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REGIONAL GENERALIZATION IN SUPPORT OF GEOLOGIC CARTOGRAPHY

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The task of regional generalization for geologic cartography can be resolved by establishing sectors where the characteristics of the observed fields show certain homogeneities. These procedures reveal in many cases the presence of lateral variations of physical properties that control the behavior of the intensity of the field. In this study, several techniques used by different investigators are combined. The results provide a solution to the task of regional geological generalization. The method of principal components is used for the first time in Cuba to solve the task of territorial generalization. The results are presented using both a theoretical model and a field investigation in western Cuba.

THEORETICAL ASPECTS

Geophysical methods used in geologic investigations provide information about the behavior of the physical and geometric characteristics of field sources, and establish a possible physical - geological model that is appropriate for the problem to be solved. To create this physical - geological model, the data contributed by the physical fields are used, together with all available complementary information, to reduce ambiguity in the resolution of the inverse problem. It is possible to identify two stages during the problem solving process that can contribute results during the interpretation of the primary data and information.

QUALITATIVE STAGE

In this stage, it is possible to establish the character of the sources of the field, as well as to propose the existence of certain regularities in its distribution. Possible contacts and the main limits of structures can be identified. It is also possible to establish the relative dimensions of the geologic bodies, their possible extent and orientation, and anomalies that later will be subject to a more rigorous process of quantitative interpretation.

QUANTITATIVE STAGE

A quantitative analysis is not always possible, at least in such way that guarantees confidence in the results, because it will be necessary to have enough complementary information to assure the success of the interpretation of the primary results. An infinite number of theoretical models can be developed. These models provide an answer that satisfies the distribution of the measured physical field. The characteristics of the source could described in terms of the data error. For this task, it is necessary that the physical and geometric characteristics of the sources, and the analytic expression for the behavior of the field created by the body, be known.

The task of regional generalization can be resolved using different procedures, including the following variants:

Autocorrelation Function

The autocorrelation function identifies the presence of tracts, according to the longitude where the characteristics of the field sources are homogeneous. In this way, sectors can be distinguished where there are lateral variations of physical properties that govern the behavior of the intensity of the field. This procedure can be executed starting from the energy characteristics of the gravimetric and magnetic anomalies, and studying the behavior of the autocovariance function along the investigated profile (Cerkirov, 1990).

To solve the task of regional generalization using the correlation radius, the autocorrelation function is calculated with constant intervals. Once the correlation radius in each section of the area is obtained, it is necessary to plot their values as a graph of variation of the correlation radius over the area of investigation.

The generalization using this method can have many variants, although in general two are used:

First variant. The correlation function, and consequently the correlation radius, are determined starting from the data of the non-centered anomalies. Then, in the areas with large average values of the anomaly, the correlation radius will not be very sensitive to boundaries. With these results it is possible to reconcile opposites between large tectonic elements.

Second variant. In the chosen limits of the boundaries of the anomalies, the values are centered and the correlation radii are determined by these centered anomalous values. According to the graph of the variation, the intervals are determined among the boundaries.

The physical meaning of the correlation radius for the generalization is summarized by the following: the correlation radius constitutes a parameter that depends on the depth, shape and dimensions of the anomalous bodies. In regions with homogeneous geologic structures, similar structures are subordinated to certain laws. For this reason, the correlation radius remains constant in the limits of homogeneous regions, and varies significantly when passing from one region to another.

Coefficient of heterogeneity

This method of carrying out the generalization, for the case of working with physical fields, was developed by Alfonso (1986). Although developed for the study of karstic phenomena in geologic engineering investigations, in general it can be used to study the behavior of any variable physical field, at least in a qualitative way. This coefficient establishes quasi-homogeneous behavior tracts and defines the sectors of high heterogeneity starting from the variability of the physical field. The hypotheses that support the use of the coefficient of heterogeneity (α) are the following:

The sources of noise are inside the rock of interest and they are considered to present heterogeneity with attribute values different from those represented by uniform rocks.

The measured values of the attribute do not contain noise and are caused by features of interest if the rock is completely homogeneous.

The noise is not stationary, but rather its width increases as it is larger than the half value of the attribute and the degree of heterogeneity of the rock according to the following pattern:

$$M(x) = S(x) + r(x) \tag{1}$$

and

$$r(x) = \alpha(x) \,.\, S(x) \,.\, e(x) \tag{2}$$

where:

$M(x)$ is the observation that depends on the physical property of the uniform rocks, the measuring device and the degree of heterogeneity of the rock.

$S(x)$ is the value of the magnitude of the physical dimensions for the uniform rock.

$r(x)$ is the noise due to heterogeneity.

$\alpha(x)$ is the coefficient of heterogeneity.

$e(x)$ is a variable that is a function of the normal distribution and its behavior is homogeneous at all points.

To obtain the values of the coefficient α, the autocorrelation function of the measured attribute is calculated. Starting from the correlation radius, it is possible to define the energy filter that carries out the efficient separation of the value of the physical magnitude of the uniform rock from the noise. The smoothed values are determined for a certain correlation interval. With the observed and smoothed values of the attribute, the residual is calculated with its deviation and coefficient of apparent heterogeneity at each point.

The method developed by Alfonso in 1986 was applied to karstic environments using results of investigations with electric methods. Starting from the α values, he considered that for completely homogeneous rocks, $\alpha = 0$. As α approaches unity, the degree of heterogeneity increases.

He demonstrates that the method can be used with effectiveness during regional generalization. Of course, it is necessary that the physical field on which this transformation is applied experiences fluctuations associated with the heterogeneity characteristic of the geologic features under study, as in the case of potential fields (Rodríguez, 1995, 1998).

Principal component analysis

The method of principal components analysis is used to carry out the regional generalization, integrating the results of both potential fields and rising spectrometric and geoelectric fields, if they were available. The analysis is carried out in the following steps:

1- From the isoline map of the available fields, the digital file is conformed in matrix form, according to:

$$\theta = \begin{matrix} X_{11} & X_{12} & *\;*\;* & X_{1M} \\ X_{21} & X_{22} & *\;*\;* & X_{2M} \\ * & * & *\;*\;* & * \\ * & * & *\;*\;* & * \\ X_{N1} & X_{N2} & *\;*\;* & X_{NM} \end{matrix} \qquad (3)$$

where each column represents one of the *M* observed physical fields, and each line one of the *N* points belonging to each one of the points of the studied area.

2 - The principal components are calculated for the system of present attributes (*M* columns).

3 - The behavior of these principal components allows certain regularities to be established for the investigated area. These are associated with different geologic events that could be reflected in the original fields.

The projection in the plane of the first two principal components allows a clear visualization of the cartographic value of the original system. The use of attributes to separate the geologic objectives present in the area, similar to what happens when techniques of non-supervised classification is applied, have been used before (Rodríguez and Valcarce, 1997; Valcarce, 1998).

AVAILABLE SOFTWARE FOR THE REGIONAL GENERALIZATION

To facilitate the execution of the regional generalization, two computer applications have been combined:

I. **PERFIL System** (Rodríguez, 1995, 1998). **–** Developed by the author, it executes all of the transformations considered here, using a “pull-down” menu, under the DOS system. A preliminary version exists for Windows.

II. **SURFER™ System** (Golden Software, 1996)**. -** SURFER™ allows the graphic representation of the final results in an appropriate format, besides guaranteeing a wide range of possibilities during the regularization.

VALIDATION OF THE RESULTS

Synthetic modeling of a gravimetric profile

For this theoretical model, shown in Figure 1, the calculations were conducted with a sampling interval of 500 m and a total of 100 observation points.

The ***coefficient of heterogeneity*** for the synthetic profile shows separate homogeneous sectors exist that are characterized by values with relative increases of α.

- High values on the main vertical contacts are shown.

- The separation of the central and right blocks is shown by the presence of two relative maxima, which reveal the existence of an area of complex transition associated with the sinuosity of a separation surface.

- The areas associated with the different blocks are shown by the presence of very small values of α that indicate the relative homogeneity of the geologic section in these sectors.

- The position of the vertical contacts in the two side blocks, although not very obvious, seem to be revealed by the small increment of α values at exactly their respective projections on the surface.

The ***energy characteristics*** of the potential function showed the following:

- The autocorrelation radius takes a value of $R = 23$, indicating the relative homogeneity of the function according to the location studied.

- The autocorrelation function in the location of the profile, shows the presence of two areas of

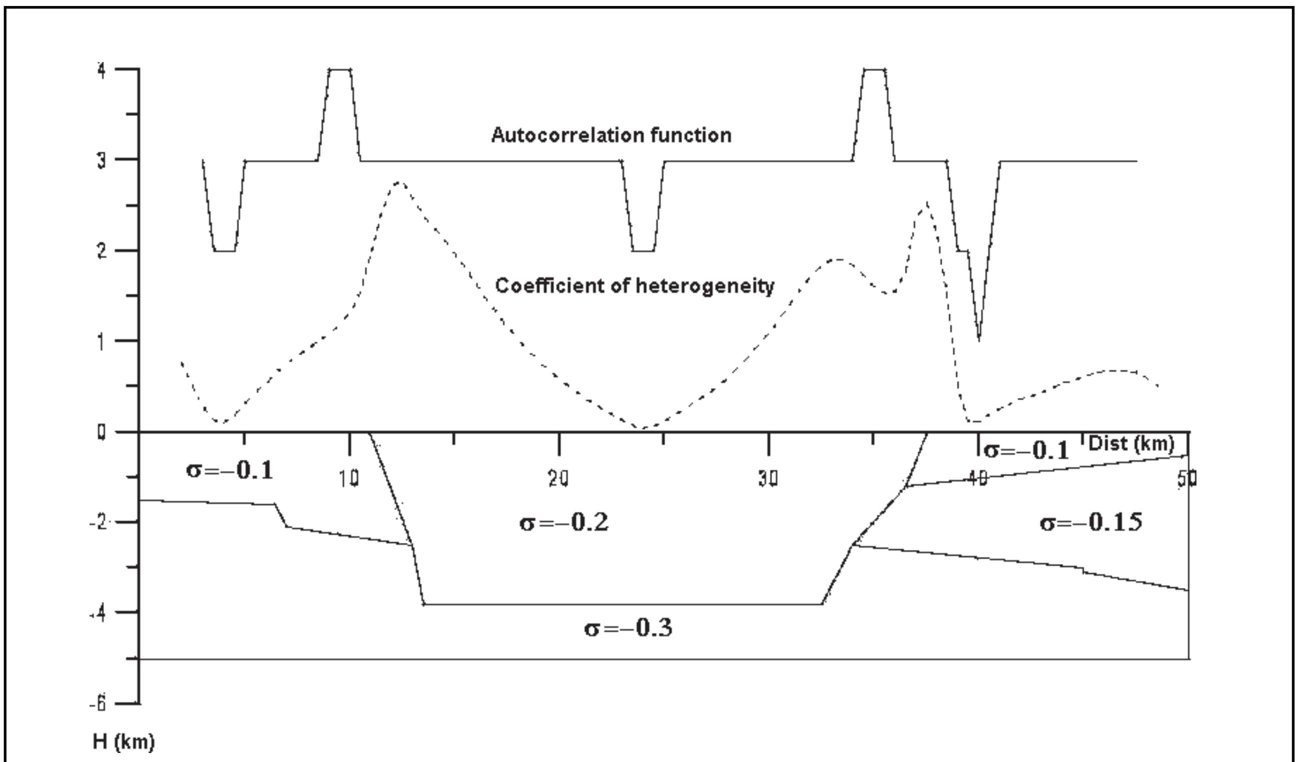

Figure 1. Cartographic results using the synthetic profile (Rodríguez, 1998).

marked variation that coincide with the fundamental vertical contacts of the pattern, spaces associated with the areas of relative maxima of the coefficient α. An area appears inside the central one, where the value of the function diminishes and coincides with the smallest values of α inside this block.

- The largest complexity is shown again in its final section (right block).

The generalization for the profile identifies the presence of three sectors with behaviors statistically different and with a larger complexity in the final sector (Figure 1).

The ***method of principal components*** is applied to the normalized total gradient (Beriozkin, 1988) as follows (Figure 2):

- The first principal component shows the general behavior of the pattern. There is a lengthened maximum limited by areas of strong vertical gradients, defining the position of the two fundamental contacts. Also, the alignment of the maximum defines the presence of a horizontal boundary in the right block, while the presence of the upper area of the minimum flanked by the two maxima in the left block, suggest the possible position of a horizontal boundary.

- The second principal component confirms the presence of the main vertical contacts, associated with areas of maxima. There is a possible horizontal boundary in the right block, given by the alignment of maxima and minima, as well as in the left block. In this case, the dip angle of the contact can be seen between the left and central blocks, starting from the alignment of maxima and minima. Finally, the presence of a chain of minima flanked by the maxima associated with the fundamental contacts, begins to define a horizontal boundary in the central block.

- The third principal component highlights the presence of areas associated with the main vertical contacts. The presence of the existing horizontal boundary is highlighted by the principal component. Chains of minima are observed that confirm the possible existence of a continuous horizontal boundary in the central block, as well as others in the left block around point 10 (kilometer 5) revealing the existence of a vertical contact in this position. In a similar way, the presence of maxima and minima aligned in the right block indicate the possible presence of two horizontal boundaries.

Two-dimensional geologic cartography

The possibilities of these transforms were tested in the Los Palacios Basin (Figure 3). When using ***the energy characteristics*** of the field it is possible to establish the following regularities (Figure 4):

- The largest variability in the magnetic field had a correlation radius of only 5 km, while for the gravimetric case variability was 13 km.

- The use of the autocorrelation function in the magnetic field shows a circular pattern toward the center of the area. The function takes an elliptical form with the largest axis southwest-northeast and the presence of more gradients perpendicular to this axis. On the contrary, the gravimetric case shows a structure lengthened in the same direction with two parallel sectors and with similar gradients.

The ***coefficient of heterogeneity*** showed the following characteristics (Figure 4):

- The gravimetric field shows two areas lengthened northwest–southeast, one in the north and the other toward the southwest.

- The magnetic field shows the presence of two areas with marked heterogeneity, one in the northwest sector and the other one with a west–east direction in practically the whole south border of the studied area.

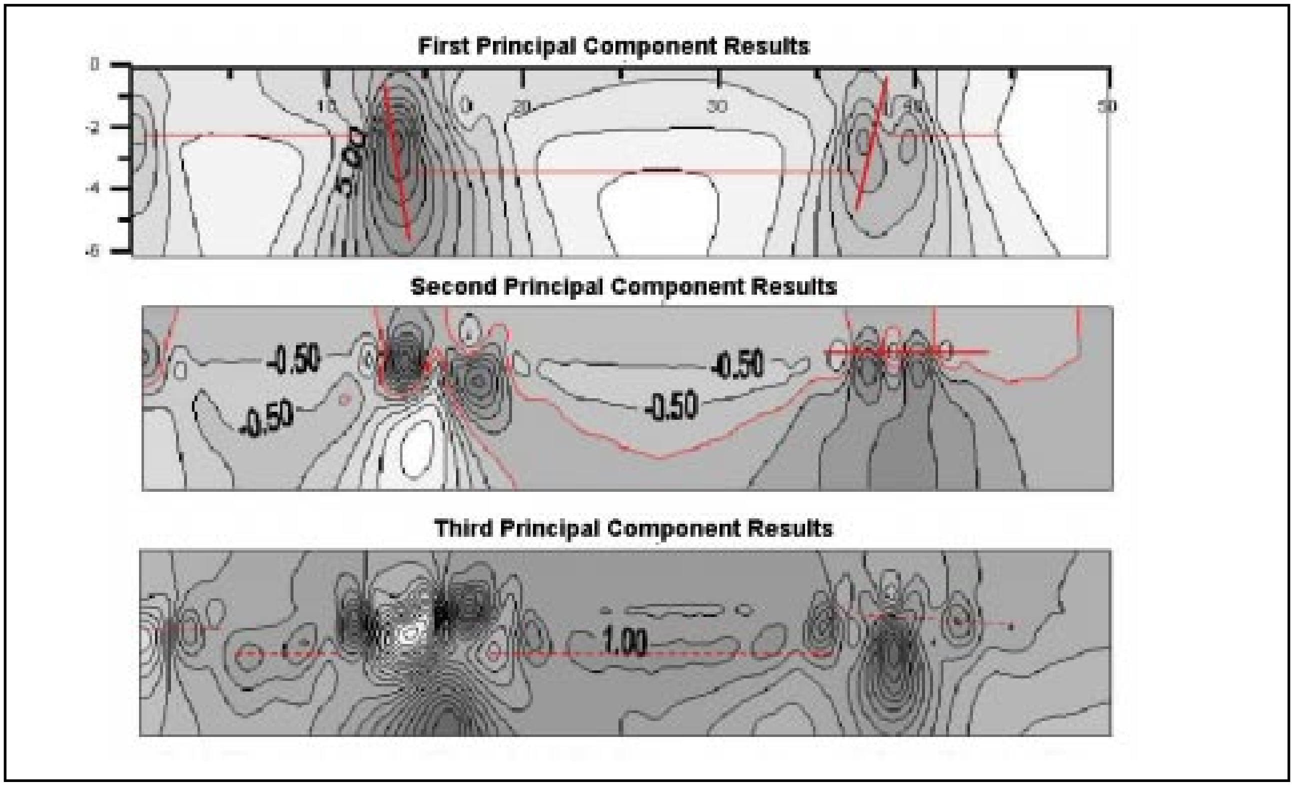

Figure 2. The use of the principal component method normalized total gradient transform on the synthetic profile (Rodríguez, 1998).

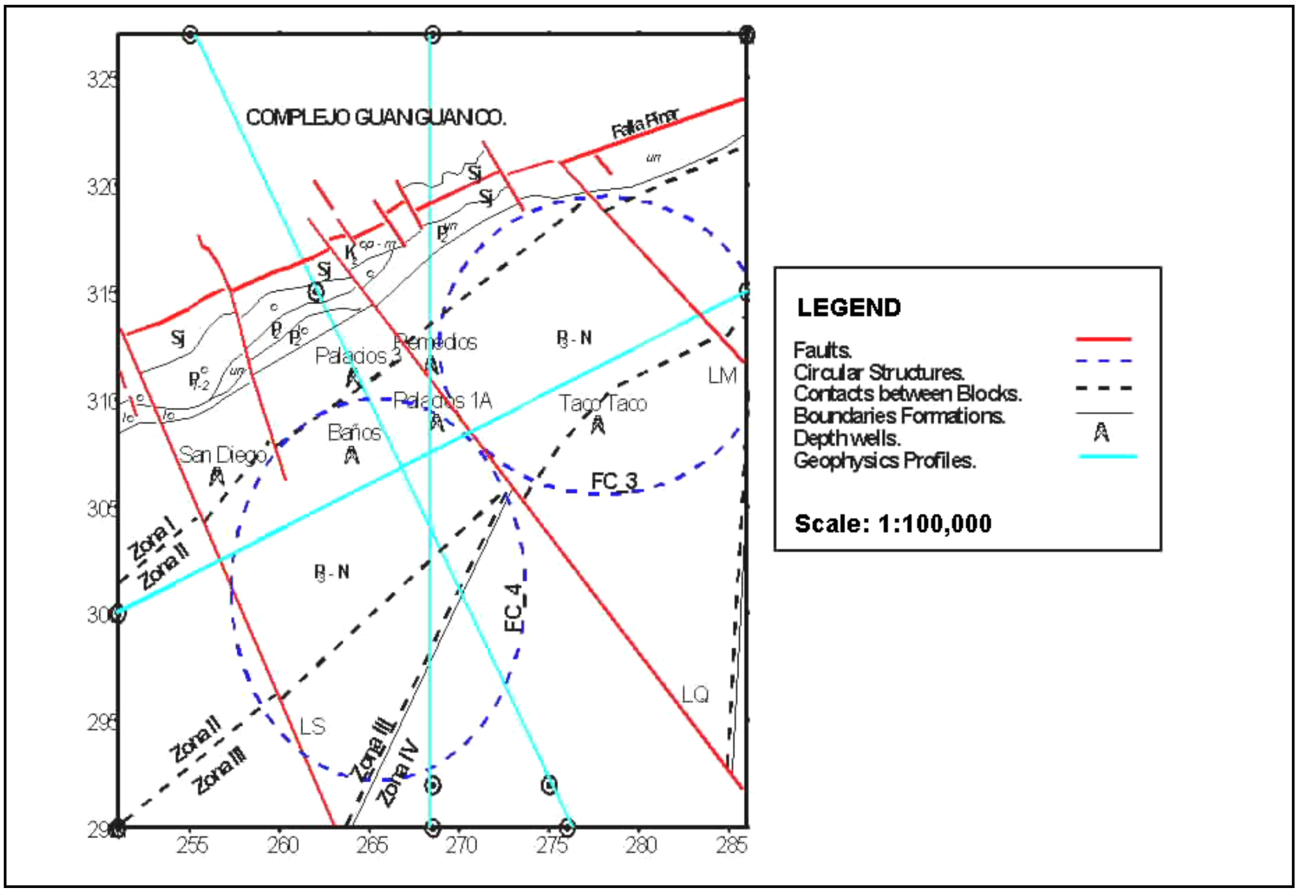

Figure 3. Geological schema of the Los Palacios Basin (Garcia, 1995).

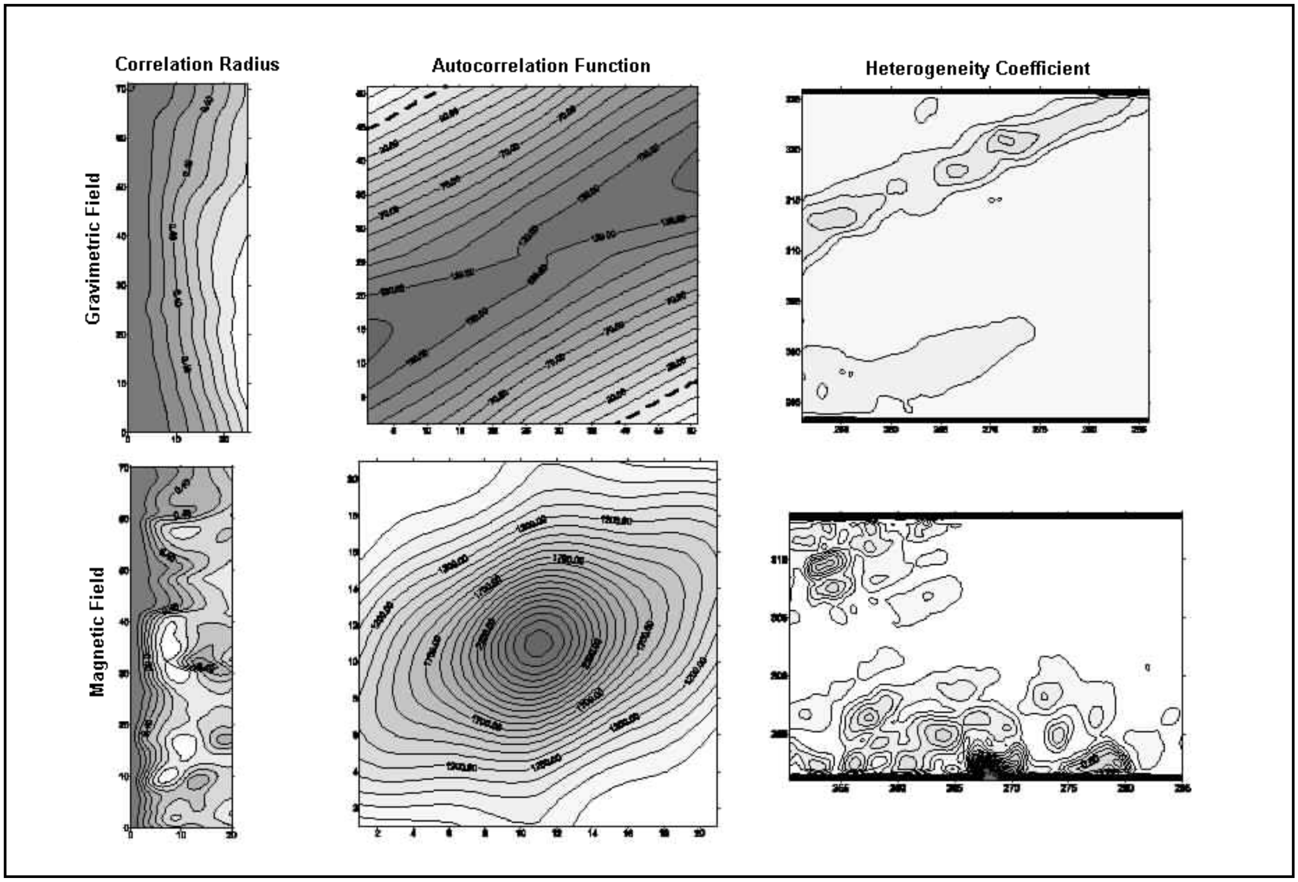

Figure 4. 2-D cartography using the energy characteristics of the field in the Los Palacios Basin (Rodríguez, 1998).

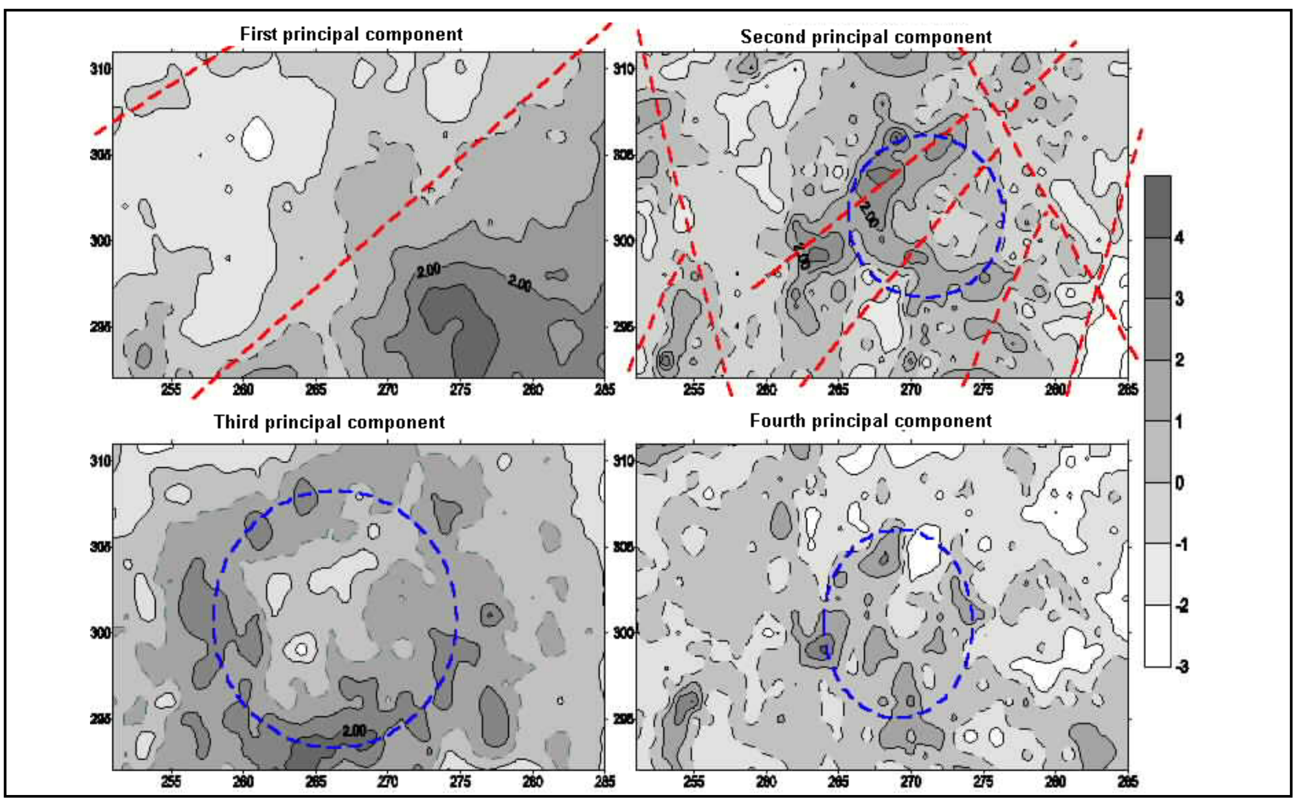

Figure 5. Use of the principal component method for geological cartography (Rodríguez, 1998).

The ***method of principal components*** for the regional generalization contributes new information on the characteristics of the basin that can be of interest during the cartographic process. In this case, the potential fields were used in an integrated way with the results of the rising spectrum (Figure 5). The following results were obtained for the sector using all the available attributes.

- The first principal component defines perfectly two areas limited by the isolines of zero value, with positive values to the south and negatives to the north.

- The second principal component shows the presence of two alignments of positive maxima, one to the north and the other to the south, both with southwest–northeast directions, as well as a perpendicular at two o'clock from the south center of the area. The presence of two areas of negative values is also shown lengthened in a northwest–southeast direction, as well as another of almost south-north direction in the right lower end of the study area.

- The third principal component reveals the presence of a great circular structure defined by a chain of positive values, limited by isolines of zero value and with a central nucleus of negative values.

CONCLUSIONS

It is shown that regional generalization represents an initial step during the process of geologic cartography. This generalization allows a primary division of the study area according to the energy characteristics of the observed fields. In this work, a group of techniques are proposed that allow the appropriate separation of effects caused by different sources in such way that facilitates the process of geologic cartography.

The effectiveness of the techniques is demonstrated to support geologic cartography, by showing its use in two practical examples. It is demonstrated that the same techniques can be used satisfactorily in the case of profiles, just as they are applied in areal applications.

The availability of the necessary software for the execution of each of the transformations presented here guarantees the execution of the proposed procedures with the speed and effectiveness required by applied geologic investigations.

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