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QUANTITATIVE DESCRIPTION OF DENUDATION FORMS IN THE WESTERN AFRICAN SAHEL

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ABSTRACT

In Western African Sahel, the everlasting denudation of the soils is a danger for their productivity, more especially as bare light soils have often been over exploited by farming and pastoralism. Hence, these areas are threatened with degradation increased by the climatic variations. From remote sensing data , we study a set of desertification indicators. We experiment recurrent procedures that may allow the identification and measurement of parameters connected to these indicators, whatever origin the data may have. We shall apply these procedures to Landsat MSS data with two examples to explain the whole process:

. a description of bare areas around villages (degradation of cultivated areas due to permanent cropping) by estimation of their surface and by calculation of a set of shape parameters;

. the description of sand seas, by estimating the orientation of the bars and their repetitivity.

The employed algorithms run morphological transformations and measurements of predefined objects on the image. Their degree of generalization let us use them on images coming from different scenes and even different sensors.

OBJECTIVES

In this case, quantitative description means that we have defined and estimated parameters measuring the shapes of patterns on remote sensing datas; these patterns have been previously associated with some degradation features in semi-arid environment.

The study of natural environment and of the impact of human activities are not resolved, in this semi-arid environment, by the only spectral signature of objects. The problems of interpretation are related to the environmentcharacteristics; dynamics, related to meteorological and climatic changes, are very rapid and the details of the landscape features are not wellknown; the spectral channels are highly correlated; the landscape units are distinguished by low radiometric gradients; weak contrasts are still reduced, here in the Sahel, by frequent haze; hence, in this case more especially, the results of an interpretation cannot be directly reproduced from one image to another: other dates, other sensors, other scales...

Then in order to analyse thematic objects, in addition to the spectral answer, we use the concept of the shape of the objects as seen from the azimuthal point of view, the spectrum being an interface between the objects and their shapes.

On Earth, environmental determinisms (as climate, slopes, surface of soils...) and human impacts (as types of land use, factors of production and the different elements of the relationship between man and his environment) build the features of the landscape: the landscape units are interwined one with another , outlining more or less regular shapes. In some systematic examples, shape may become the indicator of the visible landscape unit: orthogonal limits of fields, dendritic hydrographic nets, irrigation features for instance.

In the Sahelian environment, some of these shapes are connected to landscape units threatened by desertification. We shall explain the examples for the two following reasons:

. they are significant of actual processes, that can be observed and measured in many countries in the sahel and the semi arid area in the world: the shape is significant of a process related to aridity; hence, measurements are highly useful;

. the apparently simple shape, resulting from complex processes, allows an easy and specific modelization.

The two following examples present the measurement with two types of parameters: surface measurements; orientation measurements. As the relationship between the objects on the field and their shape from an azimuthal point of view is identified by the thematician, the satellite data and parameterization of the shapes allow us to resolve the problems of shape extraction. In both cases we use the quantitative analysis of image: filtering by convolution, texture analysis and especially Mathematical Morphology. Objects are extracted by specific algorithms. Measurement parameters (surface, orientation) are defined by mathematical formulas, reproductible. The reproductibility has two advantages: the objectivation of results; and it makes currently possible to quantify the chronological evolution as a routine.

SURFACE MEASUREMENTS OF DENUDED CULTIVATED AREAS (GONDO PLAIN, REPUBLIC OF MALI)

Land use is organised equally in all directions around each village , drawing concentric circles:

. in the middle, the village: high trees, shadow of the walls, flat clay roofs; low level of radiance;

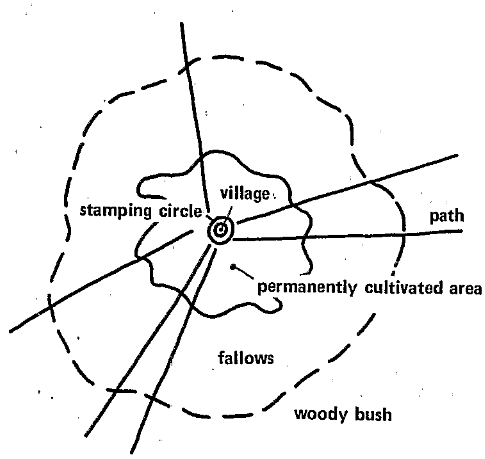
. a thin circle of permanent stamping (men and cattle paths) with quite bare sandy soil: very high radiance;

. the dense aureole of close fields, every year under cultivation and bare during the dry season, with scarce trees and shrubs: radiance is high;

. and also, an external area, more or less structured, more or less cultivated with fallow fields, where grassy and woody coverage is high; the spectral values are numerous and various, generally lower than in the previous circle.

The scheme below gives an idea of the morphological organization of these areas, the set of which makes up the "terrier" of each settlement.

The circle of permanently cultivated close fields is highly threatened by degradation because of the fanning of light organic elements during all the dry season; it is equally important to watch over the external area, as its internal border will probably get degraded.



On the scene presented as an example (Landsat MSS, 211.050, March 31, 1976) and on the other scenes we read, the theme "fields permanently under cultivation" is easily seen (high level of radiance, circular shape) but an obvious single thresholding cannot be achieved as it can be for the neighbouring themes. Estimation of its surface needs a specific analysis of spatial organization of pixel values to be done. Such an analysis is based on the tools of Mathematical Morphology. The following algorithm shows the sequence of procedures that leads to a quantitative description and to a classification of the circles.

First principal component

↓

Identification of the common center of the circles

↓

<u>Dilation</u> by isotropic and increasing structuring elements

↓

Reckoning of the mean value inside each dilation ring

↓

Graphs of the resulting values according to the radius of <u>dilation</u>

↙ ↘

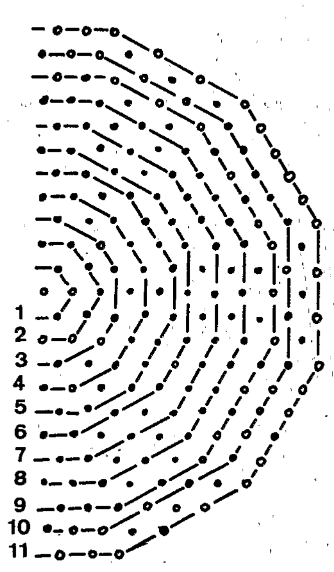
Quantitative description of the graph → descriptive parameters of the circle

Classification of the graphs → Classification of types of circles

The steps of the procedure are the following:

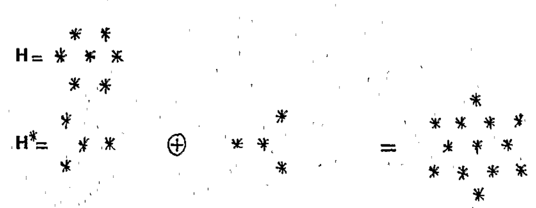
1. Identification of the center of the circles: on interactive terminal, the coordinates of a center are identified with a cursor and memorized in a binary image.

2. Successive dilations of this mask with isotropic structuring éléments: the basic lattice is hexagonal; hence, the structuring elements are hexagons. When the radius is increasing, the hexagon looks more and more like a circle, so it can be replaced by a dodecagon (fig. 1).



The ordinary dodecagon has the following form:

$D_i = nH \oplus n^* H^*$



To obtain the following one, one has to calculate:

$$\alpha = \frac{(n+1)(n-1)}{3n^*(n^*+1)}$$

If $\alpha \leqslant 1$, then $D_{i+1} = (n\ \ 1)\, H \oplus n^* H^*$

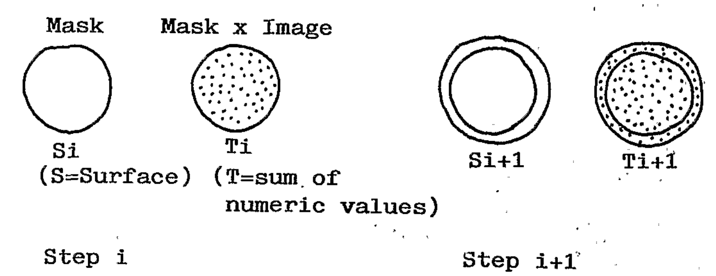
but, $D_{i+1} = (n\ \ 1)\, H \oplus (n^*+1)\, H^*$

i	1	2	3	4	5	6	7	8	9	10	
n	11	2	1	2	3	2	3	4	5	4	
n*	0	0	1	1	1	2	2	2	2	3	
S	7	19	31	55	85	109	151	199	253	295	etc.

This sequence cannot be used for a granulometry. For instance: D6 is not open by D5, one has to take one dodecagone out of two from i=4.

Fig. 1. Sequence of dodecagons

3. Computation of the mean values inside each dilation ring:



$$M(i+1) = \frac{Ti+1-Ti}{Si+1-Si}$$

For each village, it gives a graph of 40 points.

4. Hierarchical classification tree: the correlation between all these graphs is computed. After descending hierarchical classification, one can notice a discrimination between North and South: the circles of the northern villages are thinner and more reflectant than the southern ones.

5. Direct measures on the graphs:
. abscissa and ordinate of the maximum,
. width of the lobe at a given height,
. slope from a given distance.

This whole procedure is founded on the estimation of the distance from a center: it is specific of a description of a simple concentric circular system.

We have experimented two other procedures, that can be used for geometrically more complex systems.

In one of these, we suppose there is a dimensional discontinuity between the dense circle of permanently cultivated fields and the small scattered cultivated areas in the external circle (fig. 2).

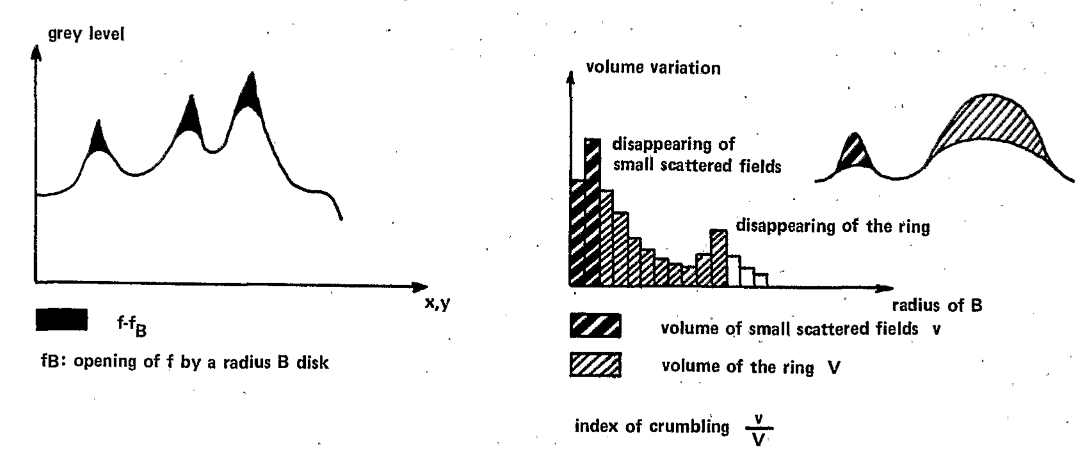


Fig. 2. Grey level granulometry

The other procedure is founded on the compacity of the shapes outlined by close grey levels: for each grey level; a compacity index of the corresponding binary image is estimated (surface of the Opening / surface of the Closing): the function shows a single relative maximum, that gives us an estimation of the perimetric measure of the "close cultivated area" set.

The development of models applied to denudation process measurements and their application to chronological series of images can then give us useful informations in order to control the potential of production, at the local and regional levels.

MEASURES OF ORIENTATION OF SAND-HILL BARS
(NORTH OF LAKE FAGUIBINE, REPUBLIC OF MALI)

Our objective is to estimate the modifications in the orientations of the sand-hills in the northern area of the lake, in order to find a relation between the differences in their structure and the hypothesis on their genesis.

In the north-eastern part of this region, sand hills are organized as long regular bars, approximatly oriented NE-SW, with a coverage of grass and scarce shrubs in the dune valleys and the marks of an ancient hydric erosion. In the South West, this structure becomes irregular, oriented E-W, with deeper gullies.

The basic image is a MSS Landsat, 212.048, May 10, 1982.

In order to study the transformation of the sand-hill structure, we shall select eight samples having the same size (300 pixels x 300 pixels), regularly set along a NE-SW axis, and on which we have processed the same numerical treatments.

The processed image is, in any case, the image of the eight directions achieved by a Gabarit filtering on the first principal component given by the four MSS bands (fig. 3): this image has eight different shades of grey, each shade being the code of the highest local gradient direction calculated inside a 3 x 3 window by the Gabarit method (from /3/).

Two types of treatment have been processed:

- statistical treatments on the eight directions of every sample
- treatments using Mathematical Morphology methods.

The aim of these two different sets of treatments is to estimate principal and secondary directions in order to compare the samples (called A, B, C..H).

Statistical analysis

The first basic treatment consists in working out the distributions of the eight directions in each sample (fig. 4, samples A and B). This analysis is completed by two proceedings estimating the regularity of the directions inside each sample. They consist in comparing statistics on two successive concentric windows:

- the calculation of the Chi 2 distance between two successive windows Fn and Fn +1 described by the variable "direction" obtained through the Gabarit filtering:

$$\text{Khi 2 } (F_n, F_{n+1}) = \sum_{j=1}^{8} \frac{1}{f_{j.}} \left[\frac{f_{nj}}{f_{n.}} - \frac{f_{n+1j}}{f_{n+1.}} \right]^2 \qquad f_{j.} = \sum_{n=1}^{NF} f_{nj} \qquad f_{n.} = \sum_{n=1}^{8} f_{nj}$$

(NF = total number of windows)

- the calculation of the number of permutations of the order of the frequencies of the directions between Fn and Fn+1.

The parameters describing these samples are given by summing up the 150 values of Chi 2 an Permutations relatives to the 150 successive concentric windows. The results relative to the eight samples are shown on the following table, but we will only comment the two first sets: A and B.

TABLE 1 Indexes of directions regularity

Samples	Chi 2	Number of permutations
A	0,0001324	133
B	0,0001055	241
C	0,0001245	170
D	0,0003169	102
E	0,0002144	120
F	0,0001858	127
G	0,0004412	167

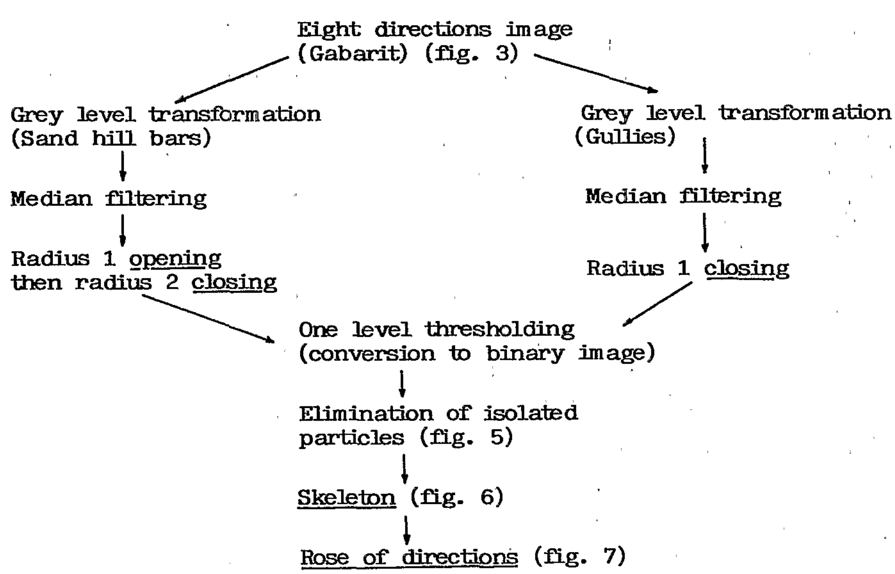
The two variables Chi 2 and Permutation, measured on the samples, are not correlated. The results on the sample B are typical, it has the lower Chi 2 and the higher number of permutations. It can be explained both by the high number of changes in the local gradient direction in the southern part of the image (fig. 3) and by the regularity of the frequency of the changes in the same area. The values of the two variables Chi 2 and Permutation indicate both the high number of permutations in the order of the frequencies of directions between two successive windows and the low level of variations between the two distributions of these windows.

Since the objects in the example A are seen as more regularly and more continuously structured, the Chi 2 is higher than in the sample B: the regularity of the shapes does not produce such a high regularity in local gradient changes. The number of permutations, which is very much lower than B, is explained by the main importance of a single orientation on the whole sample.

The analysis of the directional gradients repartition in the windows gives us unidimensional parameters; however, it does not allow the perturbations of directions to be located inside the image: this is the subject of present development; moreover, the shape is reached here only through a local orientation (the local gradient) at the level of each pixel. For this reason, we made measurements starting with the extraction of the shapes (sand-hill bars, gullies) achieved by morphological transformations.

Morphological transformations

Algorithms are applied to the same image of eight directions as above. We made separate filterings for the main structure (the bars) and for the gullies, in order to estimate the importance of each direction and to compare samples to each others: the use of two different algorithms, one for extraction and measurement of gullies, one for extraction and measurement of bars, is here justified by the difference of significant grey level of each theme.



As the estimation of the order of directions is precisely the object of our research, we choose an isotropic structuring element to prevent any a priori about the anisotropy of the image. With the rose of directions method (from /1/) we can parameter 12 directions in place of 8.

In the sample B, with the Gabarit filtering and the Mathematic Morphology in grey level technic, we can schematize a shape represented by a set of consequent grey levels and we can study separately each directional structure.

About the three images presented in fig. 7 (A bars, B bars and B gullies), all the South component directions are very low: the screen of the directions is more evident here than in the upper statistic method above.

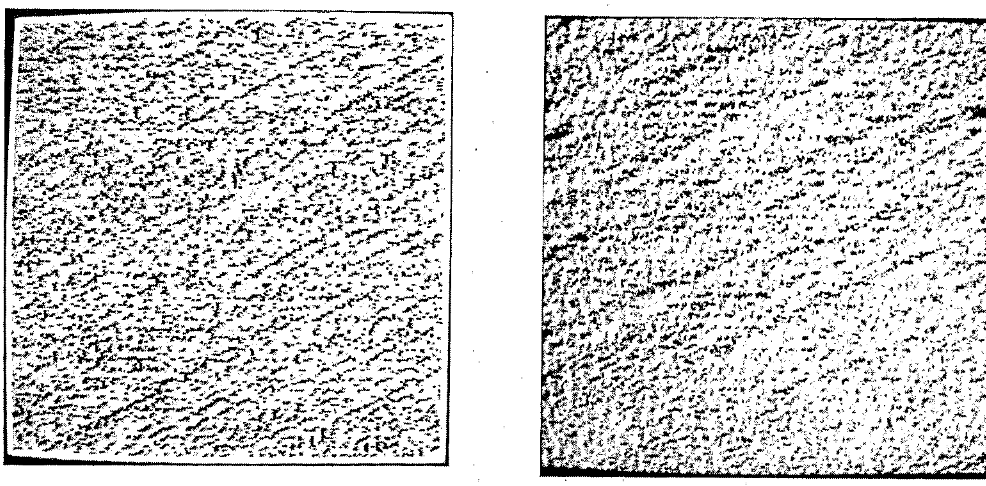


Fig.3. Two images Gabarit Directions:
samples A (left) and B (right)

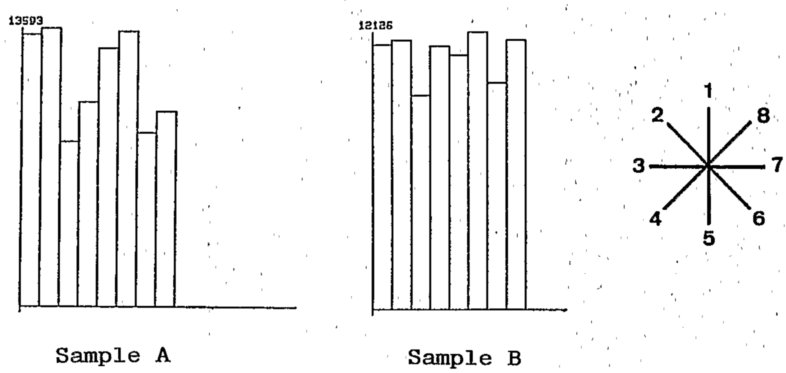


Fig.4. Histogram of directions

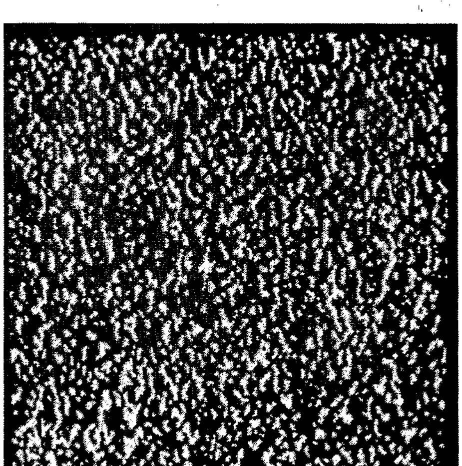


Fig.5. Binary and clean image:
sample B gullies

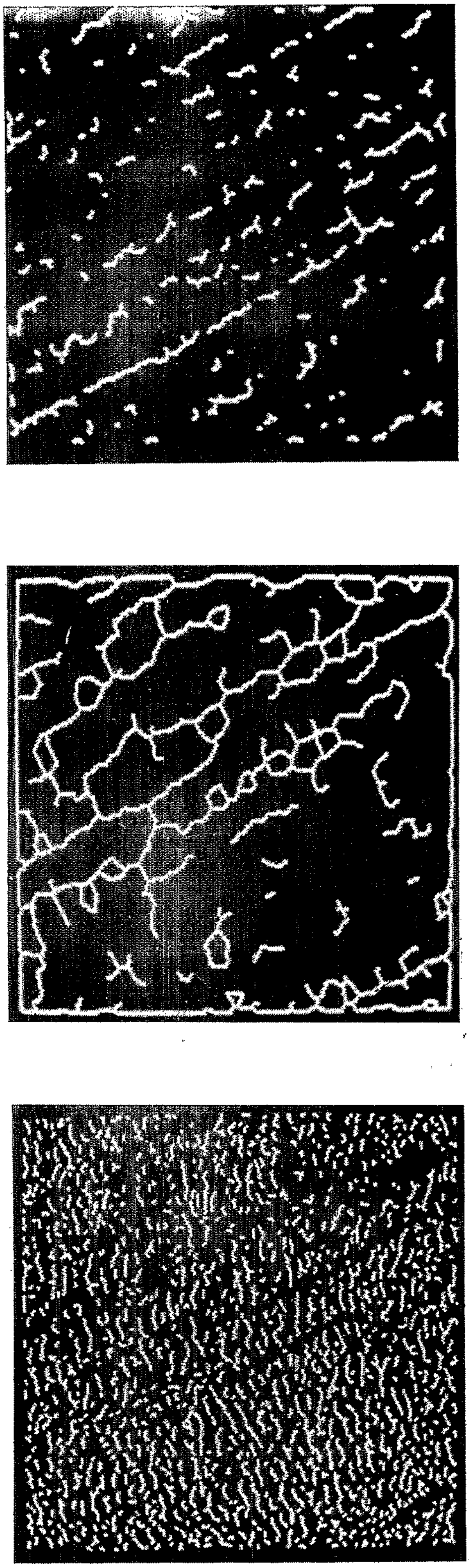


Fig.6. Skeleton: three samples
A bars, B bars B gullies

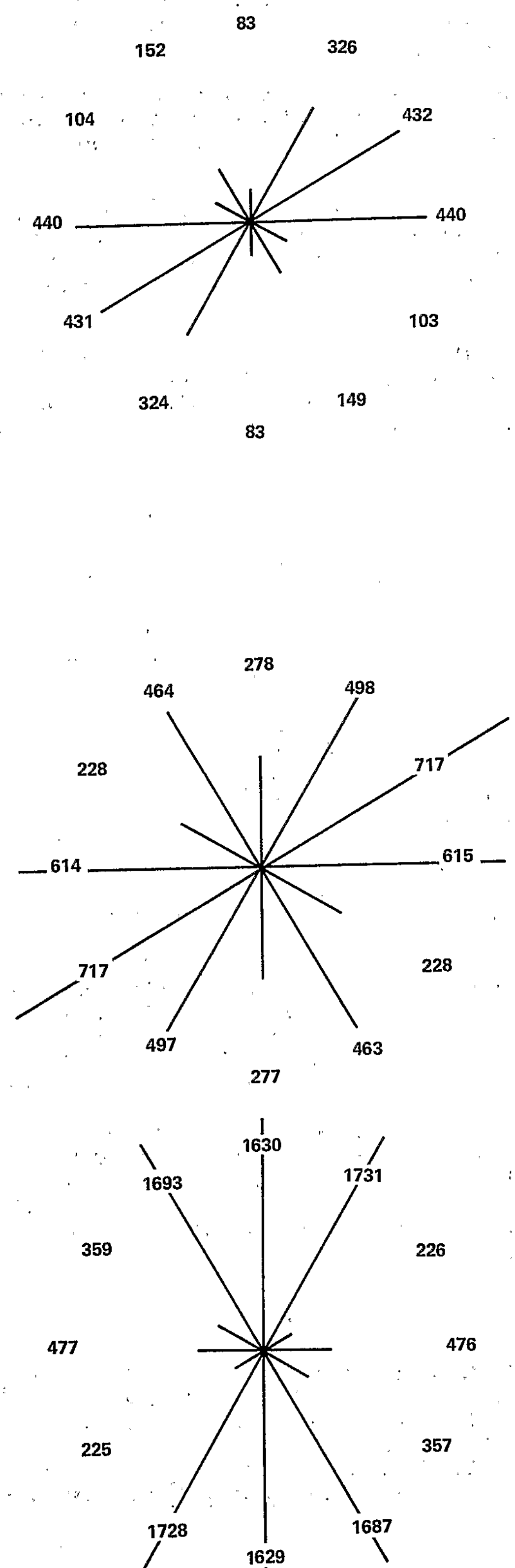


Fig.7. Three roses of directions
A bars B bars B gullies

We compare now the rose A bars to the rose B bars; then the rose A gullies to the rose B gullies. In A bars and B bars, the same directions (E and ENE) are the most frequent; in A gullies and B gullies, the directions N, NNW and NNE are more frequent.

Hence, we have given rise to a 12 levels variable, which allows a quantitative characterization of the structure anisotropy: we consider this characterization as a signature of the extracted structure.

After having applied this algorithm to the eight previous samples, we obtain comparable measurements on the directions of the shapes extracted from the image. The only transformations we should eventually reconsider are the grey level transformations and their final thresholding, which suppose of the operator a personnal decision in every case. But the "elimination of isolated particles" operation, followed by the "skeleton" operation presents the benefit that an operator's choice is not required.

In the same time, we experimented with a technique used in material sciences /1/, isolation of particles on the image, then calculation of the skeleton by zone of influence or Skiz (from /4/). In that case, the original image is the outline from Gabarit filtering (not, as used above, the directions image). We use the following algorithm:

Radius 1 dilation

↓

Thresholding

↓

Skeleton by zone of influence (Skiz)

This process presents the advantage to be short and to require only one operator's decision: the thresholding; however, its automatization, which will allow comparison of results of the whole set of samples, would apparently depend on (for instance) a settled number of particles obtained at the thresholding step: the experiment is now to be done.

Radiometric signal processings as bi-dimensionnal Fourier Transform have been experimented by our staff (from /2/) in order to study sand-hills structures and to measure directions. In the present example, the direction calculation implies an image interpretation by the operator, on the contrary of the bi-dimensionnal Fourier Transform, which does not require any choice during the operation. But as the maximal energy spectra from a Fourier Transform on single sub-linear structured images can easily be taken for principal directions, there is a higher chance to misinterpret them in the case of various structures here presented. Besides, it shall be necessary to make further researches on the unicity of grey level transformations and of the thresholding, which allows the extraction of the objects: sand-hill bars, gullies.

With above processes, precise measurements on landscape shapes and structures are made possible: then very precise and detailed comparisons become equally possible, allowing to find a relationship between the very same structures or to estimate little changes in a given structure. Moreover, the parameters we obtain, based on Earth images, can be related to other analytic measurements about the same objects, the same phenomena.

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(translated from french by the authors)