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Automatic Recognition of Geological and Geomorphological Forms from Digital Elevation Models (DEM) in the Exploitation of Data from SPOT

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Abstract

Many techniques of image processing have been developed to analyse more precisely geological information obtained from satellites.

SPOT, which is a recent project in France, will furnish stereoscopic images, with good resolution of surfaces(20m x 20m or 10m x 10m), and give altitudes(DEM) which can be restored automatically. One of the researches for the exploitation of this data, intends to recognize and distinguish automatically the geomorphological forms, containing important geological information from DEM. Along with the information obtained from image processing, it will play an important role in the understanding of the surface of the terrain. This study was carried out in collaboration with University of Paris-6 and Ecole National des Sciences Géographiques(Institute Géographique National of France: IGN).

(1) Introduction

The first point of view comprises the extraction of parameters of forms in only two dimensions with DEM, which is disposed on a rectangular matrix. Most image processing treats texture of the image on the scale of either a pixel or group of pixels. Another approach concerns drainage patterns and lines of crests of a different scale, but are less used. This study follows the later approach.

Another point of view is recognizing the forms in three dimensions. They are the geomorphological forms or structural forms, and can be translated into geological terms. Relatively few studies (H. M. Dufour, 1983) were done in the domain of geology and geomorphology. This study is limited by recognizing automatically the geological and geomorphological objects concerning crests and cuestas, which are very frequently found in sedimentary regions. In the later part of this work, images (Landsat) combined with this data will be presented.

(2) Conceptual Frame of this Study

(2-1) Digital Elevation Model (DEM) and DEM issued from SPOT

* DEM is the numerical and mathematical representation of terrain from observed points, and their numbers and dispositions permit the calculation of altitudes($Z=F(x,y)$) of all points. For DEM, the following should be defined(P. Hottier, 1977);

– seisure-mode of data (density of the observed points),

– methods of interpolation and conversion of brute data(in general, substitution for a grill form),

– algorithms for utilisation of DEM (ex: calculation of contour lines),

– precision which we expect to obtain.

* DEM issued from SPOT: By calculating the geometric model (H. Guichard, 1983; Masson d'Autume, 1979) of each dual image, we can describe the geometry of images permitting the interpolation. This model will give the geographic coordinates of each pixel in an image Two methods for calculation of DEM are used :

– the logiciels 'Traster' (Y. Egels, 1981 and 1983) for analytic restitution from images (films),

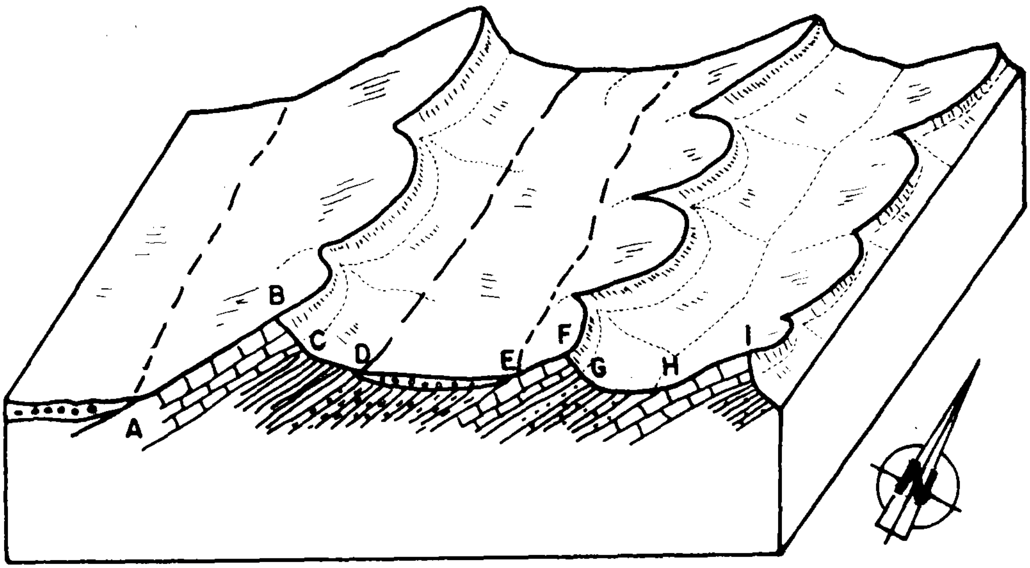
– automatic correlation (Masson d'Autume, 1984) using the information of numeric forms.

* Due to the absence of DEM issued from SPOT, DEM made by IGN were used for this study. They were calculated by the method of elastic grill(Masson d'Autume, 1978) using spline function (two dimensions) with contour lines, which were digitized from aerial photographs by equipement of numeric restitution. They are presented in grill forms, and the resampling distance is 20m in two directions(x, y). This grid corresponds to one pixel of a SPOT image in multispectral mode.

(2-2) Definition of geological and geomorphological objects researched

In sedimentary regions, structural relief concerns the morphology of a crest when the formation is steeply inclined, or a cuesta when its inclination is very slight (Fig. 1).

* *geomorphological aspect:* (1) Abrupt side (front: BC & FG) hangs over talus (CD & GH) of a concave form. (2) The other side of the crest (reverse: AB & EF) being slightly inclined, and has a surface without significant variation in slope. (3) The limit of talus (D, H) can be prolonged



Front (BC, FG): abrupt, C and G: rupture of slope (lithologic contact).
Reverse (AB, EF): structural surface, Talus (CD, GH).
B, F and I: crests (lithologic traces).

Fig. 1. The geological and geomorphological objects for automatic recognition.

by a plane surface (DE) or by another reverse (HI).

* *geological translation:* (1) The foot of abrupt (C & G) corresponds to *principal lithologic contact,* and is the *rupture of slope.* The crests (B & F) are the traces of formations resistant to erosion. (2) Reverse (AB, EF & HI) is the back of hard formation. This structural surface give us its dip. (3) Talus is elaborated in a less resistant formation (CD). The bottom of the talus (D) sometimes is the limit of fluviatile alluvium, or limit (H) between the talus and another hard formation.

In the case of a valley, passages between a flat bottom and its sides (walls) are characterized by significant variation in slope. They generally correspond to limits of alluvium, but presence of alluvial terraces will need more detailed works for the determination of these limits.

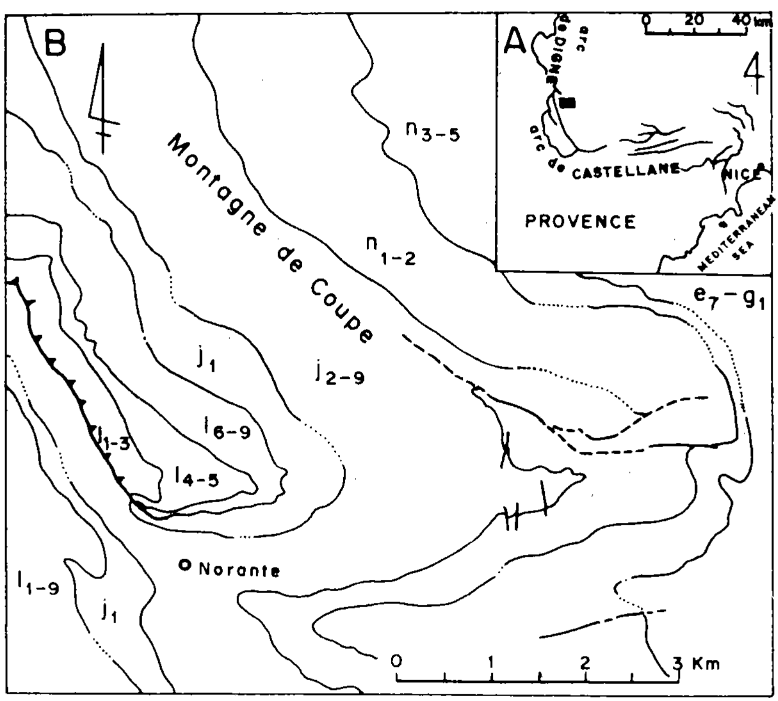
Therefore, analysis of *variations in slope* of topographic surface is essential for this work: concave, convex, plane or not, rupture of slope, crest, thalweg and so on.

(2-3) Description of test zone (Fig. 2)

The Norante area in the sourthern part of France (Alps region) was selected for this work, due to the fact its geomorphology was more interesting to us. The concern was not the finding of new geological phenomena.

This area is situated both on the images obtained from Spacelab (Dec. 5, 1983, 25 orbit), and on the flight line of Mystere 20 (IGN) whose mission was co-ordinated with the passage of a satellite.

The Norante area presents a type of fold in association with a thrust movement, which is a typical tectonic style of a sub-alpine zone. A thrust fault being well developed toward the north, and constitutes a part of the Arc of Digne (Fig. 2-A). The sedimentary rocks suffered by this



37-gl: Priabonian and Sannoisian, blue marls.
n4-5: Barremian to Bedoulian, grey limestones.
n3: Hauterivian, calcareous marls.
n1-2: Berriasian and Valanginian, marls.
j6-9: Kimmeridgian-Portlandian limestones.
j2-5: Bathonian to Oxfordian, Black-Terrain.
j1: Bajocian, calcareous marls.
16-9: Domerian to upp. Aalenian, calcareous marls.
14-5: Lotharingian to Carixian, marls and limestones.
11-3: Hettangian to Sinemurian, black limestones.

Fig. 2. Geological map of the Norante area.

structure, consist of carbonated or marlaceous Lias, thick calcareous marl of the Bajocian, the Black-Terrain of the Oxfordian facies and the Kimmeridgian-Portlandian limestones (upper Jurassic) on the gypseous shales of upper Trias. The Valanginian, Hauterivian and Barremian (lower Cretaceous) are new calcareous marls. The Albian and Cenomanian (black marls: upper Cretaceous) are laid in discordance with the Priabonian and Sannoisian (lower Oligocene) which comprise the sandstones, marls and conglomerates in the Barreme syncline.

(3) METHODS

Representation of terrain must be fixed by Z = H(X, Y) which is continuous and derivable from 1 to 3 times, because it is impossible to consider all discontinuities of surface(thalweg, cliff, rupture of slope..) with numeric representation. In accordance with tradition of geologists, this work was carried out in profiles simplifing our study. The significant and usable profiles must be perpendicular to topographic structural lines. Thus, this study was begun by recognizing crest and thalweg lines.

Proceeding by these four steps(Fig. 3):

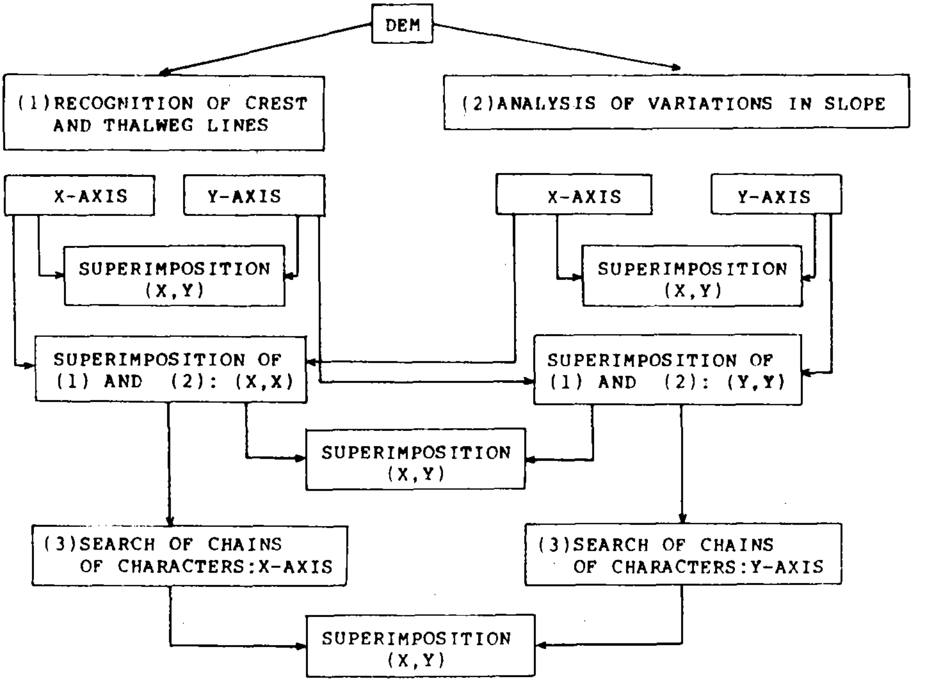


Fig. 3. Flow chart for automatic recognition of objects from DEM.

(a) automatic recognition of crest and thalweg lines.

(b) analysis of variation in slope.

(c) composition of characters(words) for automatic recognition of objects.

(d) combining data obtained from DEM with images.

(3-1) Recognition of crest and thalweg lines

The study of drainage patterns represents one of the more practical approaches to an understanding of structural and lithological control of land form evolution. That is well related with our first step. This work was allowed to have a profile(cross section) whose direction is transversal to principal topographic lines. This profile was used for analysing the variation in slope at the second step. Avoiding the application of complicated formulas, the objects were analysed in natural regard.

(3-1-1) Analysis of objects and principle

Some forms concerning crests and thalwegs can be distinguished on a profile obtained from DEM (Fig. 4-F):

- sharp-pointed form of crests and thalwegs (Fig. 4-A)
- rounded form of crests and thalwegs (Fig. 4-B)
- plateaux (Fig. 4-C)

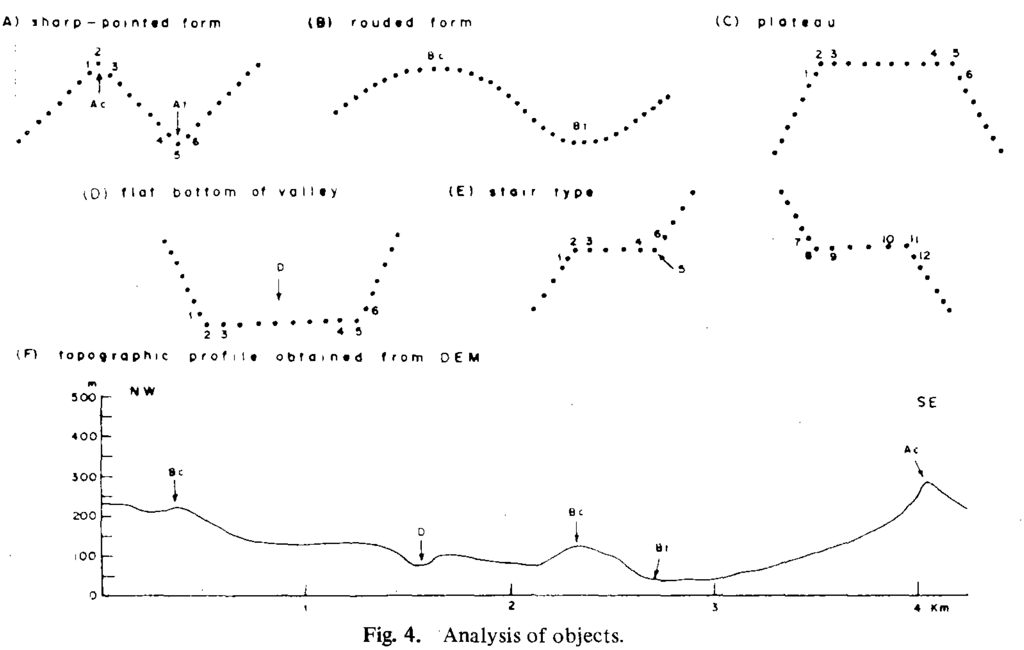


Fig. 4. Analysis of objects.

– flat bottoms of valleys (Fig. 4-D)

– ascendent or descendent stair-types (Fig. 4-E)

The algorithm is composed of the following three processes:

1. Comparing the neighbouring altitudes, DEM is transformed into second matrix comprising 3 characters (+, –& 0). This operation give the signs of slope (descendent or ascenent) in each direction.
2. calculation of variation in slope: This process transforms the second matrix into another matrix to recognize forms by some characters :

   ex: – thalweg (V) and crest (S); – + + + – → V..S,

   – plateau (E) and flat bottom (A); + + 0 – – 0 + + → .EE. AA.
3. superimposition of data obtained along each direction (Fig. 5).

After calculations(1 and 2) along principal directions (x and y), a superimposition was followed to avoid the loss of information obtained in each direction and to distinguish more definitely the forms.

(3-1-2) Results and discussion

(a) Sampling distance of altitudes for DEM is a very important factor. It must be determined by considering the object of study and the capacity of main computer.

(b) Distinguished forms: The types of crests and thalwegs were well recognized, but the stair-types proposed some problems of superimposition (indefinite forms). This difficulty can be resolved by adding scanning directions on DEM. According to our experience, the calculations were effected in two axes(x, y) instead of four directions(x, y, NW-SE & SW-NE) to avoid complexity of superimposition. Fig. 6-A presents only the types of crests and thalwegs.

In order to verify the algorithm, aerial photographs were interpreted. The results concerning crests and thalwegs lines are satisfied. In the western part of Norante area, parallel patterns of thalwegs (see Fig. 6-A) are observed in a straight line. They present the existence of fractures, or contact zone of two different formations which can occur by widening of a valley or by the incision of erosion.

(c) Variability of altitude for recognition of a horizontal surface: Recognition of alluviums and plateaux causes an important problem for certain ranges of difference in altitudes, considering the notion of a horizontal surface. Big differences were observed in the results obtained between 0 cm and 50 cm of this variability. In Norante area, alluviums were well represented by 50 cm. That depends on experience and topographic condition of the studied area.

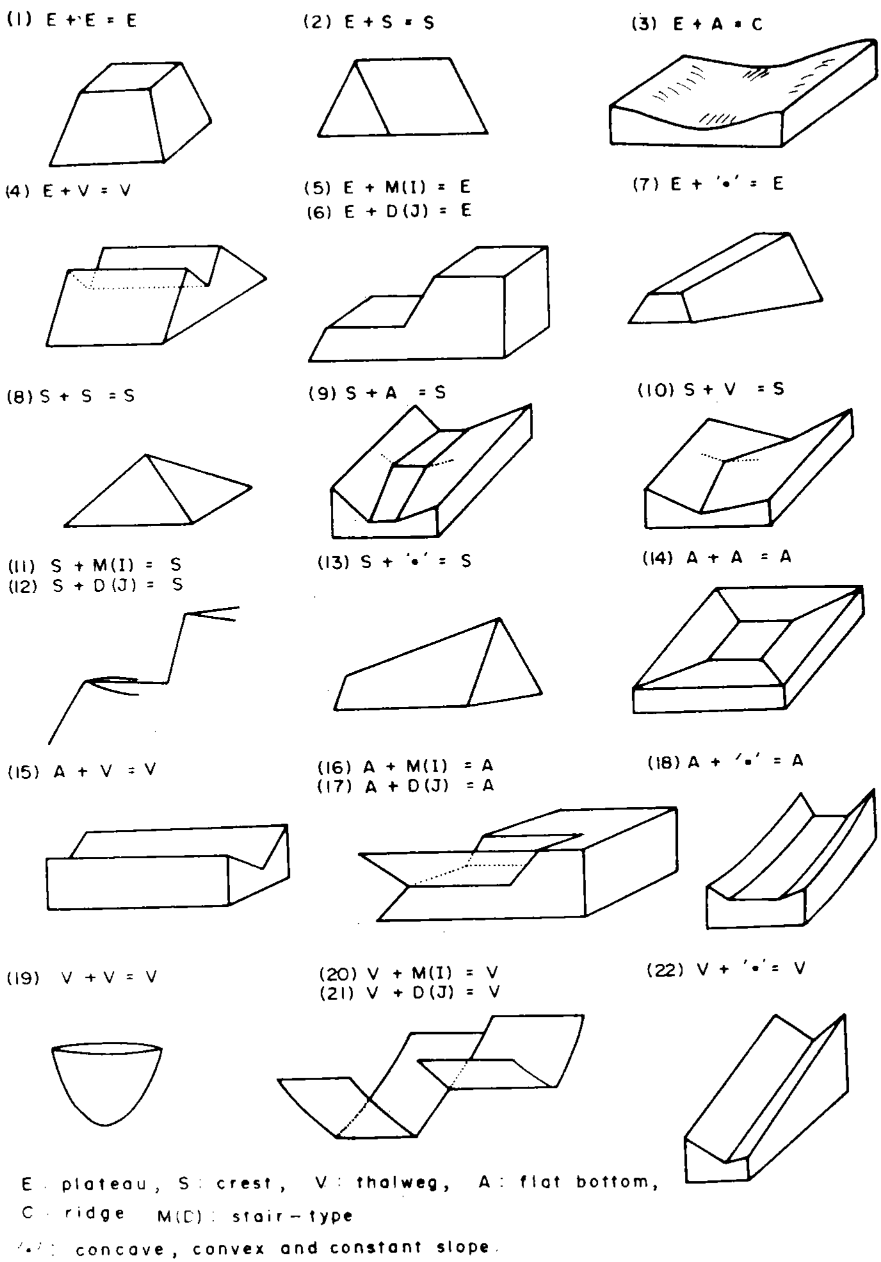
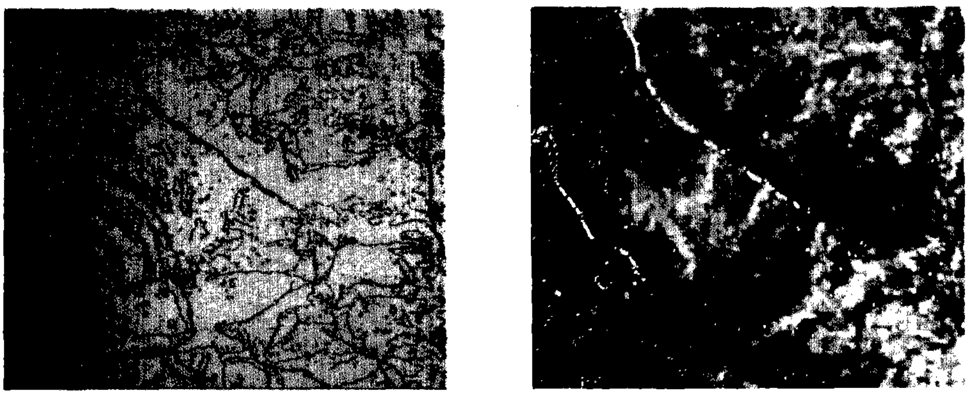


Fig. 5. Forms obtained by superimposition of two axes (X and Y).



(A) (B)

A: Crest and thalweg lines, red points - ruptures of slope.

B: Colour composite image (Landsat 4, 5 and 7; resampling distance: 20m) including chains of characters (ruptures of slope concerning crests), whites points - lithologic contacts.

Fig. 6. Images fabricated by data obtained from DEM.

(3-2) Analysis of variations in slope

For recognizing a morphology of crest and cuesta, it is indispensable to find crests and thalwegs, but they were insufficient. The variations in slope of topographic surface must be analysed. After analysing these variations in terrain and profile obtained from DEM, the following three operations were carried out on each profile of DEM:

(a) Calculation of second derivative (z") and the arrangement of them in five groups.

(b) Search for the maximum value of z" at a given position in two or four scanning directions (x, y and two diagonals).

(c) Superimposition of (a) with the result obtained by the first step (recognition of crest and thalweg lines).

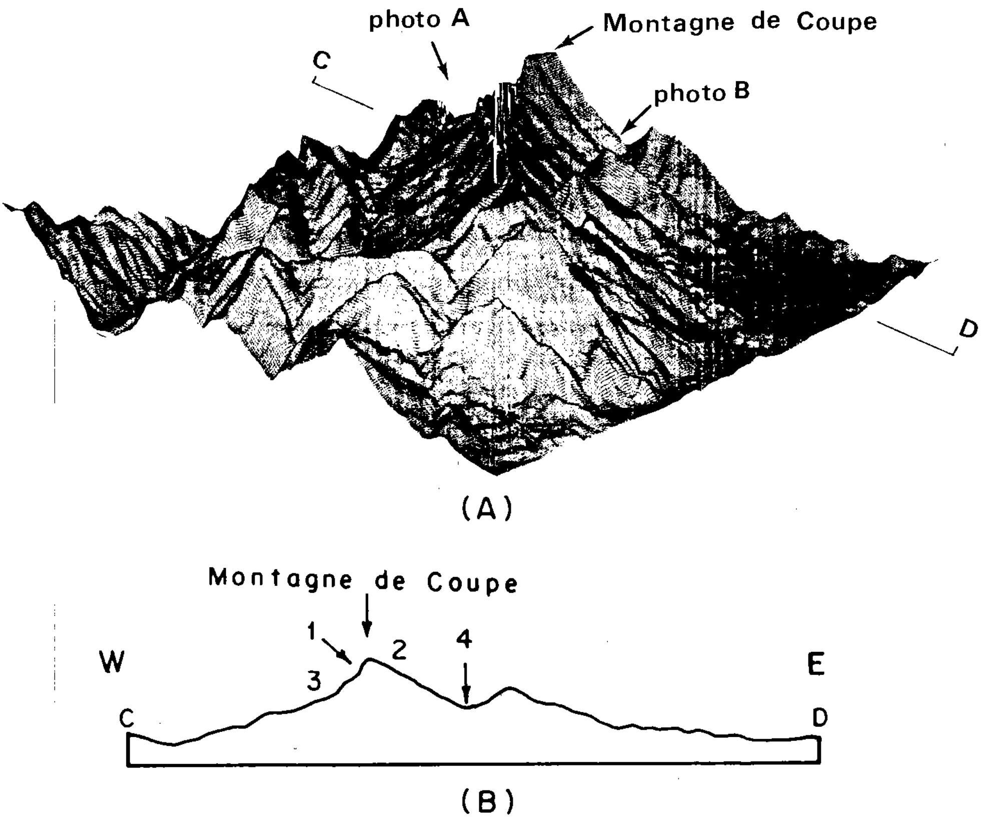
Several terms concerning variations in slope must be defined:

- rupture of slope: significant variation in ascendent or descendent slopes.
- change of slope: significant variation between ascendent and descendent slopes (or inverse case); crest, thalweg etc..
- constant slope: surface without significant variation in slope (horizontal or not).

(3-2-1) Observation of slopes in terrain and profile (DEM)

(a) Front: The principal lithologic contact is found at the bottom of the Kimmeridgian-

Portlandian limestones (j6-9, Montagne de Coupe), and is very visible in the profile of Fig. 7-B ('1'), because of significant variation in slope (rupture of slope). Below this abrupt, talus is well develped with unimportant variation in slope ('3' of Fig. 7-B). Other reptures of slope, which don't concern the morphology of the crest-type (ex: small ravins), are also observed on this talus. They must be distinguished with former case.



A: Block diagram (Norante area).

B: Profile obtained from DEM along the direction of CD.

1: principal lithologic contact between j2-5 and j6-9 (rupture of slope).

2: structural surface of j6-9 (constant slope).

3: talus (concave or convex form).

4: thalweg at the foot of '2' (contact between n2 and n3; change of slope).

Fig. 7. Analysis of variations in slope.

(b) Reverse: Structural surface of j6-9 with inclination toward the west, presents a slope without significant variation ('2' of Fig. 7-B: constant slope). The Barriasian and Valanginian formations (n1-2) affected by severe erosion, are laid on this surface without important modification of slope. It is difficult to observe the limit between these formations and j6-9 on the profile. A valley (change of slope) found at the bottom of this surface, corresponds to the limit between the Valanginian and the Hautervian ('4' of Fig. 7-B). A relief of the Hauterivian limestones appears as a cornice-form.

(3-2-2) Calculation of second derivative (z") and arrangement of them in five groups

In order to express the variations in slope by z", two limits of z" must be defined:

* $|a|$: high value (not maximum) of $|z''|$ for rupture($+|a|$) and change of slope ($-|a|$).
* $|b|$: the nearest value (not minimum) to zero for a surface without significant variation in slope (horizontal or not).

After the selection of these limits ($|a|$, $|b|$), the values of z" can be divided into the following five groups: $z'' \geqslant +|a|$, $z'' \leqslant -|a|$, $-|b| \leqslant z'' \leqslant +|b|$, $+|b| < z'' < +|a|$, $-|a| < z'' < -|b|$. The morphologic forms will be distinguished by these five groups on the profile:

(1) $z'' \geqslant +|a|$:

* rupture of slope in concave form (R),
* change of slope:
  – valley (V), limit of alluvium (A),
  – last (or first) point of horizontal surface in ascendent (or descendent) stair-type (I, J).

(2) $z'' \leqslant -|a|$:

* Sharp-pointed crest (S),
* two extremities of plateau (E),
* first (or last) point of horizontal surface in ascendent (or descendent) stair-type (M, D).

(3) $-|b| \leqslant z'' \leqslant +|b|$:

* horizontal surface in alluvium (A), plateau (E) and stair-type (M, D) etc.
* constant slope (P: not horizontal).

(4) $+|b| < z'' < +|a|$: concave form (N).

(5) $-|a| < z'' < -|b|$: convex form (X).

However, the biggest problem is the confusion of ruptures of slope (R) and valleys (V: significant change of slope)in the domain of $z'' \geqslant +|a|$. Also, the valleys and the limits of alluviums with unimportant variation in slope, are in the domains of (4) and (5). That is why these calculations will be superimposed with results obtained in (3-1) (recognition of crest and thalweg lines).

(3-2-3) Superimposition of calculation of z'' with the result obtained by recognition of crest and thalweg lines

For avoiding the complexity of superimposition (3-1-2, (b)), this process was carried out along each scanning direction (x, y) (Fig. 8). The confusion of forms (3-2-2) was resolved (see '*' of Fig. 8): ruptures of slope, thalwegs and alluviums.

The highest value of z'' in a position is more significant than the others in most cases. But, this result wasn't superimposed with the matrix of crests and thalwegs due to the problem mentioned in (3-1-2).

the domains of z''

crest and thalweg lines / z''	E	S	A	V	M	I	D	J	'•'	
$z'' \geq +\lvert a \rvert$			A*	V*		I		J		R*
$z'' \leq -\lvert a \rvert$	E				M		D			S
$-\lvert b \rvert \leq z'' \leq +\lvert b \rvert$	E		A*		M		D			P
$+\lvert b \rvert < z'' < +\lvert a \rvert$			A*	V*		I		J		N
$-\lvert a \rvert < z'' < -\lvert b \rvert$	E	S			M		D			X

- see Fig. 5 for the significances of characters (P: constant slope, N: concave, X: convex).
- a and b: two limits of z''.
- '*': distinction of ruptures of slope (R), thalwegs (V) and alluviums (A) from the domains of z''.

Fig. 8. Superimposition of calculation of z'' with the results obtained by recognition of crest and thalweg lines.

(3-2-4) Results and discussion

(a) Superimposition of results obtained from (3-1) and (3-2), allows us to understand simultaneously two important parameters (crests-thalwegs and variations in slope). However, this algorithm can't distinguish the rupture of slope concering crest ('1' of Fig. 7-B) from the others (ex: rupture of slope on the wall of valley). For this problem, the *chains of characters* (words) indicating this form, will be recognized in the next step. The red points on the Fig. 6-A represent the ruptures of slope in concave form.

Several ruptured levels are observed on the front (RR..; Fig. 10-A). This phenomenon is due to the variants of crest (or cuesta) and the selection of $\lvert a \rvert$.

(b) Two limits of z'' ($\lvert a \rvert$ and $\lvert b \rvert$): It ascertains that the good values are different in each studied zone. The higher values of $\lvert z'' \rvert$ are important for recognizing ruptures of slope, but it is also necessary to deal with the lower values which can offer us the information about lithologic traces. In Norante area, 0.01 (or 0.008: |a|) and 0.0003 (|b|) were good limits for recognizing the variations in slope.

(3-3) Automatic recognition of objects

That is the context of geomorphological elements which can permit geological translations. This context can be expressed by *chains of characters* (*words*) defining each case.

(3-3-1) Appreciation of the gathered information

The geomorphological forms recognized in (3-2), are only an alignment of toporgaphic elements on the profile. Each rupture of slope, crest and thalweg can include different geological information. A geological element corresponding to each case (see (3-2-1)), must be defined to automatically recognize the objects :

- ruptures of slope situated at abrupt breaks in crest and cuesta ('1' of Fig. 7-B): principal lithologic contact.
- thalwegs of a 'v'-type found at the foot of structural surface with steep inclination ('4' of Fig. 7-B): lithologic contact
- when the changes of slopes concern the bottom of valleys and are situated between a horizontal surface and a slope in any variation, we have a limit of alluvium.

(3-3-2) Principle

(a) Crest

The forms of crest were classified into three categories: typical case, variant and particular case.

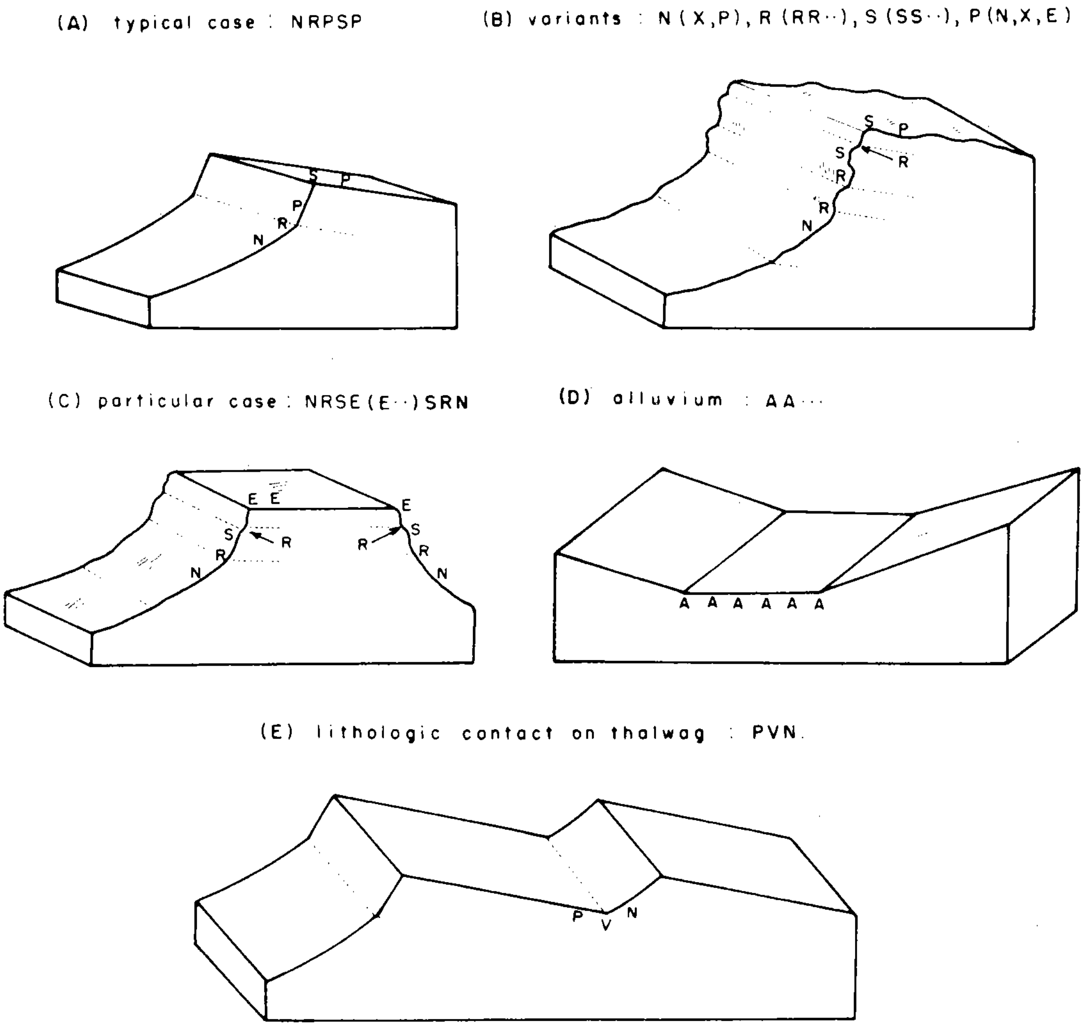
(a-1) Typical case (Fig. 9-A)

It has been already described in (2-2). This form can be expressed by a chain of characters such as *'NRPSP'*. For the significances of characters, see (3-2-2):

- N: talus in concave form,
- R: limit between talus and front (rupture of slope: lithologic cantact),
- P: zone of an abrupt front, but without significant variation in slope,
- S: crest (significant change of slope: litholigic trace of a hard formation),
- P: the beginning of reverse (inclined structural surface of a hard formation without significant variation in slope).

(a-2) Variants (Fig. 9-B)

The typical cases are seldom observed. The complex forms occupy most cases in the terrain:



— see Fig. 5 and 8 for the significances of characters.

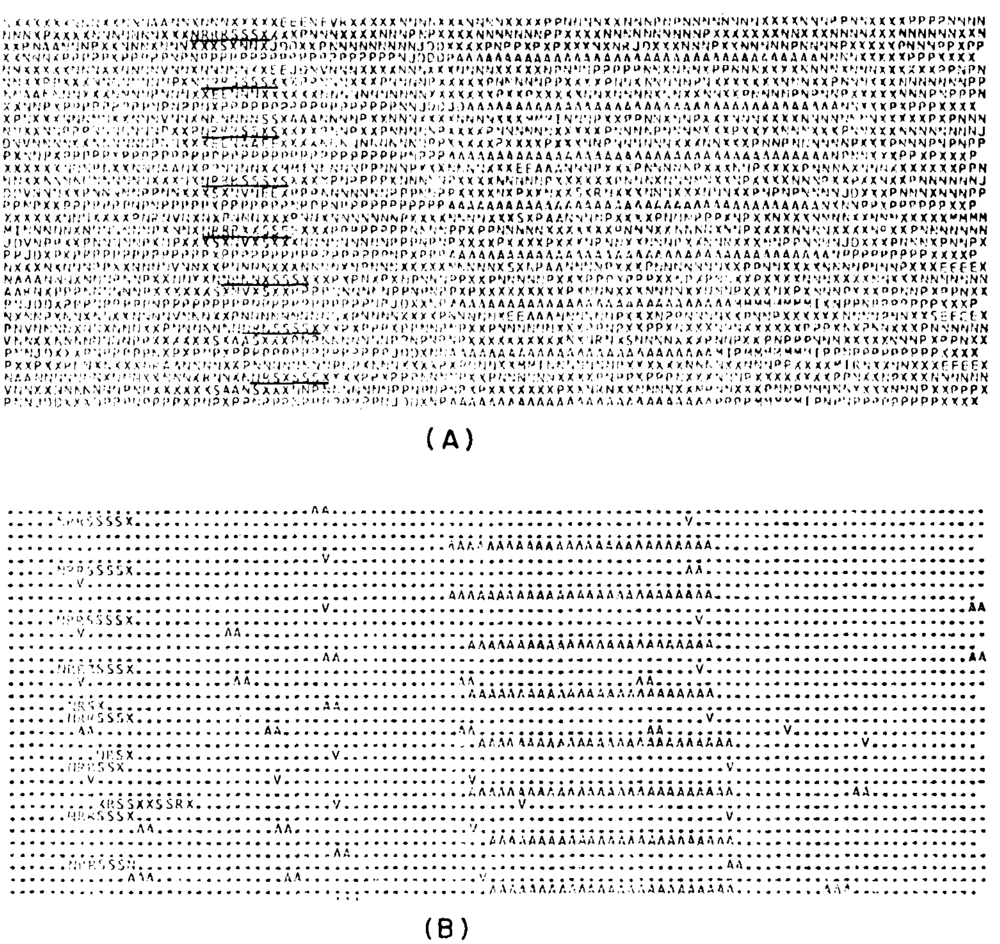
Fig. 9. Chains of characters (words).

(1) The crest contains several ruprured levels of slope in front ('RR...', see Fig. 10-A).

(2) 'S' form (sharp-pointed crest) can be inserted with an overhanging-form in the abrupt zone (third position (P) of (a-1)).

(3) Talus and structural surface present concave, convex and constant slope.

However, it is impossible to recognize all of them. They must be expressed by more frequent and gereral cases, and can be represented by a chain of characters such as *'N (or X, P), R (or RR..),*



A: results after the second step (analysis of variations in slope).
– underlined characters: crests (Montagne de coupe).
B: recognition of chains of characters.

Fig. 10. Results obtained from DEM (see Fig. 5 and 8 for the significances of characters).

S(or SS..), P (or N,X,E)':

- N (or X, P): Talus has some possibilities in the variation of slope.
- R (or RR..): one or several ruptured levels of slope.
- S (or SS..): one or several changes of slope (overhanging, crest).
- P (or N,X,E): The beginning of structural surface has some possibilities in the variation of slope.

In this category, the various types of typical case (a-1) were included: 'N (or X,P), R, P (or N,X), S, P (or X,N,E)'

(a-3) Particular case

* Residual hill(Fig. 9-C): It is a plateau, whose surface is the back of a hard formation, and whose two abrupt sides constitute two fronts of a crest. This form can be expressed by the chain such as 'N (or X,P), R (or RR..), S (or SS..), E (or EE..), S (or SS..), R (or RR..), N (or X,P)'. After the fourth character (E), this chain is continued by several 'E' (horizontal surface of plateau). Another front appears again in an abrupt form.

(b) Alluviums (Fig. 9-D)

Automatic recognition of alluviums has been already resolved in (3-2). In our algorithm, alluviums are presented by the characters of 'AAA...'. They include the limits and the horizontal surfaces of alluviums.

(c) Lithologic contact on thalweg (Fig. 9-E)

At the foot of structural surface with steep inclination, a thalweg is found in a 'v' form. The side of new formation appears as a concavity due to erosion. Theorically, a chain such as *'PVN'* is obtained. However, this form is confused with other thalwegs, because its profile presents a unimportant variation in slope except the position of 'V'. It is necessary to find a longer chain for indicating this particular case, or to add other data (the radiometric values of images).

(d) Algorithm

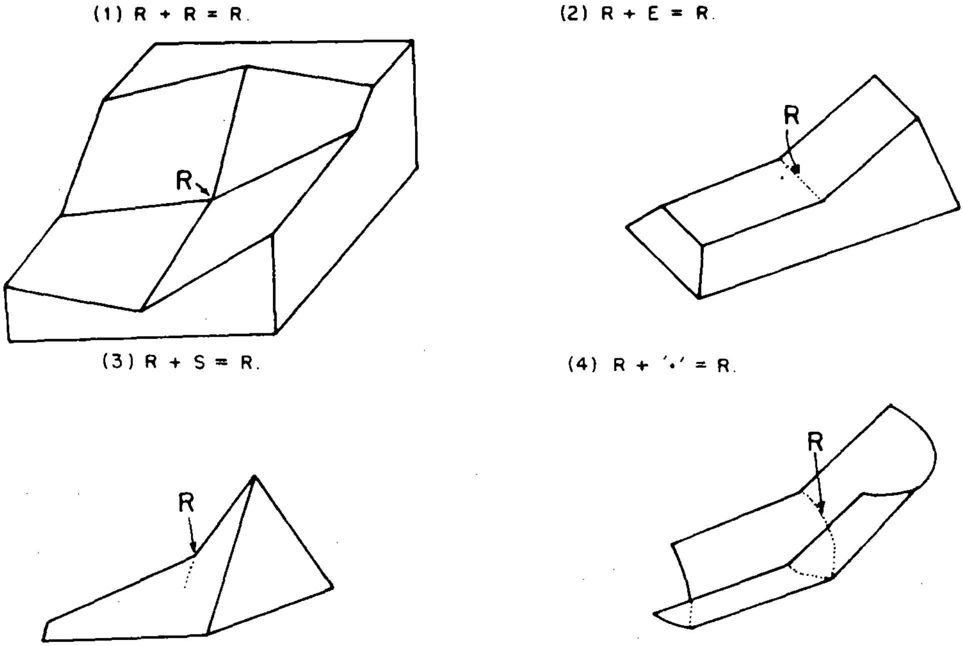
* On each profile of the results obtained in (3-2), groups of characters corresponding to each chain were searched. A test for recognizing the inverse cases (ex: 'PSRN') must be added. Fig. 10-B presents the final result obtained along the x-axis.

* Superimposition of the results obtained by scanning the axis of x and y: Three characters (R, S and E) in the chains constitute the elements of geological information (geological contact or lithologic trace), thus the other characters (N, X and P) are classified into the same group ('.') in order to simplify the process. The important operations are as follows:

- R+R = R (Fig. 11-1): intersection of ruptures in slope.
- R+E = R (Fig. 11-2)
- R+S = R (Fig. 11-3): line of crest with significant variation in the slope at position of 'R'.
- R+'.' (N, X, P) = R (Fig. 11-4): curve corresponding to ruptures of slope in concave form (R+N).

(3-3-3) Results and discussion

(a) Despite good representation of typical cases and variants, were lost in some particular cases: NRRNSXSP (see Fig. 10-A). The abrupt zone can have some variations in slope (concave or convex), and its size can't be recognized. These problems bring the appearance



R: rupture of slope, S: crest, E: plateau,
'.': concave, convex and constant slope.

Fig. 11. Final superimposition.

of very complexe variants of crests. Although, one or two cases were added in the algorithm, all of them couldn't be represented due to their intense variability.

(b) The lithologic contacts concering ruptures of slope (white points of Fig. 6-B), are good except in the southern part of the Norante area. This problem concerns the inprecision of source-data for calculation of DEM, due to forests and the discontinuities of terrain. The thalwegs situated on lithologic contacts could not be distinguished from other thalwegs, in spite of some attempts by different chains of characters, due to the simplicity of source-data (alititude).

(c) The final superimposition which was carried out by four elements (R,S,E,'.'), permits to avoid the complexity (3-1-2) of this operation.

(3-4) Combination of the obtained data with images

This process was effected to offer the better data for geological interpretation of images. For image processing, several classic methods were selected: colour composition, principal components analysis and stretching. Due to the absence of SPOT images, Landsat images were used for this work.

(3-4-1) Resampling by bi-cubic interpolation

After geometric correction of images, IGN did the resampling of pixels at a distance of 50m. In order to have the same distance as the grid of our DEM, we had to effect a new resampling (20m) from these images. The interpolation function is the following :

$$F(x*,\ y*) = f*(\&,\ \$,\ I*,\ j*) = \sum_{K=-2}^{+2} \sum_{L=-2}^{+2} y(I*+K,\ J*+L)\ T(\&-K)\ T(\$-K)$$

with

(x*, y*): indexes of lines and columns in final image,

(I*, J*) : indexes of lines and columns in initial image,

&, $: reduced variables of x and y,

T(x): spline function

$0 < |x| < 1 : T(x) = 1 - 2x^2 + |x|,$

$1 < |x| < 2 : T(x) = 4 - 8|x| + 5x^2 - |x|^3,$

$2 < |x| < \ : T(x) = 0.$

(3-4-2) Combination of the obtained data from DEM with images

Simultaneously scanning each Landsat image and our image created by the data obtained from DEM, a maximum value of grey (255 = white) was affected to the pixel of Landsat image, corresponding to the position of our data. Then, without the loss of initial parameters of Landsat images, a new colour composite image was fabricated. The data obtained from DEM, were completely saturated by the maximum value and appeared as white points on the new image (Fig. 6-B).

(3-4-3) Analysis of Spacelab images

Interpretation of these images was conducted to find out their geological validity. Images with good resolution (25m~30m) on the surface of terrain, were capable of offering geological and geomorphological information, but less detailed than aerial photographs. In Norante area, the analysis was sufficient for recognizing the fold in association with thrust movement in spite of important shades. If it is possible to extract DEM from Spacelab images, the automatic recognition of forms can supply more precise data for geological interpretation of images.

(3-4-4) Results and discussion

The important problem was a detection of the identical position of each pixel on two different images (Landsat and DEM). Three colour composite images, including the chains of characters (ruptures of slope concerning the crest, thalwegs and crests), were fabricated (Fig. 6-B), and can accelerate directly the interpretation of images recevied from space.

The types like (3-3-2-c), which were difficult to represent due to the absence of predominant characteristic of morphology, were recognized by the information from the images (reflectance and texture). If this information was added in our calculations, better results could be obtained from DEM. Although the resampling by bi-cubic interpolation fabricated good images in quality, the images have lost their clarity due to successive resampling.

(4) Conclusion

The application of DEM in geological domain has not played an important role. Now, along with SPOT and Landsat images with good resolution, DEM will become a important source for remote sensing, because it is directely obtained from space measures. The utilization of DEM is a new and important subject in geological study by remote sensing.

In the future, it will be necessary to *superimpose the techniques of image processing and the automatic recognition of forms by processing DEM.* It will permit obtaining automatically more precise information in geology and geomorphology, and a study of the terrain will confirm their validity.

Despite some difficulties in techniques of processing DEM, the automatic recognition of forms will furnish considerable data to geologists, and will constitute a systematic and automatic operation in the work of geological interpretation.

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