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GEOLOGIC APPLICATION OF LANDSAT IMAGERY ENHANCED BY TOPOGRAPHIC DATA

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I. ABSTRACT

Structural analysis of geological phenomena may be enhanced by real or simulated illumination conditions of satellite data. With this concept in mind, an experimental project has been developed to manipulate the Landsat radiances under the control of simulated illumination conditions and viewing geometry. To achieve this, a digital terrain model (DTM) was created by digitizing contour lines of topographic maps on a scale of 1 to 50 000. Using a specially designed algorithm, elevation was later calculated for each grid point at an interval of 50 meters on the ground and overlaid on a geometrically corrected Landsat image. After calculation of (1) the normal to the ground for each "pixel", (2) the direction cosines of the line from each pixel to the simulated satellite position and, (3) the simulated solar illumination, different algorithms were used to derive new satellite radiances.

It is shown that even with a simple algorithm like a multiplication of radiances by $\cos \psi$, where ψ is the angle between the sun illumination and the normal to the terrain, the interpretation of geologic features is dramatically enhanced.

Examples of current geologic maps compared to interpretation made with the present algorithms show clearly the potential of this methodology. The main constraint still remains the long computing time needed to process the data, even though it is still economically advantageous. The foreseen production of a low cost parallel processor will definitely result in the systematic use of the present methodology.

II. INTRODUCTION

Geologic structures often result in local modifications of the surface elevations and in alterations of ecologic features. Consequently, these phenomena will modify the reflectances of the ground in the visible and in the infrared as seen by the earth observation satellite¹. Landsat images thus contain information on structural phenomena in geology. Difficulties arise for the photo-interpreter because this valuable information is diluted with other sources of radiance modifications, such as soil or vegetation differences, cultural patterns, etc.

The idea of simultaneously combining the topography with remote sensing data to enhance the interpretation of data is certainly not new, but the process necessary for the realization of this operation has always been cumbersome, costly, if not impracticable. The present experiment was designed to try to overcome the combined barriers of new technology management which is faced with the complex integration of multi-source data and of human adaptation to this technology.

III. METHODOLOGY

The methodology used in this experiment was a by-product in research conducted at Laval University, Quebec, aimed at eliminating the effects of the topography and the atmosphere on radiances measured by satellite^{2,3}. Obviously, in the present case, the topographic input is used to maximize, rather than minimize, the modification in Landsat radiances according to the position of a simulated source of light or to the location of the simulated observation platform.

More specifically, the basic methodology involves the following steps:

A. CREATION OF A DIGITAL ELEVATION MODEL (DEM)

This operation has been carried out up to now by manual digitization of elevation contours on 1:50 000 topographic maps produced by the Department of Energy, Mines and Resources of Canada (UTM projection). A high precision laser scanning system is now replacing this tedious work. Tests with the Gestalt photomapper have, on the other hand, demonstrated that a high density DEM could be produced with this technique for low height vegetated areas such as those in Northern Canada.

The elevation at each intersection of a UTM grid is later calculated from the contour lines using a linear interpolating algorithm developed by Letts and Rochon³. The main characteristics of the polygon to raster algorithm and the polygon interpolation procedure are:

- output pixel height and width can be specified separately by the operator;

- contour lines can be added singly or in groups to existing files, or deleted as well;

- groups of contour lines can be affinely registered to a specific pair of axes;

- automatic recognition of peaks and depressions, and optional manual entry of corresponding elevations.

- interpolation by successive binary division of the spaces between each pair of adjacent contour lines.

The net result of this procedure consists, for each topographic map covering an area of about 27x37 km² at a latitude of 45°, in an array of about 400 000 elevation points in 16 bits precision when the grid spacing is fixed at 50 meters. An example of digitized contours as they appear on our video colour display is given in Figure 1. The resulting DEM looks like a continuous colour picture with the colour modulated by the elevation of each pixel.

B. COMPUTATION OF SURFACE ORIENTATIONS AND GEOMETRY OF VIEWING

For every pixel, the slope, the slope aspect, and the cosine directions of the normal to the ground are computed using the best fitting surface to the 8 points surrounding this pixel (a 3x3 box with a quadratic fit).

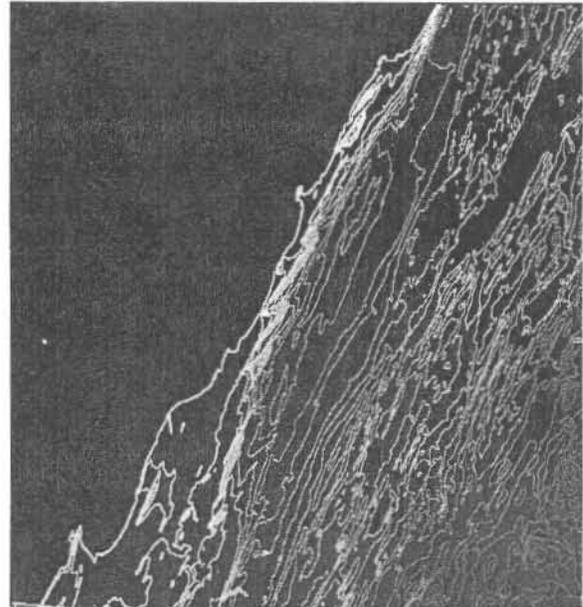


Figure 1. Example of digitized contour lines.

At the same time the direction cosines of the line joining the simulated sensing platform and each pixel are also computed. The platform may be set arbitrarily at any altitude and may move in any rectilinear movement across the area of interest.

Finally, the direction cosines of the simulated sun illumination are fixed for the whole image by the operator.

It is thus possible, for example, to simulate the ground scene viewed by an observer flying over the territory from west to east in the middle of the image at an altitude of 1 000 metres when the sun is in a north position 15° above the horizon.

C. INTEGRATION OF REMOTE SENSING DATA

This step is automatic with the image analysis system used in this experiment, since both sources of data (DEM and Landsat data) were resampled on a UTM grid with 50 meter spacing. Landsat data geometrically corrected and resampled with a cubic convolution algorithm on a UTM grid are available on a standard basis from the Canada Centre for Remote Sensing.

D. TRANSFORMATION OF SATELLITE RADIANCES

Radiances from each MSS band can be transformed using one of the following two operations:

$$L_i^* = k L_i \cos^a \psi + b \quad (1)$$

$$L_i^* = k L_i \cos^a \theta + b \quad (2)$$

where L_i is the radiance in band i ,

ψ the angle between the normal to each pixel and the incident illumination,

θ the angle between the specular reflection path and the sensing platform,

k , a and b are constant, positive or negative,

and L_i^* is the corrected radiance value.

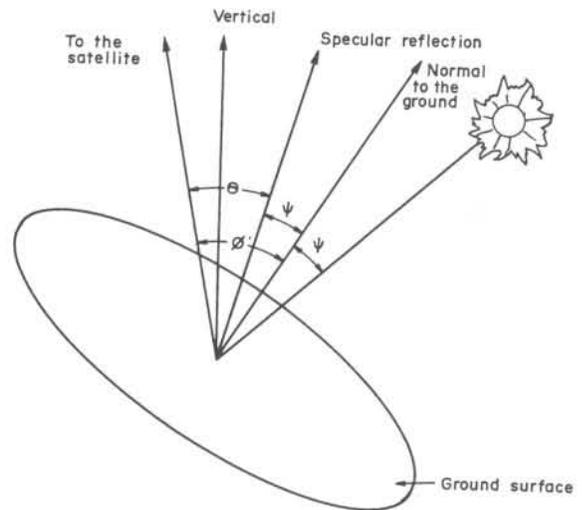


Figure 2. Geometry of viewing and illumination.

Figure 3 gives an illustration of such a transformation when the coefficients of equation 1 are $k = 1$, $a = 1$, $b = 0$ for band MSS7. This image covers the same territory as a standard topographic map 1 : 50 000 originally produced on the same scale.

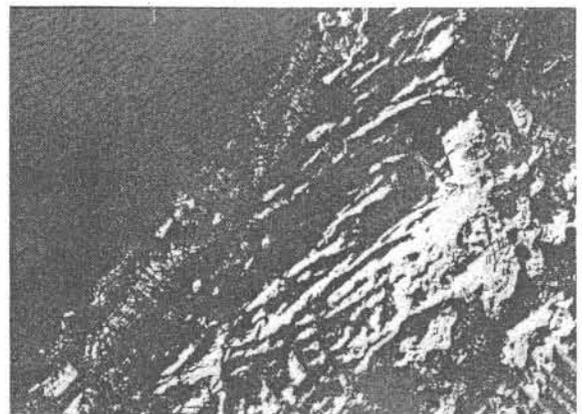


Figure 3. Example of Composite image.

Map 21 M/1; original scale 1 to 50 000;
Solar elevation 40°; solar azimuth 150°
Landsat MSS 7; original in colour.

E. CREATION OF COMPOSITE IMAGES.

Each MSS band can be corrected in this manner with different values for the parameters. It is also possible to create false colour imagery by combining three input images, each reproduced with a primary colour or through a colour transformation to other systems (L-a-b system for example: 1) brightness 2) redness-greenness 3) yellowness-blueness). The same MSS band may thus be seen simultaneously under three different simulated positions of the sun, or any other combination of bands, viewing or illumination conditions.

IV. APPLICATION OF THIS TECHNIQUE IN GEOLOGIC MAPPING

The preliminary results of the interpretation of such images are briefly presented for a region on the south shore of the St. Lawrence downstream from Quebec City. The area under study covered about 7 000 km² and required the partial digitization of more than 15 topographical maps.

A. IDENTIFICATION AND MAPPING OF LINEAMENTS

The production of images with different sun azimuthal positions was found very useful for the identification of lineaments. Band MSS7 was usually chosen with a sun elevation of 40°. The position of the observer was not of prime importance, and was set constant in most cases, except when "spectacular" views were needed.

A high resolution film printer produced black and white 70 mm transparencies which were enlarged to 1:50 000 or to 1: 250 000 for photo-interpretation of each Landsat/topo image. Figure 4 gives an illustration of a map resulting from this study. The value of the real information content of this map is discussed below

B. DETERMINATION OF THE GEOLOGIC NATURE OF LINEAMENTS MAPPED FROM LANDSAT/TOPO IMAGES

Lineaments identified on the Landsat/topo images have been thoroughly compared with published geologic maps of the same area. The particular test area chosen from these maps was one which we considered to be relatively well studied. The aim was to establish specific and statistical correlations.

The specific correlation was established by setting the links between a specific lineament and a geologic or topographic feature, between a specific lineament and a group of geologic or topographic features. The statistical correlation was computed by comparing a group of lineaments with a group of geologic and/or topographic features. Figure 6 shows, in this regard, an example of a statistical correlation. In the first case, the rosette of short lineaments was obtained with the Landsat/topo images and in the second case from the geologic map compiled by Claude Hubert⁴. The existence of NNW-SSE and NW-SE systems of joints suggests that the related system of short lineaments with the same orientation corresponds to fractures.

As we know, classes of reflectances found in Landsat images may also correspond to distinct geological units, phenomena that introduce another domain of comparison with other sources of geologic information.

We have differentiated five groups of lineaments on the map shown in Figure 4:

- Group 1 : Lineaments associated with known faults;
- Group 2 : lineaments interpreted as faults but which, up to now, have not been identified on the ground;
- Group 3 : lineaments corresponding to fold axes or to the stratification;
- Group 4 : lineaments linked to fractures or fracture zones, and lineaments of unknown geologic signification;
- Group 5 : lineaments representing boundaries between different classes of reflectances.

In order to show the real advantages of the present methodology, we have reproduced, for visual comparison, the geologic map compiled recently by Raymond Trempe⁵ (See Figure 5). Only the most striking elements of comparison will be given here.

One lineament which appears very clearly on the composite images is the one that corresponds to the limit of the lower St. Lawrence Valley map and the Saint-Michel map.

In the south-west part of the map, a lineament can be correlated without ambiguity with the Richardson fault, and the

same correspondence also exists in the north-east part of the map. Yet the computed images show clearly that it is not appropriate to connect these two faults as they have been mapped in Figure 5. Indeed, in the central part, many faults not known before have been identified. These faults face the trust faults in the north which have already been identified.

From the satellite images we can deduce that the Armagh Group has a synclinal structure in the south-west and central part of the map, but, again, a simple connection with the north-east part should not be made.

V. DISCUSSION OF THE POTENTIAL OF THIS METHODOLOGY

The results obtained so far tend to show that this form of integration of topographic data with satellite imagery may enlighten structural features that are not evident at first sight, in either of these two sources of data, and without sacrificing information that can be extracted from each source individually. Many other forms of digital images analysis are also possible with these concepts in mind: integration of other variables, such as magnetic maps, or other data transformation, such as spatial directional filtering. We thus consider that this methodology presents numerous advantages, one of these being the possibility of storing the output images, and the associated interpretation on computer tapes. The photo-interpretation of images can also be done directly on the video screen in an interactive mode, and the resultant map traced automatically at the end of the working session.

The main inconvenience for the moment is the high cost associated with such a methodology and the necessity of using complex computing equipment (hardware and software).

As an example, the total CPU time to complete all the steps from the acquisition of topographic data to the production of films has exceeded thirty hours on the ARIES mini-computer for a single topographic map. The use of an array processor such as we are developing and more efficient software or algorithm should reduce this time to less than two hours, which means that this methodology will not only be efficient but also very economically attractive compared with the cost of other well used methods of structural geology mapping.

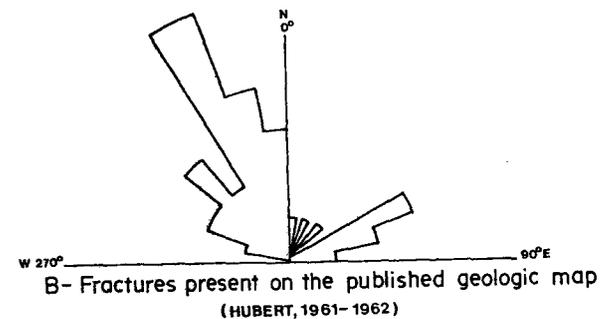
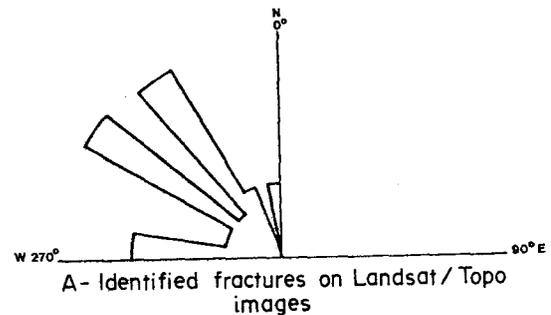


Figure 6. Comparison of fracture orientations.

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