The last step of low-resolution processing is to scale (resample) the low-resolution DEM to a full resolution DEM (coarse).

The high-resolution processing steps, which are shown at Figure 3, are achieved as follows. The preprocessed stereoscopic SPOT images are resampled in the MIS using the coarse DEM. The matching of the images is then performed at full resolution, producing new parallax files. Again, the parallax files are filtered and used as input for the space intersection. The elevation values are interpolated producing a relative DEM. The steps for the combination of the DEMs simply consist of adding the relative and the coarse DEM and rotating (resampling) the resultant DEM from the MIS to the cartographic system. The result is the raw DEM.

When stereo-reduction is not required, the preprocessed stereoscopic images are resampled in the MIS using a fixed altitude (datum) instead of the coarse DEM and the space intersection is performed in the cartographic system producing the raw DEM directly.

## 2.2 RESULTS

2.2.1 Geometric Modelling The geometric modelling of SPOT data was tested with the CARTOSPOT system at two test sites: Kananaskis in Canada and Kedah in Malaysia. As explained earlier, the geometric model allows a relationship to be established between image and ground coordinates. The Kananaskis ground data set was found to be the most accurate one, with a precision in GCP coordinates (obtained with photogrammetric restitution) better than 5 metres RMS. This data set allowed a detailed evaluation to be made of the efficiency of the proposed model. The other tests performed with data acquired over Kedah complemented the results obtained with the Kananaskis data.

a) Kananaskis Results. The stereoscopic images acquired on this test site were panchromatic with incidence angles resulting in a B/H of 0,5. Only 3 GCPs, located on the border of the stereomodel, and 19 homologous points were selected for the calculation of the geometric model parameters. A set of 36 GCPs were used as check points. The residuals obtained for the control, homologous and check points are given in Table 1.

Point type	N	RMS Residuals (m)		
		in X	in Y	in Z
GCPs	3	0,8	1,5	0,2
Homologous	19	0,5	2,4	---
Check	36	4,5	5,7	6,1

Table 1 - Modelling Residuals for Kananaskis Stereo Panchro SPOT Data

It should be stressed that the error introduced by the geometric model is negligible if we consider the accuracies of 3 to 5 metres for GCPs and of 2 to 3 metres for the measurement of image coordinates. Moreover, these results showed that a very small number of GCPs is required for the geometric modelling. The accuracy in Z of 6,1 metres (obtained with a B/H of only 0,5) should lead to a 3-m accuracy in optimal cases where the B/H is near unity.

b) Kedah Results. The stereoscopic images acquired on this test site in February 1987 were panchromatic with incidence angles resulting in a B/H of 0,87.

The geometric model was established using GCPs digitized from 1:25 000 topographical maps and homologous points. First, all GCPs were entered into the geometric modelling as well as image coordinates of homologous points. However, not all these points were suitable for a correct adjustment since they were not all completely visible in the two images. Because the CARTOSPOT geometric modelling algorithm only requires a few GCPs, only those which seemed to be the best were used after performing several tests. At the end, 13 GCPs and 46 homologous points were kept, resulting in the RMS errors shown in Table 2.

Point type	N	RMS Residuals (m)		
		in X	in Y	in Z
GCPs (1:25 000 maps)	13	9,1	6,2	6,4
Homologous	46	0,1	1,0	0,0

Table 2 - Modelling Residuals for Kedah Stereo Panchro SPOT Data

Again these results are well within the expected accuracy of coordinates from the 1:25 000 maps. They confirm that modelling residuals depend mainly on the accuracy of GCP coordinates when the measurement error is equal to or larger than the pixel size. On the other hand, the precision of the overall geometric model is believed to be well within the residual values obtained from Kananaskis data.

2.2.2 Automated Stereocompilation The SPOT HRV data's digital format allows the stereocompilation process to be highly automated. Tests were performed using the CARTOSPOT system for the Kedah test site. The stereo-reduction option was chosen as terrain amplitude was of the order of 900 m associated with a relatively large B/H.

a) Low-Resolution Processing (panchromatic). Using the parameters of the geometric model, the two panchromatic images were resampled in the MIS with a resolution of 50 m. Sub-images of the apparently most difficult areas were selected for image matching tests in order to determine the parameters for the matching of the two spatially reduced images. The evaluation of the matching success consisted in analyzing the statistics given by the image matching algorithm and looking to the image of the measured parallaxes superimposed to the stereo images displayed on the screen. The parameters chosen are listed in Table 3.

Because the creation of the DEM was obtained using stereo-reduction, the Y parallax was neglected. The matching of the images was achieved for 84% of the total area. The parallax was subsequently filtered in order to remove gross errors and to retain only the low frequency component of the terrain. The resulting X parallax file was ready for space intersection in the MIS, using the geometric correction parameters. The resulting DEM was interpolated to fill holes using the distance-weighted interpolation method.

b) High Resolution Processing (panchromatic). The two raw (full-resolution) panchromatic images were resampled in the MIS using the parameters of the geometric model and the coarse DEM, with a resolution of 10 m. Again, sub-images of the apparently most difficult areas were selected for image-matching tests in order to determine the parameters for the high-resolution stereo-matching. The parameters chosen are listed in Table 3.

Parameter	Low Resolution		Full Resolution	
	Value		Value	
Reference window size	10 lines	10 pixels	10 lines	10 pixels
Search region size	10 lines	22 pixels	10 lines	18 pixels
Increment for matching	1 line	1 pixel	1 line	1 pixel
Threshold on variance	4 grey lev. <sup>2</sup>		8 grey lev. <sup>2</sup>	
Corr. coeff.	0,2		0,25	

Table 3  
Parameters used for the Stereo-Matching Images

The Y parallax was also neglected here. Images were matched for 59% of the total area. Similar filtering and interpolation procedures applied to the 50-m coarse DEM were used for the relative DEM. Both DEMs (coarse and relative) were simply added in the MIS and rotated to the map coordinate system to provide the raw DEM.

c) Multiband Image Processing. A near-nadir acquisition multiband image was also processed in order to complete the planimetric detail extraction from the panchromatic ortho-image. The multiband ortho-image was produced using the DEM previously derived. Lake surfaces were automatically extracted and used to correct the raw DEM on these surfaces.

Figure 4 shows the DEM (before lake correction) obtained over Kedah with a density coded image with elevation intervals of 100 metres. Figure 5 represents the shaded-relief image derived from the refined DEM. The details that can be seen in this image illustrate the high sensitivity of the CARTOSPOT system for extracting terrain information.

d) Topographical Map Production. From the various features extracted from the DEM and the ortho-images, a draft of each overlay was produced on plastic film with an automatic drawing table. After verification, topographical contours, vegetation contours, grid and lines of hydrographic network were scribed automatically. The road network and other planimetric details were compiled manually on scribe coat from the draft overlays.

Finally, place names were added as well as legend, frame and coordinates, and masks were produced for surface elements. Master negatives were produced photographically by combining the different overlays.

Figure 6 shows a portion of the 1:50 000 scale topographical map obtained from SPOT data (with 20-m contour interval). At that time, no precise ground information was available to evaluate the precision of the map. Only a preliminary analysis has been conducted for the DEM, with results on a few checkpoints from the existing maps indicating that a 10-m RMS altimetric and 15-m planimetric precision must have been obtained.

### 3. GEOLOGICAL APPLICATION

Satellite images have been used extensively for geological mapping from the time the first Landsat satellite was launched. The interpretation methodology has rapidly evolved from visual interpretations to analyses that often require images to be combined with other data sets, in particular with data sets that reveals information about terrain relief. Because good SPOT data of the Kananaskis site was not available, the investigation has been limited to a prior study which is based on the manipulation of LANDSAT-5 TM data (Simard and Slaney, 1986). An outline of this study and its main conclusions are presented below.

A TM stereomodel was used to generate a DEM, which was, in turn, used to prepare a TM ortho-image. A geology map was also digitized and registered to the TM ortho-image. Two new versions of the geology map were prepared: 1) the TM ortho-image with lithologic unit boundaries and structural information overlaid, and 2) the geology theme map overlaid by a "solar" shadow mask (generated from the DEM) to portray terrain relief. Finally, a series of perspective views were made from both kinds of geology maps using the DEM information (Figure 7 is an

example). The geology maps and perspective views were evaluated for their interpretability. Using the image map, a geologist can immediately identify the characteristics of the terrain underlying each rock unit. The TM image map can also be used to revise the geological overlay by changing the location of boundaries and faults and by adding new information where necessary. Plane views are significantly easier to interpret when associated with the appropriate perspective views. The most useful perspective views generated so far have a viewpoint of 30° above horizon. The perspective view emphasizes topographic relief and is thus complementary to the plane view. Perspective viewing appears to improve the detectability of many geological features. Key marker horizons, for example, can be traced for many kilometres along the steeply sloping valley walls of the Kananaskis region using perspective views. An overturned fold structure was only identified by studying both perspective and plane views. SPOT has a superior capability for generating stereomodels and produces scenes with very high spatial resolution. Both of these characteristics are clearly advantageous for geological studies of the earth's surface.

#### 4. CONCLUSIONS

The SPOT system has been shown to provide accurate data for the production of topographical maps using highly automated techniques. The large surface covered by SPOT images, the limited ground control information necessary, and the digital nature of the data are among the most important characteristics to be considered in the use of this technology as a tool complementing conventional methods.

The capability of obtaining DEMs and topographical maps from SPOT data has been shown to extend to other applications such as geological mapping. The use of integrated components with high spatial resolution and surface-cover reflectance and efficient digital processing systems to gather terrain information will probably lead to significant breakthroughs in remote sensing applications.

#### 5. ACKNOWLEDGEMENTS

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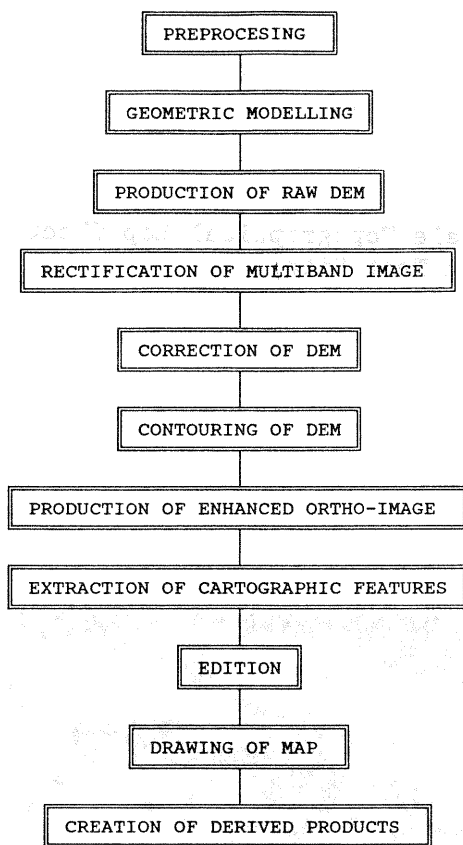


Figure 1  
Main Processing Steps of the  
CARTOSPOT System for Mapping  
from SPOT Images

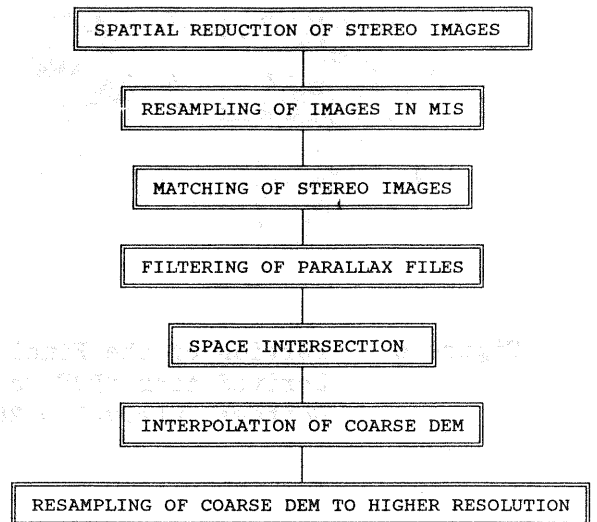
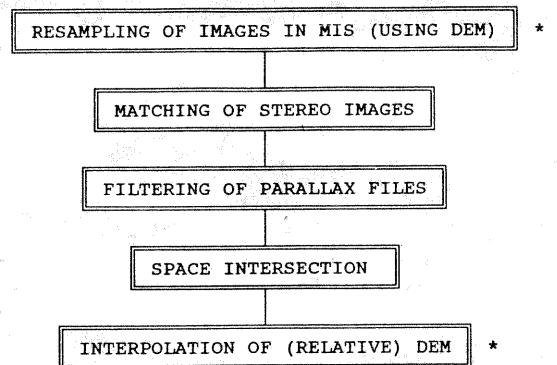


Figure 2  
Low-resolution Processing Steps



\* (IF STEREO-REDUCTION APPLIED)

Figure 3  
High-resolution Processing Steps



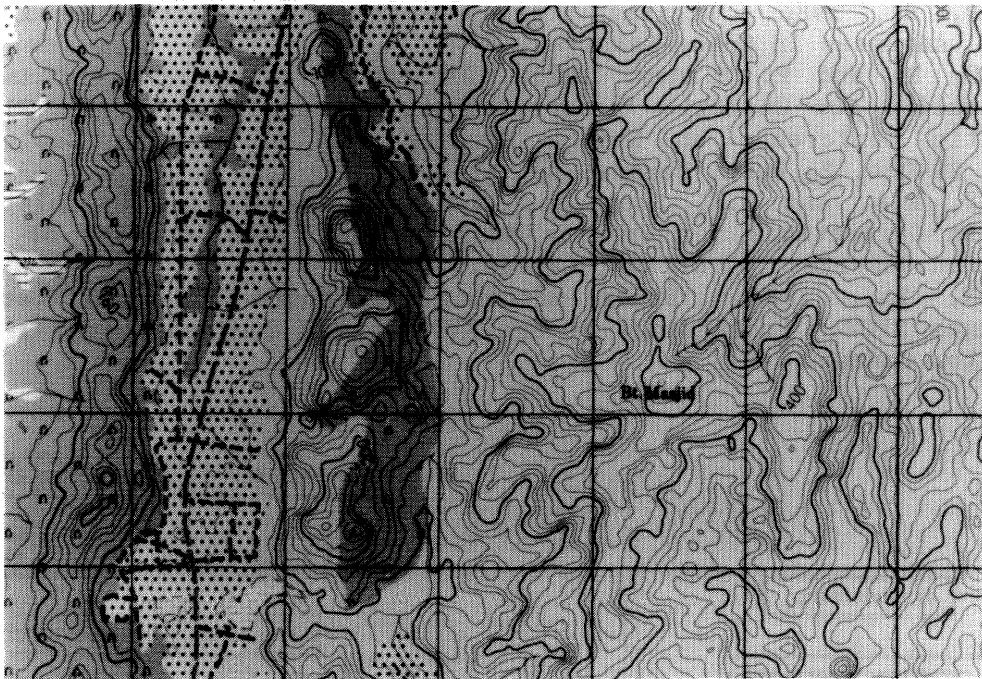


Figure 6 - Portion of the Final 1:50 000 Scale Topographical Map Sheet  
 Derived from SPOT Data over Kedah Test Site.  
 Contour Interval = 20 metres

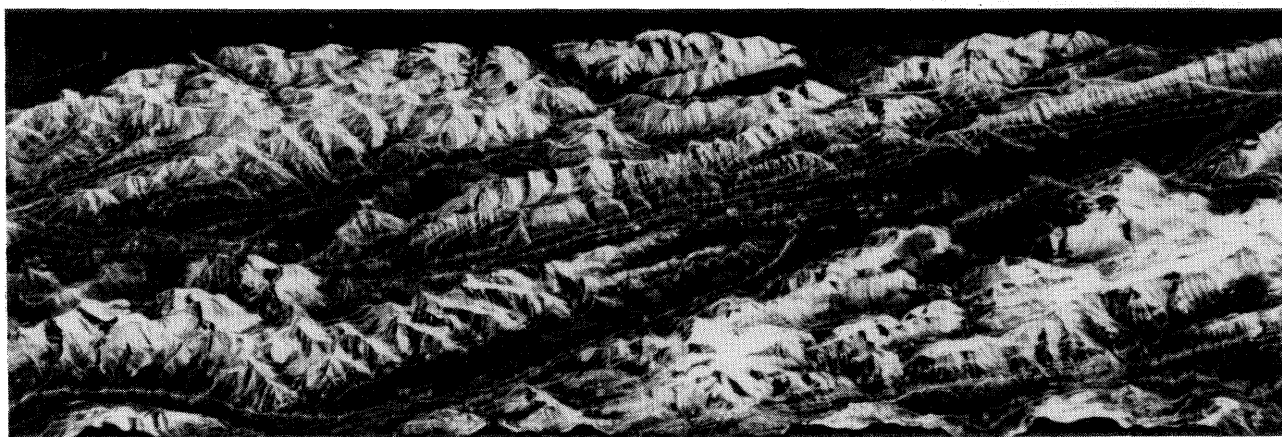


Figure 7 - Perspective View of the TM Ortho-Image with Rock Unit  
 Boundaries (green) and Faults and Thrusts (red) Overlaid.  
 (Kananaskis Test Site, Viewing Angle of 30° above horizon)

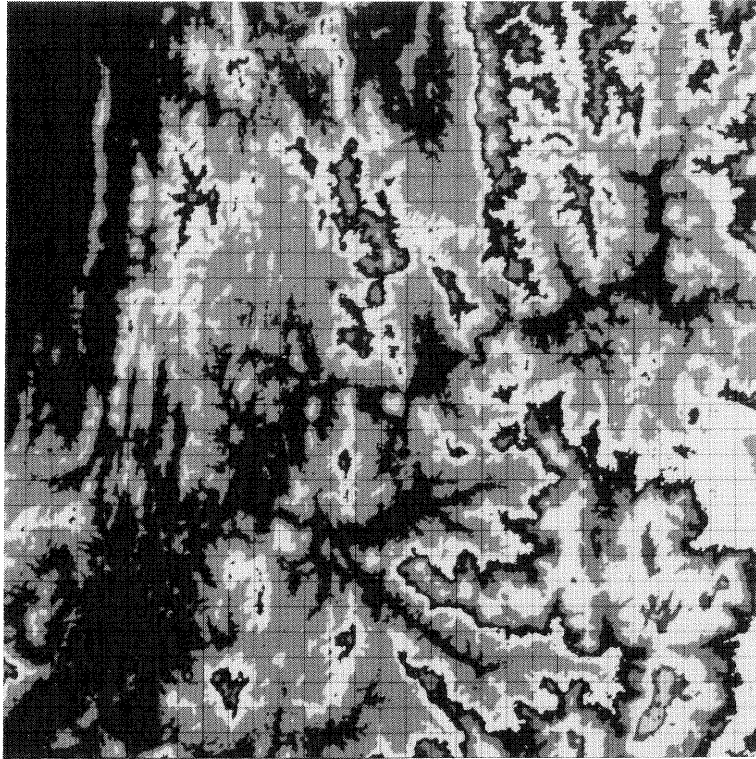


Figure 4 - DEM Covering one Topographical Map Sheet at 1:50 000 Scale Obtained Using SPOT Data over Kedah Test Site. (Color Coded Increment: 100 Metres)

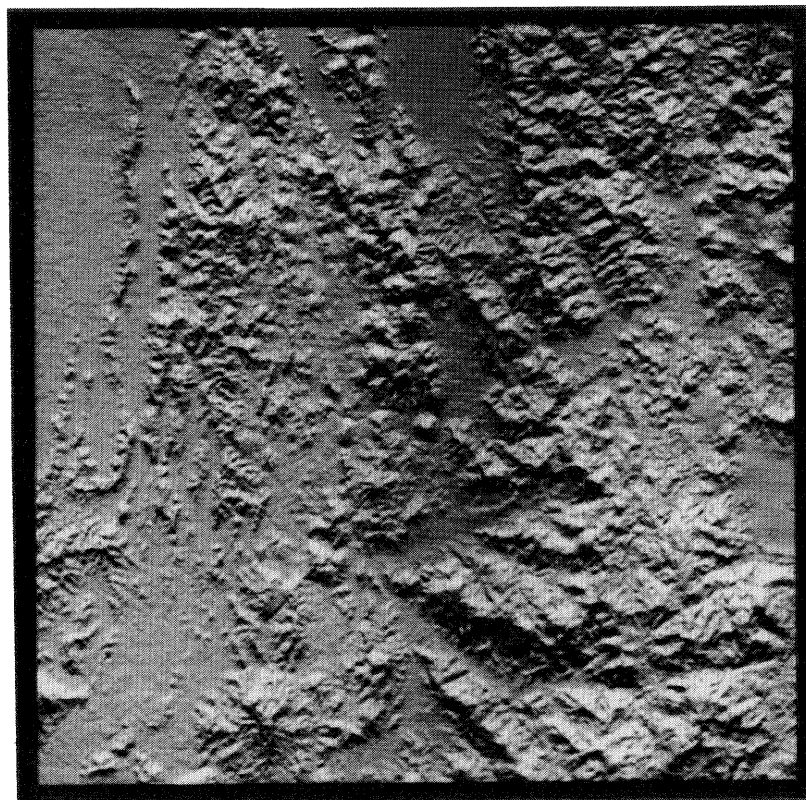


Figure 5 - Shaded-Relief Image over Kedah Test Site Produced with the SPOT-Derived DEM (Light Source: North, 35° above Horizon)

