MEASUREMENTS OF SOME CHARACTERISTICS OF THE PALYNOFACIES OF COAL USING DIGITAL IMAGE ANALYSIS

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ABSTRACT

Coal samples from a seam in the lower Tertiary Amagá Formation, “El Bloque” mine, Colombia, were used for analyzing palynofacies. Palynofacies residues obtained through the adapting palynological preparation method, were studied in white and fluorescent light.

The proposed method of image analysis consists of two steps: (1) the total fluorescence of the palynofacies was measured with a color image and binary image as a result of Otsu segmentation. A green and red (G/R) color index was measured and each level of the coal seam the G/R index ratio was compared to the results of Rock-Eval data (S1/TOC and HI) and the percentage of liptinites. (2) Some shape factors (roundness, fullness ratio, aspect ratio, and elongation) and textural curves were derived using the distance function of mathematical morphology; these were measured in two pollen species, *Cyclusphaera* and *Spirosyncolpites,* to test the techniques.

The results of these tests have shown that fluorescence intensity measured with image analysis is related to coal petrography and pyrolysis Rock-Eval data (S1/TOC, HI). The shape factors, textural curves, and fluorescence intensity together are elements that could be used in discriminating some types of organic matter in kerogen slides.

Keywords: Palynofacies, image analysis, coal, fluorescence intensity, shape factors-

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USO DEL ANALISIS DIGITAL DE IMAGENES EN LAS MEDIDAS DE ALGUNAS CARACTERISTICAS DE LAS PALINOFACIES DE CARBONES

RESUMEN

Se estudiaron palinofacies de carbones de la mina El Bloque, del manto de la Formación Amagá, provenientes del terciario inferior. La preparación de las muestras fue adaptada de la palinología, la observación se realizó en microscopia de luz blanca y fluorescente.

El método de análisis de imagen consistió en dos etapas: La primer etapa, midió la fluorescencia total de las palinofacies, obtenida de una imagen a color segmentada con el método Otsu ,de la que se extrajo, el índice de color Verde/Rojo para cada ply del manto de carbón. Los resultados de la fluorescencia fueron comparados contra los datos obtenidos de la pirólisis Rock-Eval (S1/TOC y HI) y el porcentaje de liptinitas. La segunda etapa evaluó algunos factores de forma y generó las curvas de textura morfológica, para las imágenes segmentadas, de las dos especies de polen estudiadas: Cyclusphaera y Spirosyncolpites,

Se encontró que la intensidad de fluorescencia total, está relacionada con los datos de la pirólisis Rock- Eval(S1/TOC, HI). Los factores de forma, las curvas de textura y la intensidad de fluorescencia son elementos que podrían, ser usados en la discriminación, de algunos tipos de materia orgánica presentes en las placas de kerógenos analizadas..

Palabras claves: palinofacies, análisis de imagen, carbón intensidad de fluorescencia, factores de forma.

1. INTRODUCTION

Palynofacies analysis is the study of organic facies carried out in transmitted light microscopy (Tyson 1995).[1] It involves the identification of palynomorphs, plant debris and amorphous components, their relative (and absolute) abundance, size spectra and preservation state (Combaz 1964 and 1980).[2][3] Fluorescence and morphological preservation state of palynomorphs can be used as an indicator of degradation (Bombardiere 1998).[4] On the other hand, the degradation state of sediment is an important parameter for differentiating environments of deposition. In addition, knowledge of the degree or organic degradation is useful in determining the potential of sediment to produce hydrocarbons.

According with the initial objective of the palynofacies study, (Combaz 1964, 1980)[2][3] it is possible to know the richest of organic matter of the sedimentary rock, to identify the source of organic matter and characterized the deposition environmental. This study can be applied directly to carbonatic and silisiclastic rocks and not coals, where the shape of organic components, depend of the type of organic matter and not of transport as is in the others rocks. In order to trying to understand the maceral origin and its behaviour in the oil generation, here was applied the original palynofacies concept to coal samples, but modifying the preparation method, (Blandón et al 2008)[5]

The maturity of the organic matter from source rocks depends as much on the rank (palaeotemperatures) as on the chemical composition of the organic matter and is measured by vitrinite reflectance, fluorescence intensity of sporinite, and the color change of spores (Ottenjann et al. 1975[6]; Alpern, 1976[7]; Teichmuller and Wolf, 1979[8]; Staplin, 1969[9]; Newman et al., 1997[10]).

Fluorescence intensity provides a visualization of highly hydrogenated organic matter favourable to hydrocarbon generation invisible in white light (Robert, 1980).[11] Fluorescence observation should be routinely included in order to accurately assess the proportion of highly oil-prone constituents, and the preservation state (and hence hydrocarbon potential) of amorphous organic matter and liptinitic material (Tyson, 1990).[12]

Robert, 1988 (cited in Taylor et al., 1998)[13] has described a visual means of assessing the global fluorescence index of a rock in order to evaluate its petroliferous potential. This method is highly qualitative and with a total dependence of the analyst. In contrast, an absolute measurement of reflectance can be made in any laboratory by direct comparison with a calibration standard. In the case of fluorescence, however, no absolute standard exists at present, and only relative intensity measurements can be reported. These can be given where the relationship sought is only between measurement within a group taken at one time under the same experimental conditions, or in reference to a relative intensity standard such as uranyl glass (Taylor et al., 1998).[13]

Numerous parameters for spectral fluorescence can be determined (Van Gijzel, 1982).[14] The most commonly applied maturity measure is the red/green quotient:

$$\text{The spectral ratio } Q = \frac{\text{Relative intensity at 650 nm}}{\text{Relative intensity at 500 nm}} \qquad (1)$$

The spectral ratio red/green is, in essence, a measurement of the relative proportions of more to less polymerized structures (Taylor et al., 1998).[13]

The ratio R/G was took of Van Gijzel, 1982 [14] who used it in fluorescent reflected light of polish section.

Image analysis is the process of evaluating the information contained in a digital image. The quantitative description of images usually involves two main types of information: geometric data and densitometric data, describing the distribution and relative or absolute levels of light and dark within the image. Both are essential for kerogen studies (Tyson, 1990). [12]

Prior use of image analysis for organic matter applications include automated characterization of sedimentary organic matter (Lorente, 1990)[15], automated means of optical kerogen typing to determine the probable hydrocarbon potential of the source rock (Tyson, 1990)[12], colour and grey level measurement of macerals for organic petrology (David and Fermont, 1993[16]; Cloke et al., 1995 [17]; Arango, 2004[18]), image analysis techniques for petrographic analysis (Highton et al., 1991[19]; Lester et al., 1993[20]; Lester et al., 2002[21]; Blandón and Restrepo, 2002[22]; Restrepo and Blandón, 2002[23]; Restrepo, 2003[24]; Arango et al., 2003[25]; Arango et al., 2004[26]), and color image analysis to quantify changes in the spore color (Yule et al., 1998[27]).

A simple and rapid technique is presented in the present study, based on image analysis, to measure the palynofacies fluorescence intensity, and the results are applied to the vertical variation in a coal seam of the lower Tertiary Amagá Formation in Colombia. A fluorescence index is proposed based on red (R) and green (G) colors. The shape factors were measured in two pollen grains so as to differentiate them.

2. METHODS

2.1 Description and sample preparation

The coals sampled in this study are sub-bituminous (vitrinite reflectance of less than 0.4%), with a high vitrinite and liptinite content (normally greater than 60% and 10% respectively) and a very low inertinite content (less than 5%). Most of them have sulphur content lower than 1.0%.

Coal samples were collected from seam 1 of the El Bloque mine (Fig. 1). The seam was subdivided macroscopically into lithotypes assemblages (ply, Thomas, 2002)[28]. Ten ply channel sampling were taken: one in each subdivision of the seam (samples 1 to 10). The main lithotypes are durain in various forms, and vitrain (Fig. 1). The seam also contains shales (inter-layered) and coaly shales (underlay and overlay samples). But here only the coal samples will be analyzed

Preparation for palynofacies analyses was carried out using the Adapting palynological preparation method Blandón et al. (2008)[5], which has advantages over the conventional method based on HCl and HF to observe the organic matter in the coals, because the majority of the coal particles are black and their individual components, such as vitrinitic tissues, cannot be distinguished. This preparation was made with a non-fluorescent resin (eukit ®), which gives high quality contrast (bi-modal) with the fluorescence of the organic matter. The preparation shows the particles when they are isolated. This facilitates the automatic identification in image analysis.

The maceral group point-count was done on polished coal sections observed under fluorescent light and white light, in which 500 points were measured. (ISO 7404-3, 1994).

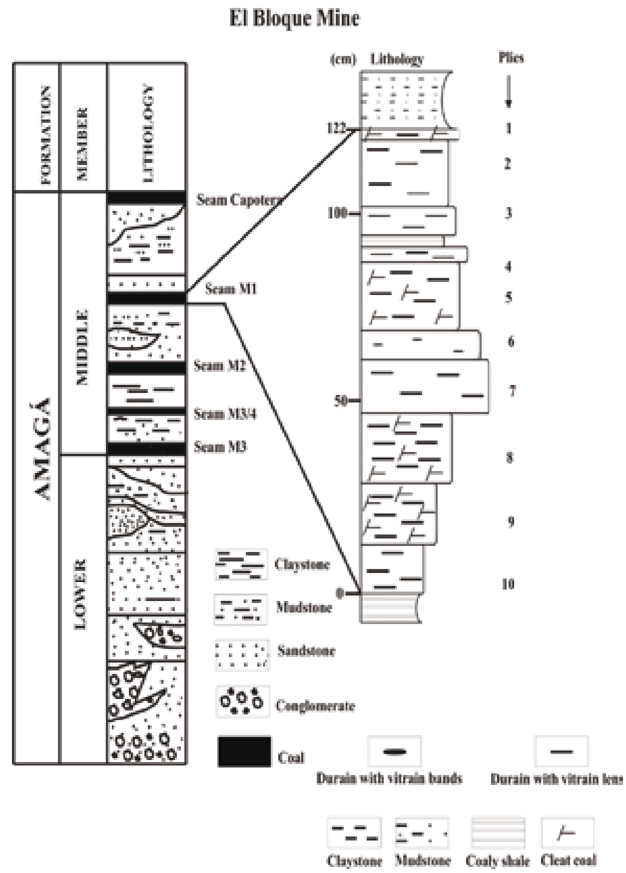

Fig.1. Coal seam of the “El Bloque” mine

2.2 Image analysis

Prior to the analysis of the image, the following steps are necessary: acquisition, pre-processing and segmentation. The images are then measured and analyzed. To standardize the image capturing, it is necessary to establish appropriate conditions for the microscope and the CCD camera. These conditions depend on the resources of the laboratory and the technical characteristics of the CCD camera. The equipment used consisted of a Pixera Pro 150 ES camera and an Orthoplan MPV Combi Leitz petrographic microscope with high pressure mercury HBO lamp for fluorescence observations. The conditions used were, a time exposure of 8s, a sensitivity of 400 ISO, blue light excitation and the image format used was “jpg”.

The segmentation is the partitioning of a digital image into multiple regions (set of pixels), according to some criterion. In this case distinguishing the colour images of the organic matter (foreground) from the resin (background) and turning these into black and white images.

The method employs two steps: first, analysis of the fluorescence using the G/R index, and second shape analysis of the particles involving studying the shape contours and morphology on interiors of the particles, (Figure 2).

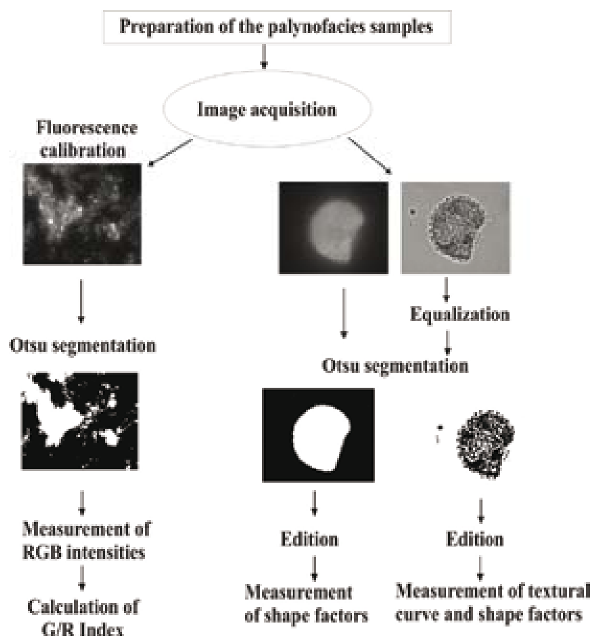

Fig.2. General scheme for image analysis.

Step 1: (Measurement of the total fluorescence for the palynofacies)

The color images have three channels, Red, Green, and Blue. In order to increase the contrast was made a equalization. Then the image of color is converting to gray level, according to characteristics of the object, high levels belonging to fluorescent particles, and low levels correspond to the background, which is observed in the histogram and for this reason is possible to apply an Otsu algorithm because permit to do a bimodal separation, Figure 2 The particles that have a high fluorescence level are the white ones in this case. And the binary image was used to identify fluorescent organic matter, and to measure the values of intensity of the RGB channels in each fluorescent object.

The average and standard deviation are measured from the gray levels of each channel. Fifty images of the palynofacies each coal ply were captured using a 20x fluotar objective. For each coal ply the average, medium, and standard deviation of the RGB intensities was measured. These measurements represent the variation of fluorescence intensity; that is the variation of the organic matter present in the sample (Arango et al., 2004) [26].

To analyze the fluorescence colors, the most important channels are red and green. The combination of red and green generates the color of the particles. These are studied using the G/R index. Brown colors signify an abundance of red components and yellow colors signify the same amount of red and green colors. Examples of fluorescence in sedimentary organic matter are shown in Figure 3**.**

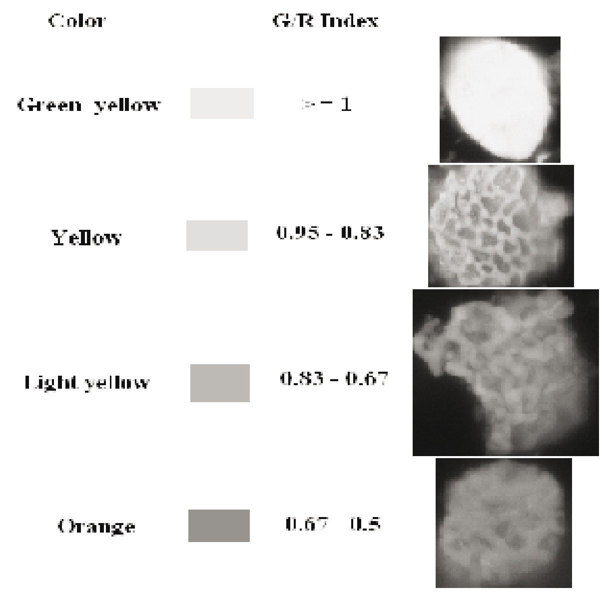

Fig.3. Colour index G/R based on digital images.

Step 2: (Measurements of the shape factors and textural index).

Morphologic mathematics was used for description of the pollen grain textures, through a textural curve. Some shape factors were also measured. These tools show differences between the pollen grains and other types of organic matter.

Index of elongation. Eq. (2) It is an index very common and it is used in grain or cells that are appreciably elongates. This index has the value one when the particle is equiaxial; when the particle is more elongated the relation is greater than one.

$$Q = \frac{Large}{Wide} \qquad (2)$$

The roundness index describes the relation between the perimeter and the area Eq. (3) the value 1.064 is an adjust factor that it corrects the perimeter effect of corners produced by the digitization of the image.

$$Roundness = \frac{perimeter*perimeter}{4*\pi*Area*1.064} \quad (3)$$

The Fc ratio characterizes the deviations of convexity. Clearly one convex figure has the value one Fc = 1, while that for other cases Fc < 1. *A* is the area of the particle. *A (convex)* is the area of the shell convex of the particle. Eq.(4)

$$Fc = \frac{A}{A(convex)} \quad (4)$$

Cyclusphaera and Spirosyncolpites were used to shape factor study, because this association of sporomorphs are characterizing and appear in proportion major in the samples that have the best source rock potential, furthermore this type of association is common in almost every coal samples.

The objectives of digital image analysis (DIA) are to identify and to quantify the elements that comprise the palynofacies. For DIA this task is complex due to the diversity of elements within the palynofacies. For this reason this paper limits itself to evaluating the texture using morphological mathematical operations and the shape factors such as roundness, aspect ratio and fullness ratio. Cyclusphaera sp and Spirosyncolpites spiralis (Figure 4) are two pollen species found among the palynofloras of the Amagá coals. These grains are analyzed using DIA. External and internal characteristics were measured in binary images of a range of pollen grains. These images were obtained through a process of global segmentation that uses the Otsu algorithm (Otsu, 1979)[29].

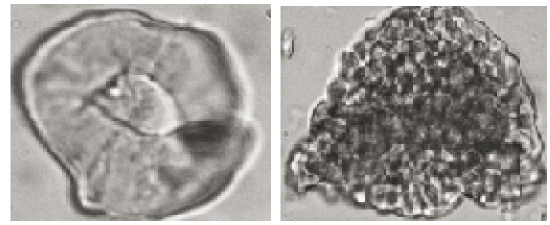

Fig.4. Ciclusphaera and Spirosyncolpites images in transmitted light.

Some artificial models of pollen grains were constructed (Figure 5 and 6). *Cyclusphaera* in its optimal view is represented as an ellipse with an ellipsoidal cavity. “Half ellipses” with an interior cavity represent fragments of *Cyclusphaera*. For *Spirosyncolpites,* the model representation is built with a circumference that is filled with circular cavities that represent the texture of the ornamentation of this species. When this curve is applied to describe the ornamentation, it is related to the cavities on the inside of the grain. The texture is based on distance to measure the shape of the pores Alvarez et al. (1997)[30], However another strategy was developed that consists of identifying the walls of the object, in this case represented by the black pixels in the segmented image of the pollen grain. The distance function is applied to these walls and this generates a second image. In these images the number of pixels is measured by gray levels and the texture curve is built with these results using the following equation:

$$Yn=(Yn-1+Xn) \quad (5)$$

n = is the distance in pixels,
Yn is the total of pixels at a level *n*
Yn-1 is the total of pixels at a level *n -1*
Xn = it is the quantity from the pixels to a distance *n*

A polynomial regression of second degree was applied in the textural curve, and then the coefficient of X_2 is used to describe the pollen grain texture. Besides the shape factors, the G/R index was measured to explore if the fluorescence could be what differentiated the two species.

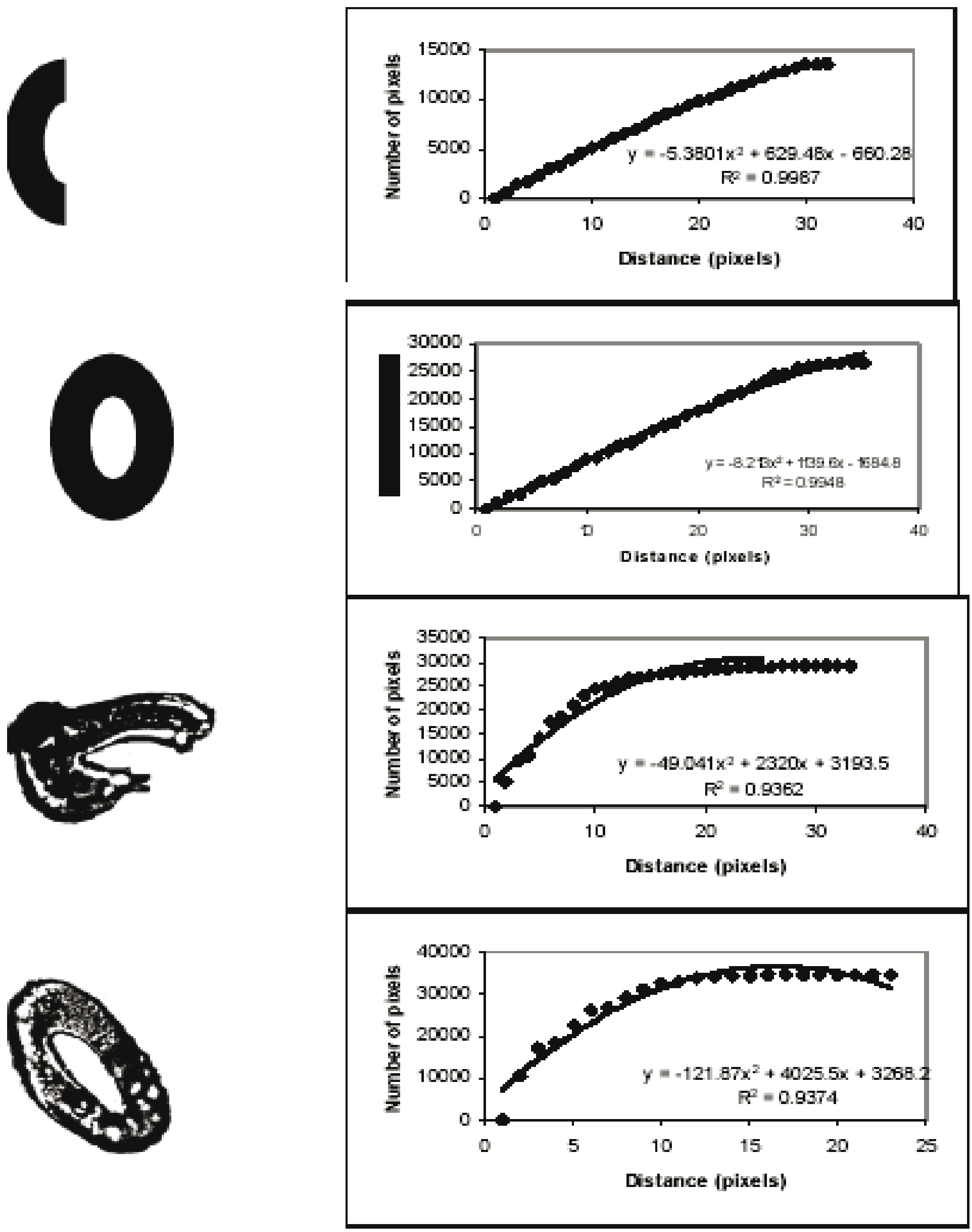

Fig.5. Models and real pollen grains of *Ciclusphaera.*

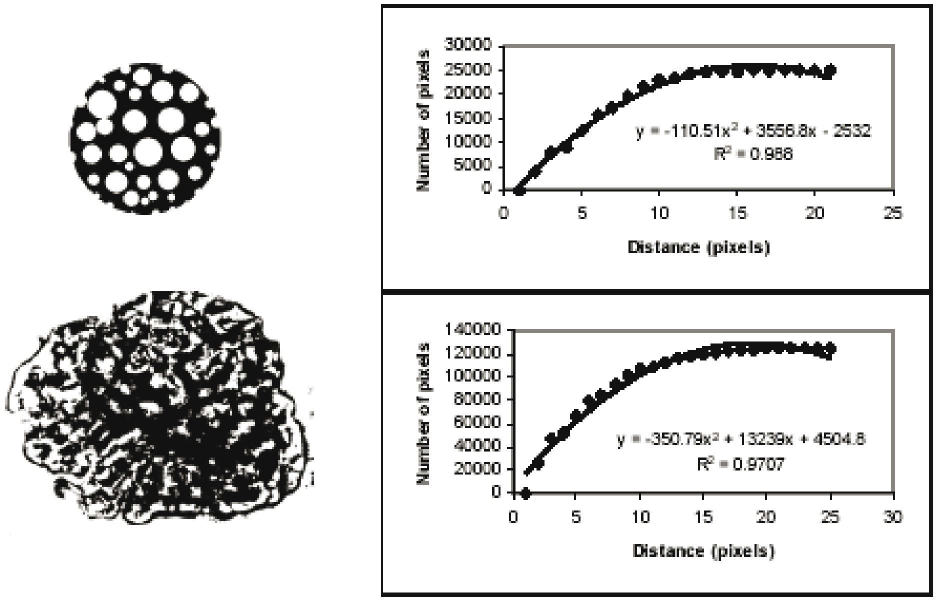

Fig.6. Models and real pollen grains of *Spirosyncolpites*

3. RESULTS

3.1 Image analysis step 1

The image analysis of the color of fluorescence of the palynofacies compared to the percentage of liptinites and Rock-Eval data (HI and S1/TOC) shows relationships that can explain hydrocarbon generating potential. For example, coal ply 3, contains the lowest percentage of liptinites, HI, S1/TOC and less fluorescence intensity. Coal plies 2, 4, 5, 6, 7, 8, 9 and 10 have characteristics similar to those mentioned above, but the plies, 1 and 4 which has the highest hydrogen index, percentage of liptinites, and S1/TOC, has lower fluorescence intensity (figure 7). This can be due to two factors: (1) bitumens expelled during sample preparation to decrease the fluorescence intensity; and (2) capturing and acquisition of the image and the segmentation introducing some problems in the representation of the palynofacies. For the samples studied it is possible to conclude that fluorescence in the palynofacies mainly relates to the S1/TOC parameter (Figure 7).

In the seam 3 of the Bloque mine the ply 4 that have high liptinitic content, HI, and S1+S2/TOC, present the lowest ratio G/R. This situation confirm the major liberation of soluble components (bitumen) and for this reason the best potential of this sample. This results permit to use the ratio R/G as additional parameter to evaluating the source rock potential of coal samples; specially, when large differences between samples exist, such as the ply 3 and 4.

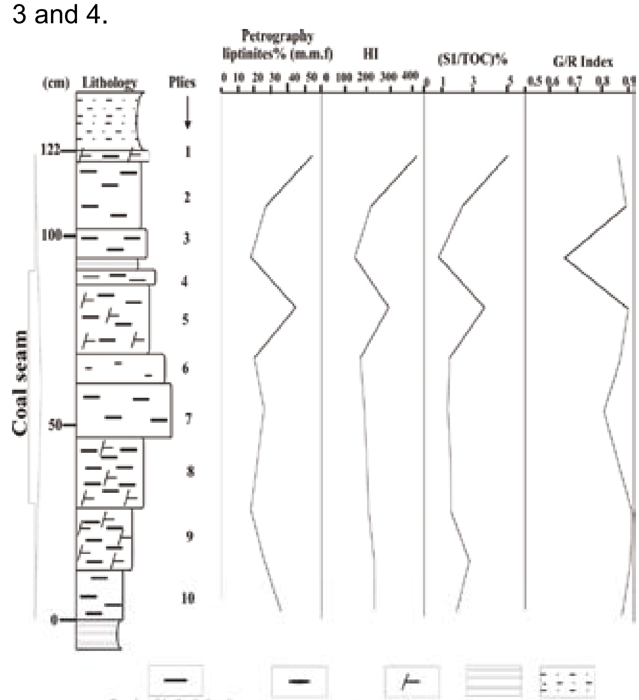

Fig.7. Variation with depth of palynofacies for G/R index (measured with image analysis), S1/TOC, percentege of liptinites, and hydrogen index.

3.2 Image analysis step 2

Qualitative description:

Generally the problems with studies of pollen grain shapes are because some grains do not have a well defined shape or they are fragments, deformed grains, or are badly focused.

Qualitative evaluation of the pollen grains was also made. Two petrographers classified the sorted the binary images into three groups: “excellent” images that allow identification of the species studied; “regular” images that have an uncertain grade of identification and “poor” images, where it is not possible to identify the pollen grains (Figure 8).

The intensity level of the red channel and the color index of the pollen grains have similar properties for *Cyclusphaera* and *Spirosyncolpites* such that differentiation is not possible. For this reason other parameters are used.

The “excellent” images of *Cyclusphaera* in an equatorial view have an ellipsoidal shape with an ellipsoidal cavity. The “regular” images of *Cyclusphaera* represent grains with boundaries describing figure eights, U-shapes, or semi-circles. These grains may also have irregular shapes and edges. The ‘poor’ images of *Cyclusphaera* do not have double edges, are not curved, and are in general continuous masses.

The “excellent” images of *Spirosyncolpites* have wavy borders, rounded shapes, and cross-linked structures that generate a well-defined texture in the segmented images. The “regular” images of *Spirosyncolpites* are fragments of grains that do not have well-defined textures. The “poor” images of *Spirosyncolpites* do not have a well-defined texture and they have sharp borders rather than a rounded form.

Measurements using the internal and external shape:

The texture index (TI) is more negative when the shape has a larger quantity of cavities. Complete ellipses have larger TI than half ellipses with cavities.

When the TI is analyzed in segmented images of real *Cyclusphaera* it has a higher (-121.87) value than for theoretical model shape (- 8.2), because the model elaborated is smooth while that true images have cavities on the interior, Fig. 5. Grains fragmented have larger indices than images of *Cyclusphaera,* with large interior cavities.

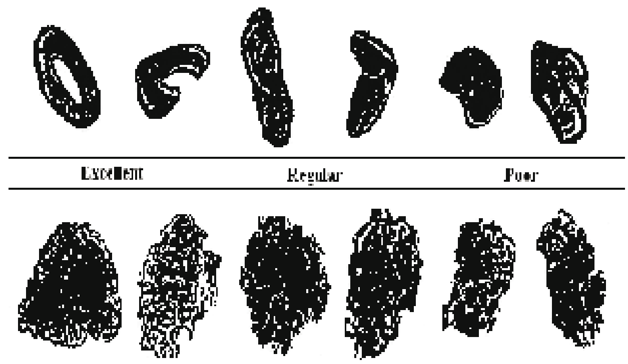

Fig.8. *Cyclusphaera* and *spirosyncolpites* images

In the case of *Spirosyncolpites,* a rounded body with pores was used as a model, and it has a TI value of -110.51, which is more negative than that of the *Cyclusphaera* models or that of real fragments of *Cyclusphaera.* This is due to the fact that the index detects the effect of the pores. In the case of the real *Spirosyncolpites,* the effect of the pores leads to values of -350.79, Fig. 6. This is consistent with the results presented by the models. This gives the possibility to differentiate the two species by analyzing the texture.

However, when the results of this index are analyzed for the real images, the two species do not differ and their mean is similar when using the student T-test. The previous results are due to the existence of two situations for the segmentation. Firstly, for *Cyclusphaera,* the global algorithm does not represent the pollen grains in a continuous manner and it gives a very porous image, such that TI values are high. Secondly, *Spirosyncolpites* present problems in segmentation: many walls are not detected because the pollen grain is out of focus and it generates large dark masses in the image. These factors cause the two species to have problems when being identified using TI. It should be noted that the texture strategy does not differentiate the space distribution of the pores because although walls of similar sizes can exist, the form is qualitatively different.

Texture vs roundness
Similar to the TI, the factor of roundness is not able to differentiate the two species, because this factor increases its value when the perimeter is larger due that the binary images have increased, Fig 9.

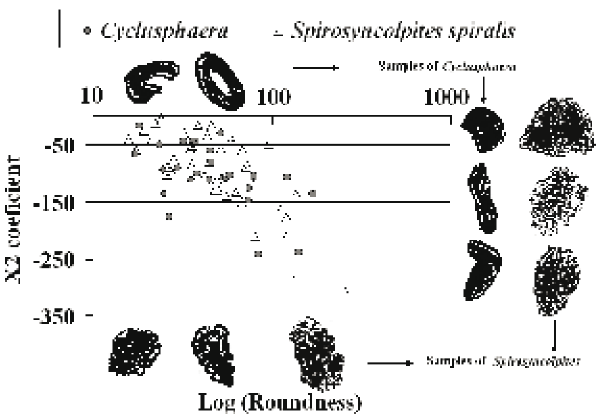

Fig.9. Textural index vs. roundness

Texture vs aspect ratio
With the aspect ratio, some grains can be identified because of differences between the species. The *Cyclusphaera* is much more elongated than *Spirosyncolpites*, which generally has a rounded shape. Some fragments of *Spirosyncolpites* however have elongated shapes, which may cause some mistakes in its identification, Fig. 10

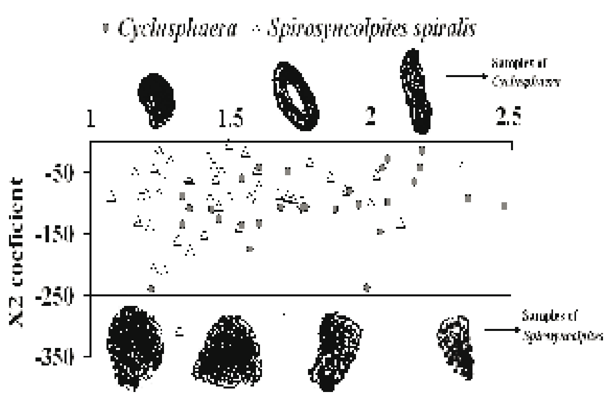

Fig.10. Textural index vs. aspect ratio.

Texture vs fullness ratio
The fullness ratio of *Cyclusphaera* has values below 0.8, indicating that it has more undulations in its external form than *Spirosyncolpites*. Both species have values less than 0.9, due to internal porosities, Fig. 11.

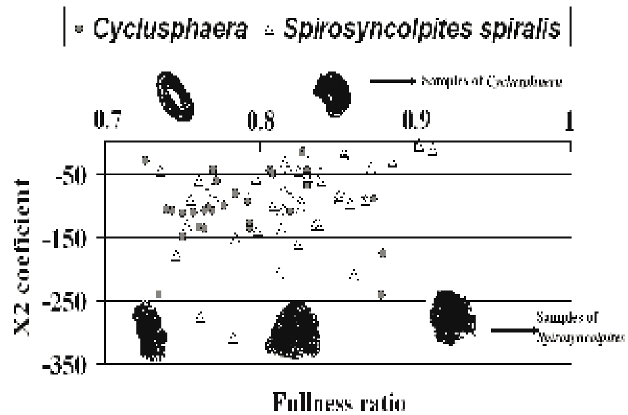

Fig.11. Textural index vs. fullness ratio

Measurements of external shape:
Before measuring the images, there was pre-processing: first the pollen grain images were reduced in size; second the images were edited, eliminating holes in the grains. After this, their external shapes were measured with respect to "roundness factors" and of "fullness ratio". These results could be a tool for recognition of species. *Spirosyncolpites* has a fullness ratio between 0.85 and 0.96 and a roundness above 1.6, which indicates that the *Spirosyncolpites* tends to a rounded shape but with a wavy outline, which is due to ornamentation. In contrast, *Cyclusphaera* has a fullness of 0.85 up to 0.95 and roundness below 1.5 because of curved outlines. Some images of *Cyclusphaera* grains have fullness ratio values below 0.85 and roundness values between 1.5 and 2.5. This is due to perimeter changes which cause the grains to have irregular shapes, Fig. 12

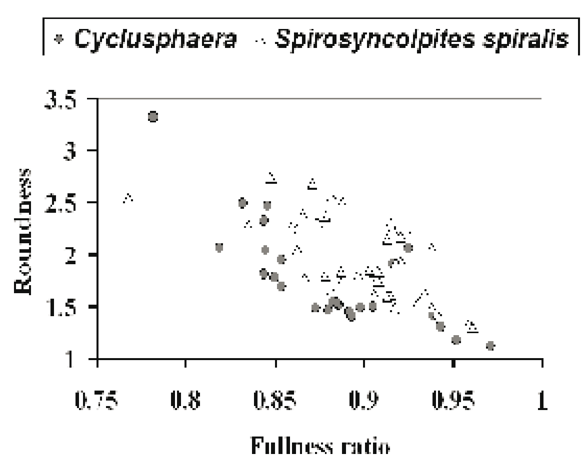

Fig.12. Roundness vs. fullness ratio (external shape)

Red intensity vs. G/R index for pollen grains: The intensity level of the red channel and the colour index of the pollen grains have similar properties for *Ciclusphaera* and *Spirosyncolpites* such that differentiation is not possible. (Figure 13) For this reason other parameters are used.

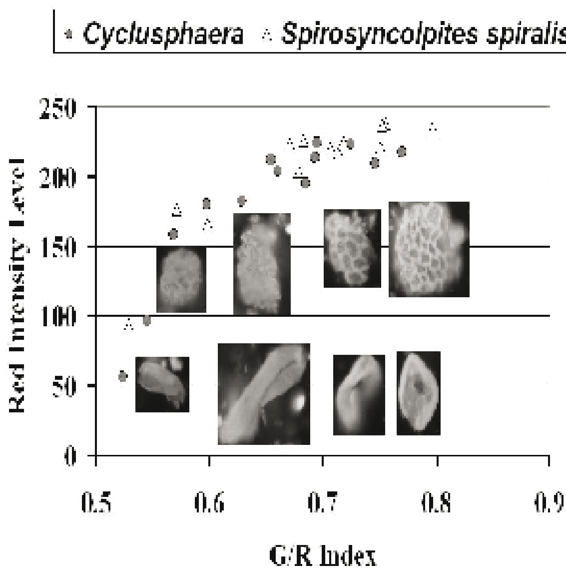

Fig.13. Red intensity vs. G/R index for pollen grains (*Ciclusphaera* and *Spirosyncolpites*).

4. CONCLUSIONS

Characteristics of palynomorphs such as shape, texture, color, and fluorescence intensity can be studied using image analysis with the objective of collect quantitative information.

The total fluorescence of palynofacies assemblages using the G/R color index (measured with image analysis) relates to other measurements such as liptinite percentage, HI, and S1/TOC. However the closest relationship exists with S1/TOC.

The shape factors used enables identification of some pollen grains of the two species studied, but problems related to fragmentation, focus, uneven boundaries, and segmentation, may decrease effectiveness in differentiation of species.

Qualitatively, *Cyclusphaera* occurs in more elongated shapes than *Spirosyncolpites* which has rounded shapes, wavy outlines, and reticulated textures.

The ornamentation of pollen grains can be differentiated using a textural index. There are differences between textural models and the porosities appearing in the real images do not allow thorough identification. This is because the segmentation process does not represent *Cyclusphaera* correctly and the images appear very porous. For *Spirosyncolpites,* poor focus affected the segmentation. This work also has found difficulties in the identification of pollen grains due to the loss of information with segmentation. The shape factors used give difficulties in identifying differences between pollen species. Also, the shape factor values reported may change when analysing fragments or folded pollen grains, which create difficulties for the analysis.

The present study indicates that shape factors and textural curves used in conjunction with fluorescence intensity are elements that could be used in discriminating some types of organic matter in palynofacies.

5. ACKNOWLDGEMENTS

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