INT. J. REMOTE SENSING, 1988, VOL. 9, NO. 6, 1175–1183

Ridge and valley line extraction from digital terrain models

SERGE RIAZANOFF

Cisi Ingenierie, DGLA, 20 rue Saarinen, Silic 232, 94578
Rungis cedex and Laboratoire de Minéralogie-Cristallographie (CNRS),
Tour 16, Universités Paris VI et Paris VII, 4 place Jussieu, 75252 Paris, France.

BERNARD CERVELLE

Laboratoire de Minéralogie-Cristallographie (CNRS), Tour 16,
Universités Paris VI et Paris VII, 4 place Jussieu, 75252 Paris, France.

and JEAN CHOROWICZ

Laboratoire de Géologie Structurale (CNRS), Tour 26, Université Paris VI,
4 place Jussieu, 75252 Paris, France.

(Received 11 December 1987; in final form 2 March 1988)

Abstract. A new method for ridge and valley line extraction from digital images has been developed. This method is based on lines drawn by moving under *logical constraints* in the image, starting from previously *selected points*. Compared to classical statistical processing, this approach, which we term 'structuralist', leads to results that allow a better understanding of image topography. Three algorithms based on this dynamic method are presented and applied to a digital elevation model.

1. Introduction

Ridge and valley line extraction from digital terrain models is of both methodological and thematic interest.

(1) Methodological, since the methods employed to extract ridge lines may often be re-used to extract edges or edge components (Haralick 1984) since the edges are the ridges of the gradient image, and
(2) thematic, since line extraction results in the expression of drainage or ridge-line patterns that are closely correlated with lithology, structural geology and geomorphology.

Stereoscopic images acquired by the HRV sensor on board the SPOT satellite are now used to generate digital elevation models. The automatic extraction of ridge and valley lines will provide additional data for the geological and geomorphological analysis of these images.

The procedures described in this paper are applied to a digital elevation model (figure 1) of a region located south-east of Digne (French Alps). The main structure, with NW–SE orientation, is called the 'Montagne de Coupe'.

To remain concise, reference is essentially made to the concept of a ridge. The concept of a valley is complementary to this and may easily be deduced from it. The method used until now has been *statistical* and concerned with each pixel in the image, irrespective of the results obtained through examination of the preceding pixel.

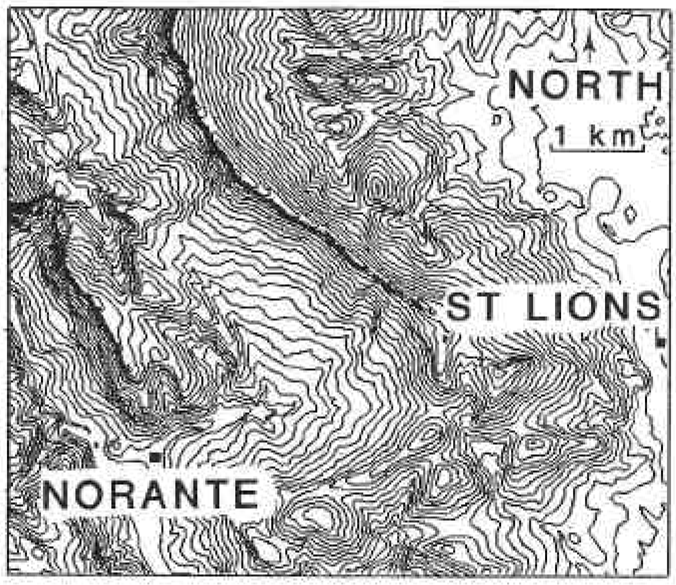

Figure 1. Digital elevation model of the Montagne de Coupe, south-east of Digne (French Alps). Contours at 30 metre intervals.

In this statistical method, if point P fulfills the qualifications for a specific relationship with its surroundings, it is then termed a 'ridge-point'. The surface may be analysed by using either a continuous (Haralick 1983, 1984, Haralick *et al.* 1985) or a discontinuous (Chorowicz *et al.* 1988) model.

1.1. *Use of a continuous model*

Haralick (1983) supposed that, in a window (3*3, 5*5, ...) expressing the neighbourhood of each pixel, discrete distribution is a sample of real values of a continuous function over this neighbourhood. He describes his method to obtain a ridge-point thus; "search for the direction along which the second derivative is negative and minimum; if, following this direction, the first derivative approaches value 0, a 'ridge-point' has been detected."

1.2. *Discontinuous analysis*

In a neighbourhood 3*3, points indicating a convex slope inversion in one of the four directions N–S, NW–SE, E–W or NE–SW are considered ridge-points. The slope is the difference between the central pixel and the neighbouring pixel under study. Ridge-points may also be defined as the convex location of significant variation in the direction of the steepest slope. We illustrate the results of this slope inversion method for ridge-points (figure 2 (*a*)) and 'valley-points' (figure 2 (*b*)).

Consideration of individual ridge-points irrespective of each other disregards the notion of a 'ridge-*line*'. With such statistical methods, if the image is conducive to doing so, a collection of ridge-points might possibly form the desired ridge-lines. Nevertheless, the network thus extracted is basically disconnected and the segments are measurably thick (figure 2).

This is the reason which prompts us to propose a dynamic approach, which we term 'structuralist'. Three algorithms are discussed and applied to the digital elevation model (figure 1).

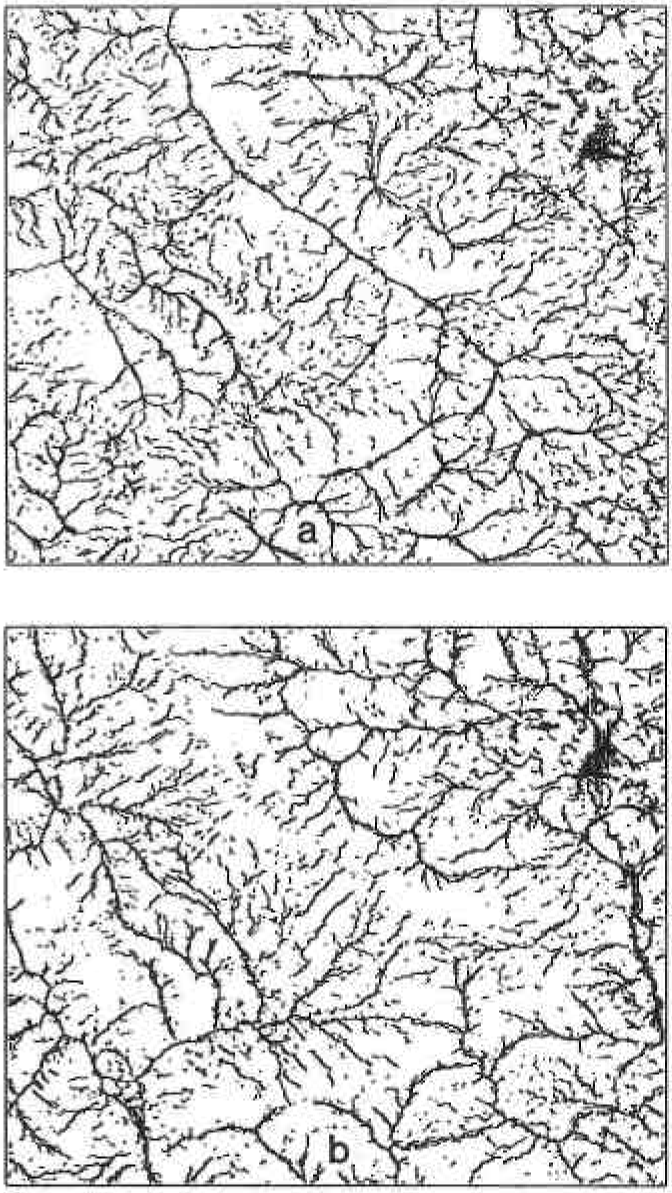

Figure 2. Results obtained using the slope inversion method ('statistical' method). (*a*) Ridges—convex slope inversion. (*b*) Valleys—concave slope inversion.

2. Structuralist approach

2.1. *Definitions and method*

Since there is no simple definition, in mathematical terms (Dufour and Abgrall 1983) of valley- and ridge-*lines*, the computerized method devised in this work was inspired by the physical model of water streaming over a terrain. A valley is first defined as a 'concave location of water convergence'. A ridge is defined conversely as a 'convex location of anti-streaming convergence'. Ridges and valleys intersect in singular points which we term 'saddle points'. Dufour and Abgrall (1983) attribute crucial importance to these points ('cols') which is borne out by our results illustrating their vital role.

Other points may also be considered singular. A partial enumeration would include local maxima, local minima, high points (local maxima of a concave zone), low points (local minima of a convex zone) and so forth. These definitions apply to a given neighbourhood; we have chosen a $3*3$ window centred on the pixel under study.

We define all paths by the joint data for a 'couple' consisting of a 'selected point' and a 'progress constraint'.

(1) A selected point is one of those described above as singular (saddle point, local maximum, etc.). They are typically collected during one pass over the entire digital terrain model in order to form the set of selected points.
(2) A progress constraint is defined as a function which associates a 'candidate', its 8 neighbour points and its 'father' (direction from which it comes) with a series of 'sons' (directions of progress). A candidate is part of the path if, and only if, it has sons, each of which then becomes a candidate in turn, and so on.

The resulting image is the set of paths obtained.

For each path, construction comes to a halt (*a*) if the path extends beyond the image frame, (*b*) if the path joins another path already marked or (*c*) if the candidate under consideration has no more sons (e.g. for a 'descend' progress constraint, the candidate is a local minimum, ruling out further descent). For each path, there is a corresponding selected point. The first candidate is the selected point itself. A search for this particular candidate's sons can be carried out by applying only the progress constraint since, by definition, the initial candidate has no father. The list of sons for the selected point must thus initiate with an appropriate function which we term 'initial progress constraint'. The precision of this function is of little importance, as 'water always returns to its bed'. One may retain, for example, the 8 neighbours of the point selected as the son.

We illustrate the results by pairs of images corresponding to ridges (*a*) and valleys (*b*) respectively (figures 3, 4 and 5). We shall now define three different algorithms based on our structuralist method. For each one, we give the ridge processing. Inverting the algorithm (e.g. descent rather than ascent, ...) yields the picture of the valleys.

It should be noted that binary (black and white) representation conceals the fact that each point marked is labelled by the selected point from which it emanates. Thus, each line constitutes an observable entity.

2.2. *'Streaming' algorithm* (*figure* 3)

The progress constraint used is 'climb along the steepest slope'. Therefore, the neighbouring point (or points in the case of identical data value) which is the highest with respect to the central point will be picked up, since it represents the greatest altitude difference with respect to the distance.

The selected points are the 'saddle points'. A saddle point is a point P which displays in its neighbourhood at least two groups of contiguous points located lower than itself, as well as two groups located higher than itself. For instance

	$+\,+\,-$	$+\,+\,-$
$+$ Points higher than P	$-\,P\,-$	$-\,P\,+$
$-$ Points lower than P	$-\,+\,+$	$+\,-\,+$

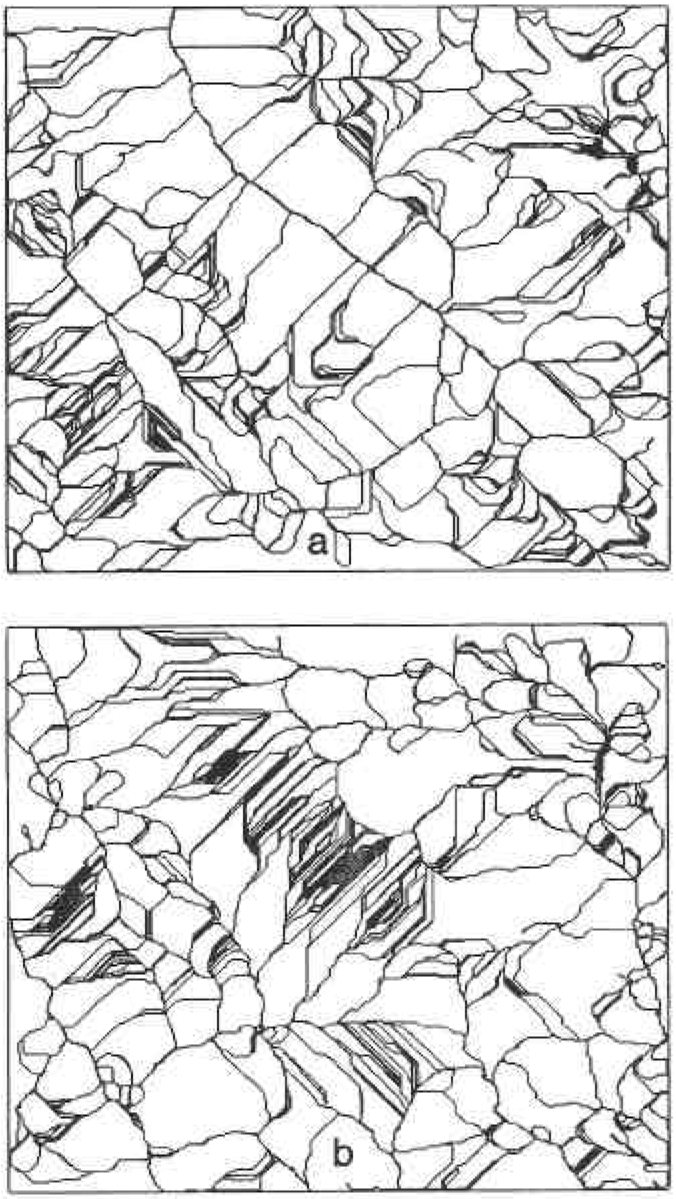

Figure 3. Results obtained using 'streaming' algorithm. (*a*) Ridge-lines—"climb along the steepest slope, starting from saddle points". (*b*) Valley-lines—"descend along the steepest slope, starting from saddle points".

Almost all the ridges and valleys we were able to survey elsewhere by hand-picking can be reconstructed using this algorithm (figure 3). However, we believe this network is too dense. In figure 3 (*a*) compared with the ground information, lines emanating from low-altitude saddle points are far less meaningful than those emanating from mid- or high-altitude saddle points. This phenomenon is particularly evident in the inverted image (figure 3 (*b*)) where all the high-altitude saddle points in the Montagne de Coupe produce noise ('noise line' cutting across the mountain).

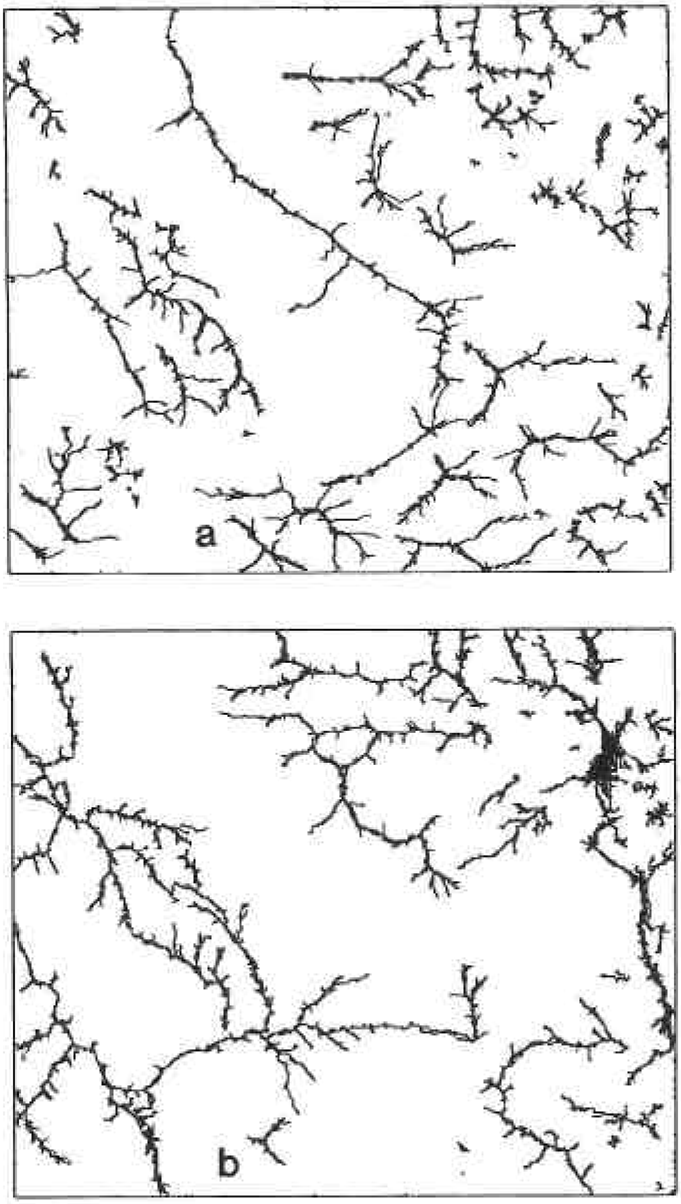

Figure 4. Results obtained using 'walker' algorithm. (*a*) Ridge-lines—"descend along ridge points, starting from local maxima". (*b*) Valley-lines—"climb along valley points, starting from local minima".

2.3. *'Walker' algorithm (figure 4)*

This algorithm represents a compromise between statistical and structuralist approaches. We define it here for ridge extraction (figure 4 (*a*)).

The selected points are the local maxima. The progress constraint is 'descend toward points displaying a convex slope inversion in one of the three directions' (the four directions listed above, less that of the father). If a slope inversion is detected, all

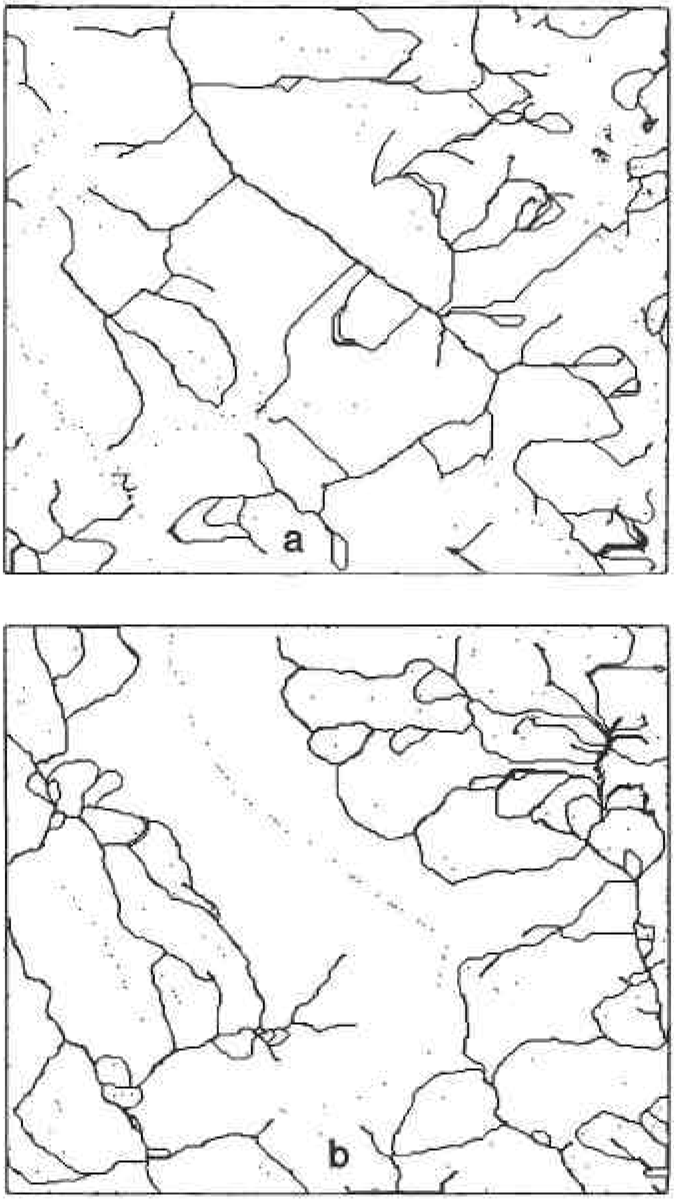

Figure 5. Results obtained using 'main saddle points' algorithm. Isolated points are marked saddle points. (*a*) Main ridge-lines—"climb along the steepest slope, starting from saddle points unmarked by the network in figure 4(*b*)". (*b*) Main valley-lines—"descend along the steepest slope, starting from saddle points unmarked by the network in figure 4(*a*)".

points lower than the central point and located beyond the isocurve passing through the central point, will be sons of the candidate.

Processing these data enables one to survey the main structures (figure 4). Unfortunately, it is very sensitive to noise since a slight disconnection can rule out examining structures downstream.

2.4. '*Main saddle points*' *algorithm* (*figure* 5)

The idea here is to overlap information from the two preceding algorithms so as to extract the selected points likely to 'sire' significant lines. The following is a description of the extraction principle for main ridges (figure 5 (*a*)).

The selected points are the 'unmarked saddle points'.

The progress constraint is 'climb along the steepest slope'.

'Unmarked saddle points' are all the saddle points which do not belong to the marker network (figure 4 (*b*)). The marker network corresponds to upstream movement, starting from local minima, over valleys. In actual fact, a saddle point located at the very end of a network branch is not to be marked. Unselected saddle points (i.e. marked saddle points) are shown on the image (figure 5 (*a*)) by isolated points.

The main ridges are clearly illustrated (figure 5 (*a*)). On a larger scale, one should be able to use this method to determine the borders of drainage basins. It is, however, possible to note certain excessive connections which may be attributed to scattering of the marker network (figure 4 (*b*)).

The result of figure 5 (*b*) is quite interesting since it produces a segmented image corresponding to the main massifs and hills. In a way, it indicates the natural access to the region.

3. Conclusions

The procedures implemented in this study are entirely computerized and yield unique results. In particular, the connectivity highlighted by the networks thus obtained constitutes a new development. The choice between the three procedures depends on the type of application. On one hand, the geologist would prefer the 'streaming' algorithm, since it results in more information on lithology and structural geology. On the other hand, the 'walker' algorithm, which allows one to survey the main running water patterns, would probably be selected for hydrological purposes. Lastly, the 'main saddle points' algorithm would be preferable for land management, such as road-making projects, since it indicates the natural entrance paths to a region.

To improve the algorithm performances, it would be necessary to make a choice among the selected points. For this purpose, we intend to either refine their definition (Depraetere 1987, proposes a more specific classification of saddle points) or sort them according to a given criteria, such as altitude, and determine a threshold.

The algorithms presented in this paper may then be considered as the first step of a more complex process of pattern recognition in geology and geomorphology. Among the many possible offshoots of this study, it would appear that this dynamic extraction of characteristic lines allows for a new quantitative approach. For instance, it will thus be possible to measure parameters, such as line density, to establish objective criteria enabling one to characterize rock types or geological structural patterns.

References

CHOROWICZ, J., KIM, J., MANOUSSIS, S., RUDANT, J. P., FOIN, P., and VEILLET, I., 1988, Contribution to geological and geomorphological mapping by remote sensing using pattern recognition. *Remote Sensing of Environment* (in the press).

DEPRAETERE, C., 1987, Exemples d'analyse géomorphométriques dans les Appalaches à partir des Modèles Numériques de Terrain. *Physio-Géo*, **17**, 49–76.

DUFOUR, H. M., and ABGRALL, F., 1983, Elements remarquables du relief. Définitions numériques utilisables. *Bulletin du Comité Français de Cartographie*, fascicule 95, **1**, 57–79.

HARALICK, R. M., 1983, Ridges and valleys on digital images. *Computer Vision Graphics and Image Processing*, **22,** 28–38.

HARALICK, R. M., 1984, Digital step edges from zero crossing of second directional derivatives. *I.E.E.E. Transactions on Pattern Analysis and Machine Intelligence*, **6,** 58–68.

HARALICK, R. M., WANG, S., SHAPIRO, L. G., and CAMPBELL, J. E., 1985, Extraction of drainage networks by using the consistent labelling Technique. *Remote Sensing of Environment*, **18,** 163–175.