Mathematical Morphology: A Tool for Automated GIS Data Acquisition from Scanned Thematic Maps

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ABSTRACT: Over several years, the demand for digital data has grown as geographical information systems were implemented. Because of the cost of database creation, data acquisition should unquestionably be automated as much as possible. Today, scanning devices produce a huge amount of data that still needs complex processing. This paper proposes an original approach using image processing tools coming from Mathematical Morphology theory to acquire GIS data from scanned thematic maps. These tools are used in order to obtain a segmentation prior to radiometric analysis. To illustrate the methodology, a subset of the Belgian soil map is treated.

INTRODUCTION

DURING THE LAST FIFTEEN YEARS, dramatic growth in the use of geographical information systems (GIS) occurred in many disciplines. This technology provides multipurpose land information systems as a means of dealing with the land records modernization problem. Natural resources modeling and management also benefit greatly from this technology by integrating a tremendous amount of data.

By far, data capture is the most expensive task in a GIS application. To make full use of GIS capabilities, accurate and up-to-date information must be provided. The usual method of acquiring data from existing maps is by manually following lines on a digitizing table. Though advertising brochures usually show an operator happily at work, this method is actually a very tedious and boring operation with a high probability of errors due to either duplicating or omitting information (Doyle, 1978). To overcome this predicament, techniques for automated and semi-automated data capture have been developed during the past several years.

Two major "automated" processes being used today for data acquisition are line following and map scanning. Line following techniques are used for digitizing lines such as stream networks or contour lines while map scanning allows the extraction of point, line, and surface information. A recent opinion of map scanning (Faust, 1987) stated that "the existing multistep-interactive procedure for creating point, line, and polygon structures with the appropriate attributes must be automated to a greater extent." In this paper, we present a method to automate data acquisition with the Belgian soil map which is of interest for natural resources oriented GIS as an example. The major feature of the method is its ability to segment the map into its different areas prior to radiometric analysis. This process makes use of Mathematical Morphology, a new image processing technique. The results indicate that the method is consistent with human interpretation of the map. However, it is not the claim of the authors to suggest that a methodology could be applied without distinction to any kind of thematic maps, because each has its own peculiarity. Nonetheless, our opinion is that some tools used here could be widely employed for processing other scanned maps.

PROBLEM STATEMENT

The problem is to capture a complex thematic map containing linework, color, text, and geometric pattern. The following features characterize the Belgian soil map (Tavernier & Marechal, 1958):

- More than 200 classes are offset printed using 12 fundamental colors.
- Black border lines delimit thematic colored areas.
- Text labeling lays inside some areas.
- Presence of a background gray colored topographic overlay.
- Typical features inside some areas like black and colored patterns (disk, ring, dashed line, ...) complete the color coding.

In any thematic map converted into raster mode, we find at least two kinds of information: line information related to the topology of the map, and surface information related to a specific texture for user identification of thematic codes. More precisely, they are two kinds of textures: macroscopic texture (represented by black and colored patterns), and microscopic texture which is the result of three components, a screen used in the offset printing, a noise introduced by analog to digital conversion, and the color distributions in the RGB (red, green, blue) channels.

Unambiguous segmentation is specific to scanned thematic maps. Indeed, when dealing with, for example, multispectral remote sensed data, segmentation problems are hard to solve due to the difficulty in determining exactly the objects to detect (Marr, 1982). Many classification algorithms use a purely radiometric approach applied to the entire image in order to produce a segmentation. On the other hand, the processing of thematic maps allows the partition of the classification procedure into two steps: segmentation by enhancement of border lines, and then thematic code identification.

Therefore, in this procedure the first challenge is to obtain thinned connected border lines and to extract separately text labeling and geometrical black patterns. Mathematical Morphology will be applied for this purpose. The second challenge is to automatically identify thematic codes. In this case, radiometric analysis will be used.

All algorithms described in this paper were programmed on the image processing system I^{2}S/M75 (International Imaging Systems).

SCANNING

The scanning is performed on a high resolution multispectral graphic-art scanner (Hell DC-300) upgraded by Eurosense Technologies N.V. in order to obtain a digital output. This scanner can digitize images at various resolutions and produces high

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quality digital images. It is to be noted that the scanner resolution setting is a very important parameter for the methodology. As border lines of the considered map are 0.1 mm wide, we decided to scan at 20 dots/mm. The scanner returns a three-band RGB image, each channel being quantified to 256 levels. For a sheet of 40 cm by 50 cm, a simple calculation leads to the surprising quantity of 240 Mbytes (uncompressed). At first glance, it might seem enormous but it has to be compared to the time consuming field and laboratory investment needed to create a soil map. Moreover, scanned data can be stored for other processing that may be needed in the future. This is surely possible because the scanning process preserves the original mapped information (colors and textures included), which is not true with manual digitizing.

Plate 1 shows the image resulting from scanning a 2.5-cm by 2.5-cm area of the Belgian soil map. Nine thematic classes are represented by eight different colors. Three kinds of geometrical patterns are clearly visible: black squares, dashed lines, and pink disks. Also observe the screen effect and the text labeling ("Pep").

PREPROCESSING OF THE RAW DATA

In Plate 1, border lines and black patterns appear as dark features. Therefore, one obtains a primary detection of these features by applying a threshold on the intensity component of the image. But the raw data, coded in the RGB color coordinate system, are unsuited to direct intensity component extraction. The conversion of the image into the HSV (hue, saturation, value) color coordinate system solves the problem because the value axis accounts for the brightness or intensity of the color (Foley and Dam, 1983). In the value component image (Figure 1), border lines and black patterns clearly have low intensity levels whereas all other features have higher intensity levels. For the chosen scanner resolution of 20 dots/mm, the shape of the histogram of the value image (Figure 2) underscores this bipolarization and allows an automatic derivation of the threshold level by using histogram mode seeking or measurement space clustering (Haralick & Shapiro, 1985). Applying a threshold on the Value component image leads to Figure 3.

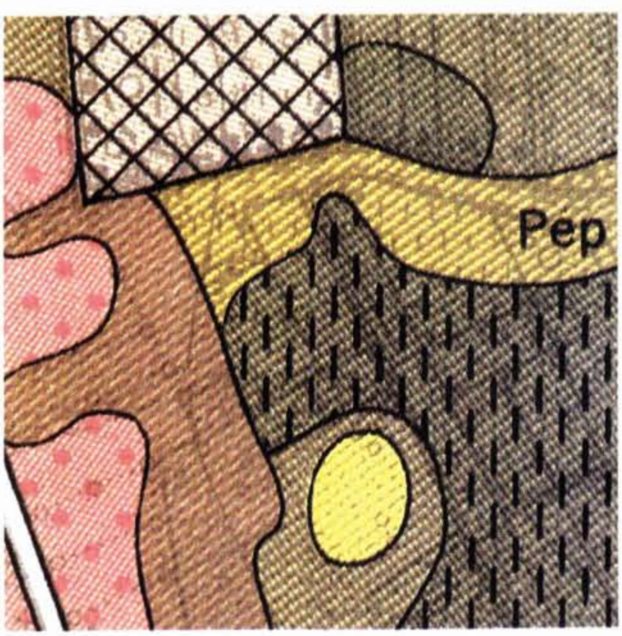

PLATE 1. Subset of the Belgian Soil Map (2.5 cm by 2.5 cm) scanned in RGB at 20 dots/mm.

Notice that, when possible, applying a threshold on a gray level image before any subsequent processing is common practice in pattern recognition. In any case, it allows substitution of the three-band image into a binary image, restoring the memory requirement to a more modest size (80 Mbits). Although Figure 3 is already a first answer to the stated problem, it is not enough. Without taking into account the problem of the splitting off between border lines and patterns, one may see from a close examination of the image that the extracted features do not have a unitary thickness and are not always connected. These problems fall completely within the competence of Mathematical Morphology as will be demonstrated in the following section.

MATHEMATICAL MORPHOLOGY PROCESSING

INTRODUCTION

Mathematical Morphology (M.M.) is a theory of spatial structure analysis which has many applications in image processing. It has been recently introduced in the field of remote sensing (Destival, 1986; Safa and Flouzat, 1989; Martel et al., 1989; Banon and Barrera, 1989). The key idea is to compare the object or set under analysis with an object of known shape called a struc-

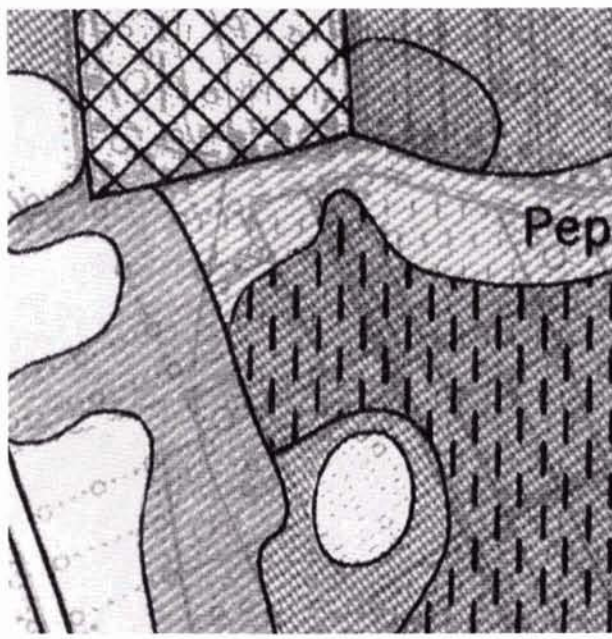

FIG. 1. Value (V) image obtained by converting the scanned image into HSV color coordinate system.

FIG. 2. Histogram of the value component image.

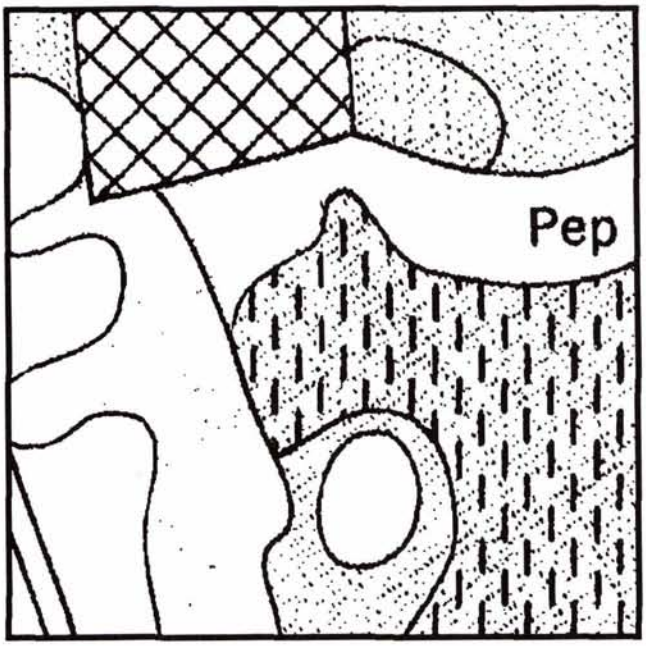

FIG. 3. Dark features extracted by applying a threshold on the value component image.

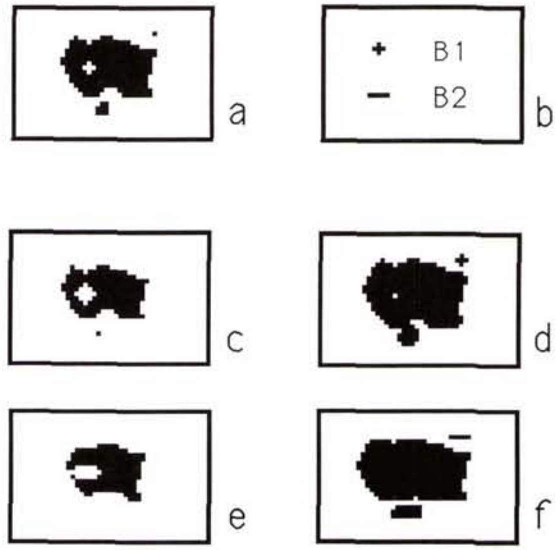

FIG. 4. Erosion and dilation. (a) Sample image. (b) Two different structuring elements B1 and B2. B1 is the elementary isotropic structuring element (within the 4-connected graph). B2 is a horizontal structuring element of length 5. (c) Sample image eroded by B1. (d) Sample image dilated by B1. (e) Sample image eroded by B2. (f) Sample image dilated by B2.

turing element. This element, defined by the user, acts as a probe to investigate the relationships existing between the various parts of the studied object. A comprehensive introduction to Mathematical Morphology can be found in Serra (1986) and Haralick *et al.* (1987). To have a deeper insight, books by Serra (1982; 1988) are recommended (see also "Advances in Mathematical Morphology" in a special issue of *Signal Processing Journal* (16)4, April 1989).

Although M.M. can be applied to n-dimensional digital gray level images, only two-dimensional binary images will be considered here. Let us simply give some elementary principles. The basic transformations of M.M. are erosion and dilation and are defined below.

Let X be a set to analyze and B a structuring element generally defined on a 3 by 3 window. The eroded set of X by a structuring element B, noted $X\ominus\check{B}$, is the locus of points x such that B centered at the point x is included in the set X. B centered at point x is denoted B_x; i.e.,

$$X\ominus\check{B}=\{x:B_x\subset X\}.$$

The dilated set of X by a structuring element B, noted $X\oplus\check{B}$, is the locus of points x such that the intersection between X and B_x is not empty; i.e.,

$$X\oplus\check{B}=\{x:(B_x\cap X)\neq\emptyset\}.$$

Erosion and dilation are dual transformations, which means that the dilation of a set X is identical to the complementary set of the erosion of X^c. X^c is the complementary set of X, i.e., the background of X. That is,

$$X\oplus\check{B}=(X^c\ominus\check{B})^c.$$

Figure 4 illustrates erosion and dilation with two different structuring elements. Observe in this figure how the results depend on the choice of the structuring element. For instance, the hole in the main feature of Figure 4a disappears when dilating by B2 (Figure 4f): wherever you center B2 in the hole, it always has a non-empty intersection with X. But the hole remains when using B1: if you center B1 right into the hole, it does not hit X (empty intersection); therefore, the center pixel of the hole remains when dilating X by B1(Figure 4d). In the case of erosion, the hole in the main feature of Figure 4a remains when eroding by B1 (Figure 4c) but it is no longer a hole when eroding by B2 because it is connected to the background (Figure 4e). Observe also the duality between erosion and dilation.

All other morphological transformations are built up by combining erosions and dilations with specific structuring elements. For example, an erosion followed by a dilation is called an opening and a dilation followed by an erosion is a closing. Thinnings can also be derived from erosions and dilations. M.M. transformations are non-linear and irreversible, e.g., there exists no way to go back from an eroded set to its initial shape. The recognition of an object is also an irreversible operation because it means that everything else has been eliminated from the scene.

A particular case of the dilation is the dilation of a set Y conditionally to another set X. "Conditionally" means that, after the dilation of Y, the intersection ($\cap$) with X is processed; i.e.,

$$D_X(Y)=(Y\oplus\check{B})\cap X.$$

This transformation produces a reconstruction algorithm if iterated until idempotence (i.e., when a fixed solution is reached) with an isotropic elementary convex structuring element. It is very useful for solving segmentation problems because it allows for the extraction of all the connected components of a set X marked by a set Y (Figure 5). The dual transformation is the conditional erosion, where after the erosion of Y, the union ($\cup$) with X is processed; i.e.,

$$E_X(Y)=(Y\ominus\check{B})\cup X.$$

If iterated until idempotence, this transformation also produces a reconstruction algorithm. But, in this case, the background of the image is reconstructed.

Now, let us present another morphological transformation, called the watershed transformation, which will be of great interest for closed contour extraction.

The watershed transformation can be derived from skeleton-

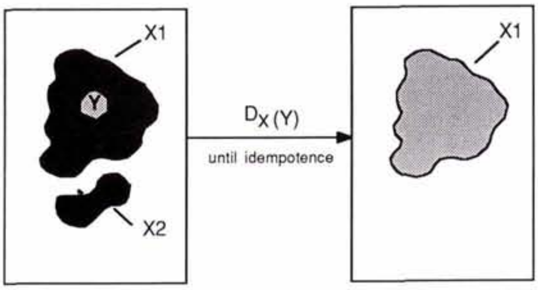

FIG. 5. Dilation of Y conditionally to X (i.e., $D_X(Y)$) processed until idempotence, only the subset X_1, marked by Y, is reconstructed. The subset X_2, unmarked, has disappeared in the resulting scene.

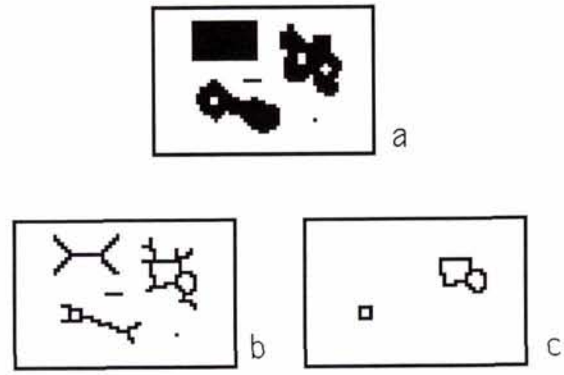

FIG. 6. Skeleton and watershed. (a) Sample image. (b) Skeleton of the sample image. (c) Watershed of the sample image obtained by pruning the skeleton until idempotence.

ization. In general, the term skeleton is used to describe a line thinned caricature of a binary image which summarizes its shape, preserves its homotopy, and conveys information about its size, orientation, and connectivity. More precisely, the skeleton of an object X is the locus of the centers of the "maximal disks" inscribable inside this object. A disk B_x centered at x and inside X is maximal if and only if one cannot find a larger disk (not necessarily centered at x) containing B_x and included in X. The skeleton is obtained from sequential thinnings with structuring elements that preserve the homotopy (Serra, 1982, p. 392). If a skeletonization is applied to a binary image (Figure 6a), it will thin each connected component to a line of unitary thickness (Figure 6b). A morphological transformation called pruning allows the removal of skeleton bones which do not make up closed contours. The pruning transformation consists of thinnings with specific structuring elements (Serra, 1982, p. 392). The skeletonization followed by prunings (see Figure 6c) is called the watershed algorithm (Beucher and Lantuéjoul, 1979; Soille and Ansoult, 1990).

APPLICATION TO LINE INFORMATION EXTRACTION FROM SCANNED THEMATIC MAPS

As all border lines and some black patterns of the thresholded image (Figure 3) are closed boundaries (except a few cuts which are filled by an elementary isotropic dilation) the watershed algorithm can be applied. The resulting image, called the watershed image, is presented in Figure 7. As expected, only closed contours remain. For example, dashed lines are deleted but three little contours subsist in place of the "Pep" letters (on the other hand, a Z or L capital letter would be deleted). To specifically extract border lines of thematic classes, the watershed image still needs to be processed to take over closed geometric patterns and to delete remainders of text labeling (e.g., the square texture pattern and the remainders of the "Pep" letters).

Let us illustrate one possible way to extract the square pattern. First, the watershed image is dilated by a vertical structuring element (Figure 8a) in order to fill in the areas bordered by the square pattern. Then, Figure 8a and the watershed image (Figure 7) are used to perform a morphological reconstruction: the former is eroded conditionally to the latter until idempotence (i.e., conditional erosions). In this way, background areas of Figure 8a act as a marker to reconstruct background areas of the watershed image. Because there was no marker inside the area with the square pattern and inside the remainders of "Pep" letters, they are not reconstructed (Figure 8b). As the square pattern lies inside a non-reconstructed area, it is extracted as follows: erode one time the reconstructed image by the elementary isotropic convex structuring element (Figure 8c), and take the intersection with the watershed image (Figure 8d).

It is now possible to substract the square pattern from the

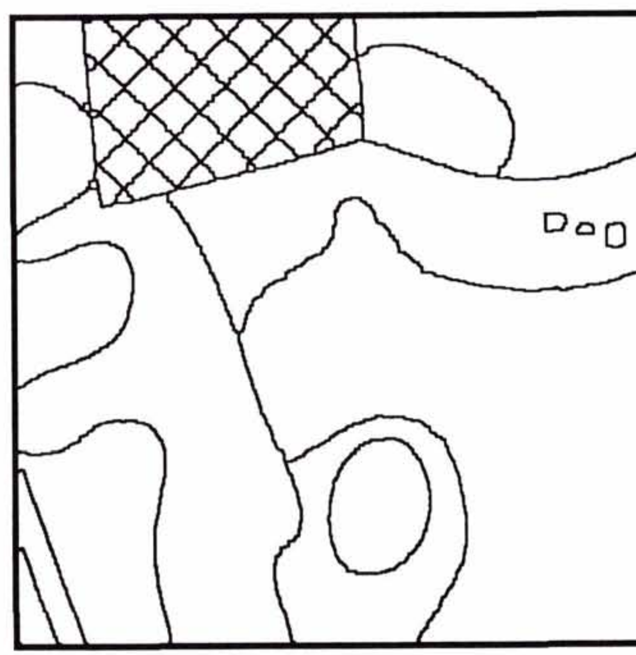

FIG. 7. Result of the watershed algorithm applied to the thresholded image (Figure 3).

watershed image (Figure 7) and to remove the remainders of the "Pep" letters by using a size of area criteria. Consequently, only border lines of thematic classes remain (Figure 9).

Remember that dashed lines were removed at the watershed step because they do not make up closed contours. To get all these lines, the thresholded image (Figure 3) is reconstructed by using the watershed image (Figure 7) as a marker. The resulting image is presented in Figure 10a. Non-closed features are non-reconstructed and can be extracted (Figure 10b) by subtracting Figure 10a from the thresholded image. In Figure 10b only dashed lines are meaningful and need to be extracted. Again, the choice of an appropriate structuring element allows the splitting off between dashed lines and other features. Therefore, the image is eroded by a vertical structuring element until the meaningless features are deleted. The resulting image (Figure 10c) is used as a marker of dashed lines to perform the reconstruction of Figure 10b. Figure 10d shows the isolated dashed lines overlay.

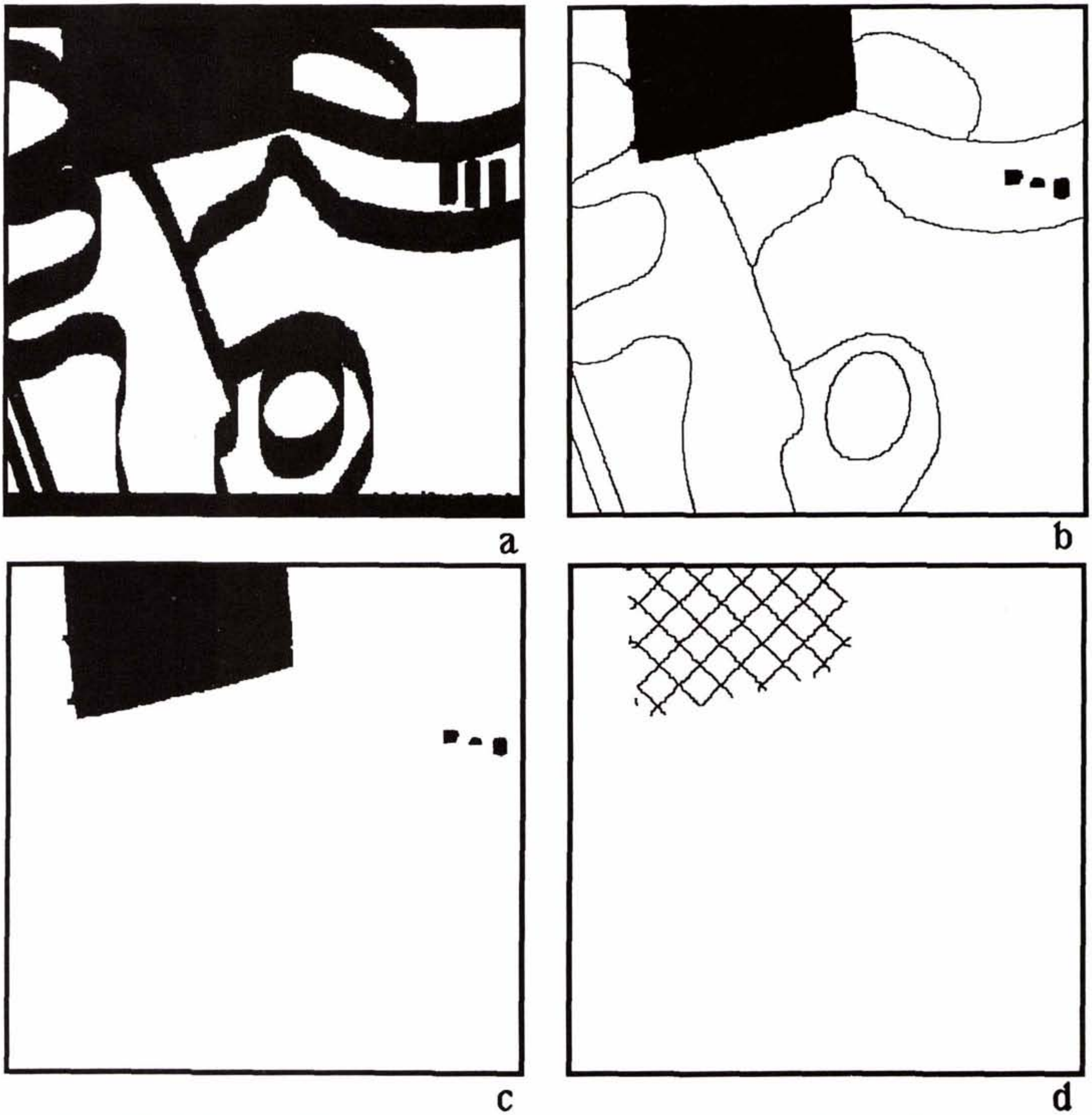

FIG. 8. Square pattern extraction. (a) Watershed image dilated by a vertical structuring element. (b) Reconstruction of the watershed image by using Figure 8a as a marker. (c) Erosion of Figure 8b by the elementary convex isotropic structuring element. (d) Square pattern mask obtained by the intersection of Figure 8c with the watershed image (Figure 7).

To summarize, this procedure permits the extraction of three basic pieces of information that will be used in the next step to fulfil the thematic code recognition:

- The mask of all black features, i.e., the thresholded image (Figure 3);
- The mask of border lines of all thematic classes (Figure 9); and
- The masks of thematic black patterns (Figures 8d and 10d).

AUTOMATED THEMATIC CODE IDENTIFICATION

First of all, each area produced by the Mathematical Morphology process needs a label or an identification number (Figure 9).

In order to define a function between a label and its thematic class, statistics of the hue channel are computed for the following reason: the topographic background does not disturb this channel, its gray color component being mostly transferred to the value (brightness) component. To eliminate effects of border lines, black patterns, and letters, the radiometric statistics of each labeled surface are computed outside the binary mask made of these features reconstructed in the thresholded image (Figure 3). Therefore, the hue channel is mainly concerned with the microscopic texture component.

To classify the areas, we will consider only mean and standard deviation in the hue channel. This choice is related to the Julesz (1973) conjecture which states that texture perception is only sensitive to these moments of the distribution. This conjecture holds for black-and-white as well as color images. Indeed, each thematic class has its own mean and standard deviation value, and, therefore, a relation can be established between the labels and the thematic classes. The scanner resolution has, of course, a critical influence on this relation, especially concerning the standard deviation value. The mean, standard deviation scattergram allows a good analysis of this relation as thematic classes appear as clusters (Figure 11). The histogram shapes (see Figure 12 for areas labeled 3, 5, 6, 7, 10, and 14) confirm well the clusters seen in Figure 11. Moreover, the partition of the mean, standard deviation scattergram might be previously established from scanning and analysis of the map legend.

To complete the identification of each area, the patterns previously extracted have to be crossed with the pure radiometric classification (e.g., areas labeled 5 and 6 have the same radiometric values but area 6 has a pattern overlay).

Concerning colored patterns, they generate multimodal distributions of the hue variable which induce enlargement of the standard deviation. To distinguish between screen effects and colored patterns with well defined geometry, M.M. should still be used. As long as thematic maps do not hold critical geometry of patterns, the above microscopic approach is enough to classify segmented areas.

Checks are desirable at the end of the segmentation and classification procedures. One easy and powerful way is the use of split screens (Plate 2) between the original scanned map and the segmented image with a color qualitative matching with the original map. This color matching is obtained by taking RGB mean values inside each labeled area. Other checks are possible, e.g., when pattern overlays are not used in conjunction with all thematic colors.

CONCLUSIONS AND PERSPECTIVES

Mathematical Morphology together with radiometric analysis has been demonstrated to be successful for processing scanned thematic maps. Mathematical Morphology was first used to segment the image into its different areas. The watershed algorithm is used to transform closed contour features of the thresholded image (Figure 3) into thinned and connected lines while removing the noise (Figure 7). Another powerful application of this theory undoubtedly lies in its ability to extract separately geometrical patterns. It has been shown how black square patterns, dashed lines, and letters have been extracted. Radiometric analysis then allows classification of each segmented areas.

How general is this approach? It can be stated that the watershed algorithm will provide closed contour information as long as the scanner resolution is suited to the line width of the map. However, the pattern recognition step needs a map dependent hierarchy of morphological operations with specific structuring elements. This step is sometimes hard to design, but Mathematical Morphology provides a lot of tools for extracting a wide variety of spatial structures. Eventually, only mean and standard deviation of the hue channel need to be computed to perform the thematic code identification.

Despite the amount of CPU time and data storage required to process a complete sheet, the proposed methodology is a real breakthrough for translating mapped geographical data into a GIS data base. Plate 2 is an example of the performance of this approach. Regarding the huge amount of data involved at the beginning of the information extraction process, it is worthwhile noting that the final raster map can be compressed up to

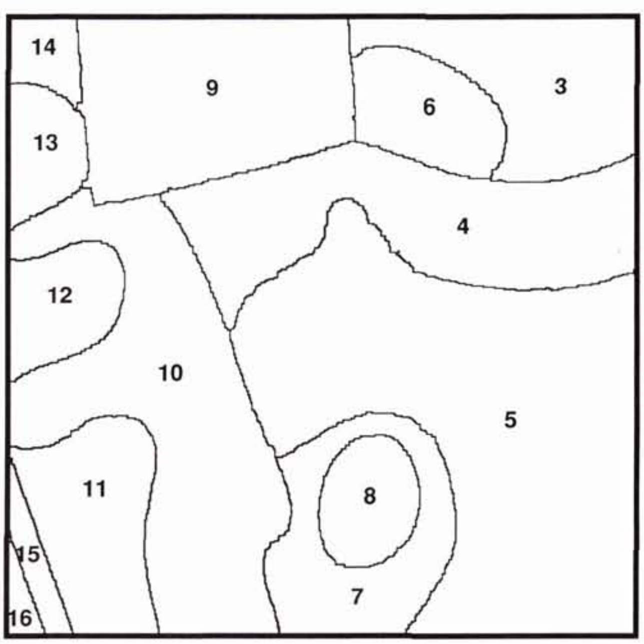

FIG. 9. Border lines mask of thematic classes with identification numbers produced by a labeling.

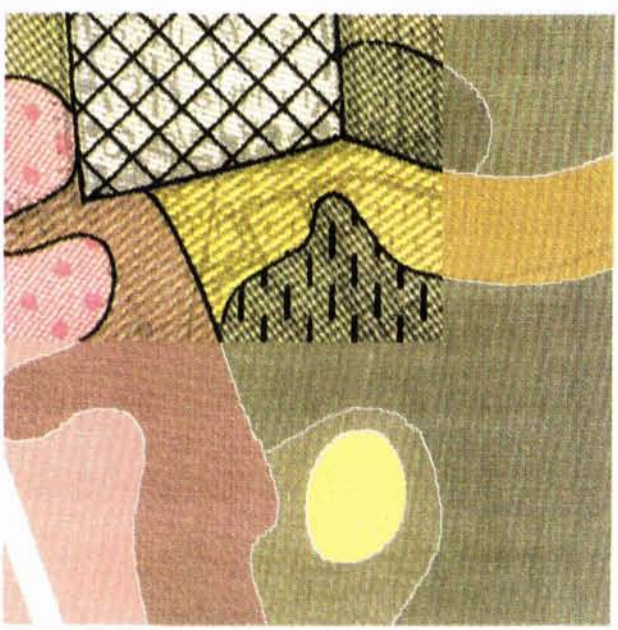

PLATE 2. Split screen between the original scanned map and processed data.

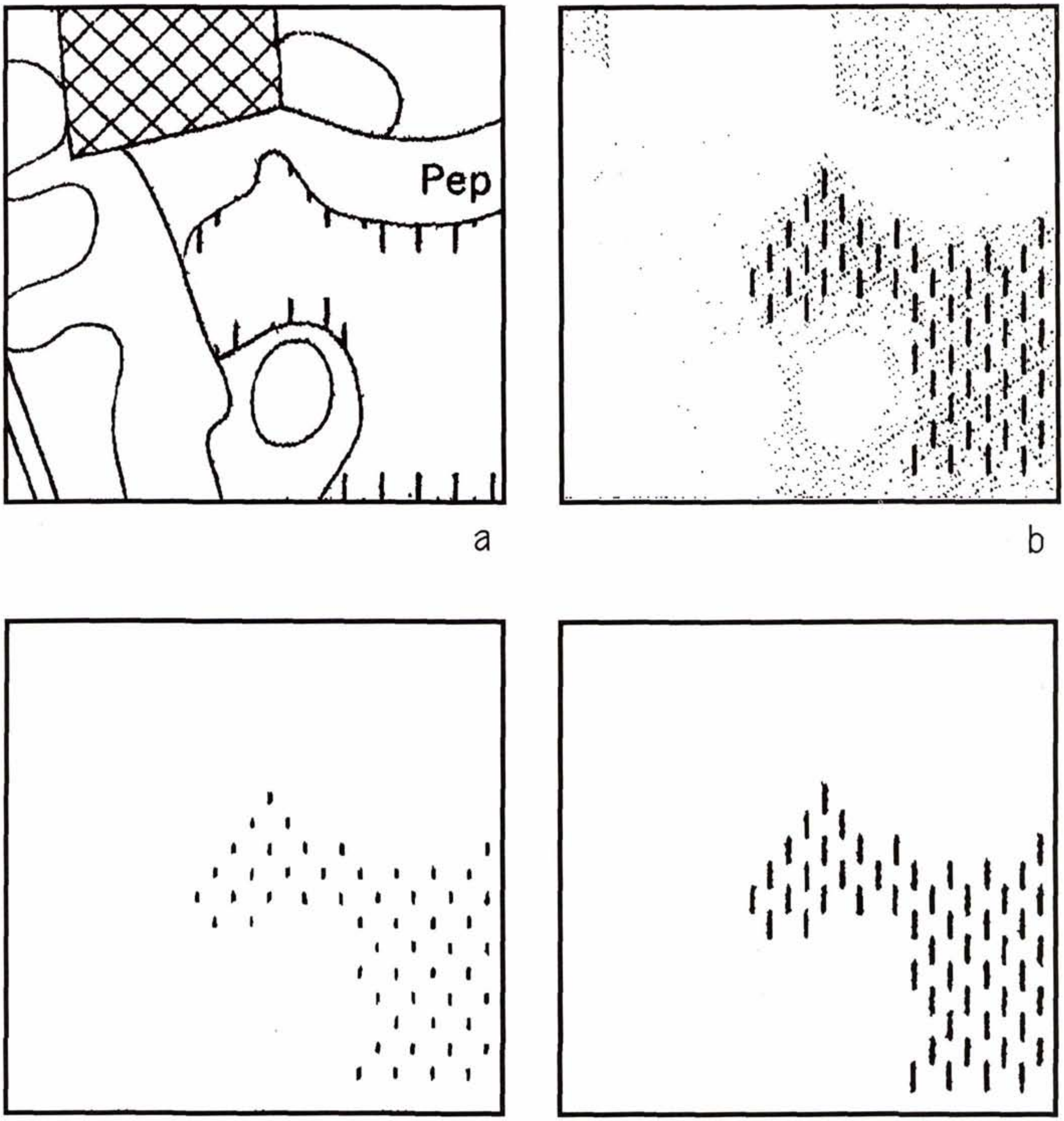

FIG. 10. Extraction of dashed lines. (a) Reconstruction of the thresholded image (Figure 3) by using the watershed image (Figure 7) as a marker. (b) Non-reconstructed features of the thresholded image (they do not make up closed contours). (c) Figure 10b eroded by a vertical structuring element giving markers of dashed lines. (d) Extracted dashed lines pattern obtained by reconstructing Figure 10b with Figure 10c as a marker.

more than 90 percent without loss of information (Loodts and Nguyen, 1985).

Information extracted by using Mathematical Morphology and radiometric analysis can also be vectorized. Yet the proposed methodology is best suited to raster-based GIS. Indeed, at the end of the process after the soil map has been decomposed into different overlays, data are already available for a GIS. Figure 9 gives border lines and area identification numbers. Figure 11 gives the relation between these numbers and thematic classes. Figures 8d and 10b are two overlays representing attributes of the classes. Therefore, it is possible to query these images to obtain, for example, a map of one particular kind of soil. The

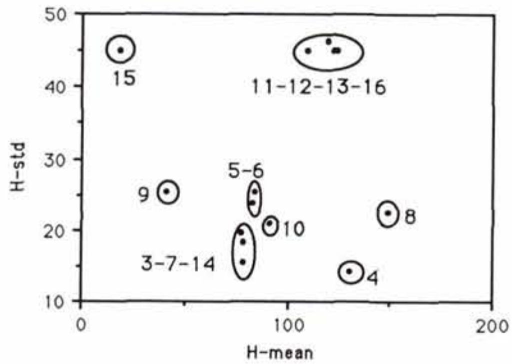

FIG. 11. Thematic codes identification using the mean, standard deviation scattergram of the Hue channel in each labeled area.

proposed methodology is thus able to translate directly scanned thematic maps into a raster-based GIS.

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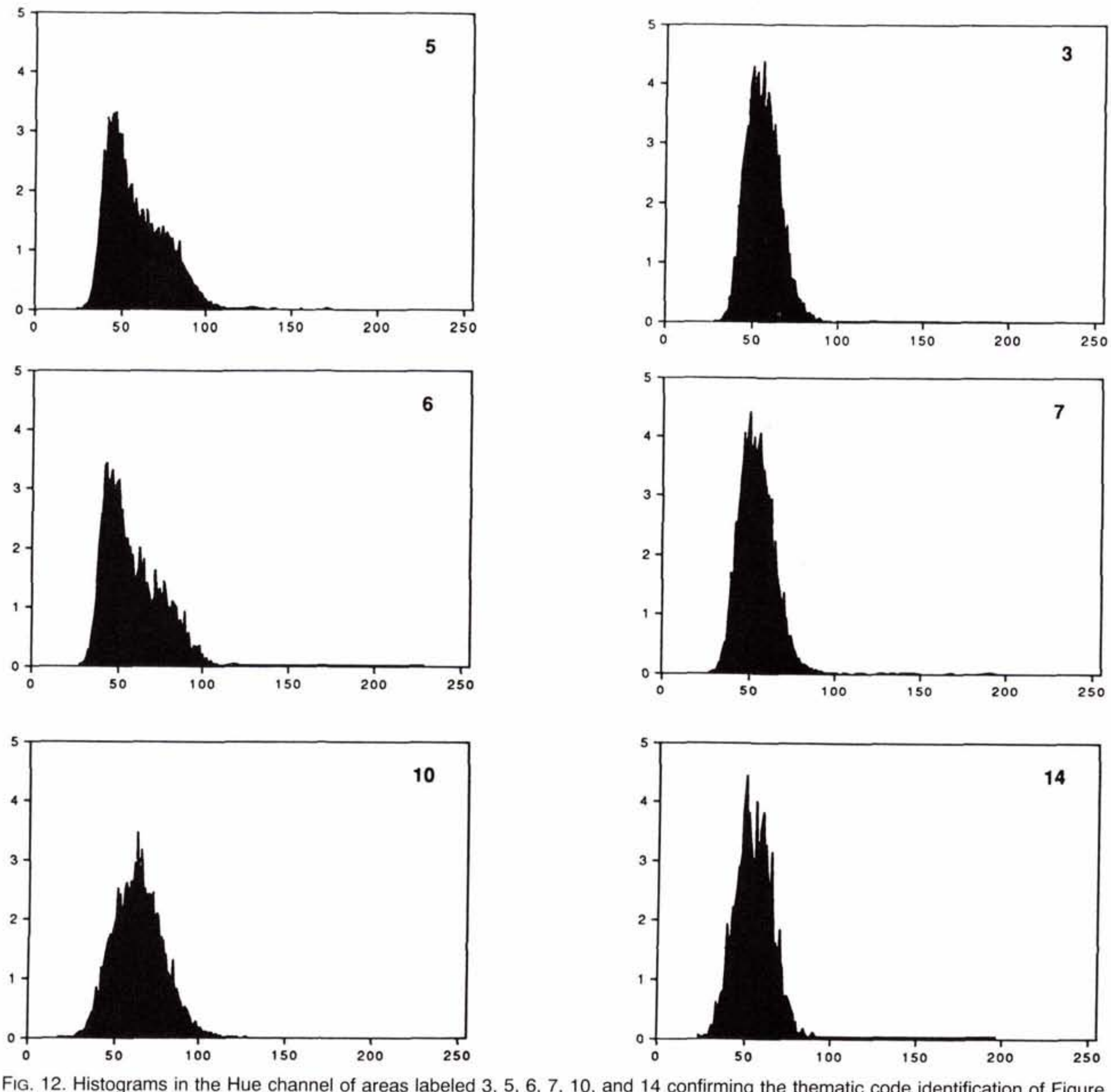

FIG. 12. Histograms in the Hue channel of areas labeled 3, 5, 6, 7, 10, and 14 confirming the thematic code identification of Figure 11.

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