

# SPECTRAL REFLECTANCE (400- 2500-nm) OF VOLCANIC ROCKS FROM THE PARANÁ BASIN

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## INTRODUCTION

The Mesozoic volcanic activity in the Paraná Basin is presently observed in an area of about  $1,2 \times 10^6$  km<sup>2</sup> in southern Brazil and portions of northwestern Uruguay, southeastern Paraguay and northeastern Argentina. In recent years, detailed petrogenetic and geophysical studies were carried out in the Paraná Basin with the purpose of evaluating the implications of such voluminous magmatism in the Jurassic-Cretaceous continental break-up and opening of the South Atlantic Ocean (Piccirillo & Melfi, 1988). One of the most interesting results of that project is that, petrologically, the basin can be compartmented into three regions: the region north of the Rio Piquiri Lineament; the area south of the Rio Uruguay Lineament; and the intermediary zone between the Rio Uruguay and Rio Piquiri Lineaments (Piccirillo *et al.*, 1988). The northern region is characterized by basic and acid volcanics with high contents of TiO<sub>2</sub> (more than 2% wt.) and of incompatible elements. The southern area is characterized by basalts overlaid by silicic volcanics with low contents of TiO<sub>2</sub> and of incompatible elements. The central area represents a transitional zone.

To evaluate the contribution of optical spectroradiometric studies to the above multidisciplinary effort, we have started a project that has the objective of identifying spectral relationships with the composition of major volcanic lithologies and the possibility of their spectral discrimination.

In this paper, we discuss our preliminary results from 77 selected samples from a total of more than 1000 hand samples: 15 andesi-basalts; 15 rhyodacites; 12 andesites; 8 dacites; 7 tholeiites; 5 latianandesites; 2 latibasalts; and 1 transitional basalt.

## SPECTRORADIOMETRY

Bidirectional Reflectance Factors (BRF) were determined with an IRIS (Infra-Red Intelligent Spectroradiometer) that makes readings at 2 nm intervals from 300- to 1000-nm and at 4 nm intervals from 1000- to 2500-nm. Small illumination and viewing angles (less than 20 degrees) provide a near nadir geometry in relation to the surface of the volcanic sample and of the reference standard (spectralon), illuminated by a 600 W tungsten lamp.

The spectra were smoothed by a moving average procedure and analysed by Principal Components. For each spectrum, we obtained the values of narrow bands (width of 10 nm) at 100 nm intervals, in order to determine a correlation matrix from which eigenvalues and eigenvectors were calculated. Spectral similarity relationships were then obtained from the projection of principal components scores as described in Galvão *et al.* (1994).

The relationship of reflectance with chemical composition was also analysed for three major lithologies: basic volcanics (less than 53% of SiO<sub>2</sub>); acid volcanics (more than 63% of SiO<sub>2</sub>); and intermediary volcanics (SiO<sub>2</sub> between 53 and 63%).

## RESULTS AND DISCUSSION

The eigenvectors obtained for the narrow bands of the 77 spectra provide an indication of the spectral characteristics, that are responsible for the statistical variance of the data set. The first component, that contains 90% of the data set's variability and shows constant weight factors throughout the spectrum, provides a measure of the variation of the albedo of the volcanics. The second component is a reliable indicator of spectral slope.

Figure 1 shows the first two PC scores of the 77 volcanics and provides a good visualization of the similarities among the samples, which are given by their relative proximity. In general, the mafic samples are located on the left side of the central portion of Figure 1, whereas the more acidic samples are distributed in the center and towards the right side and are more spread out than the mafics. Such distribution is related to several factors.

The albedo of each spectrum increases from the left to the right of Figure 1, along the PC1 axis, as illustrated in Figure 2a by the spectra of samples A, B, C and D. In this same illustration, we can observe that spectra with low albedo (sample A) are relatively flat and absorption features are subtle, but as the albedo increases, absorption features become more conspicuous. In Figure 2a, the 1400- and 1900-nm absorption features shown by the samples C and D are related to the vibrational overtones and combinations of OH and H<sub>2</sub>O (Hunt *et al.*, 1973). In B and A, the OH-H<sub>2</sub>O related features are attenuated possibly because of opaques (ilmenites and titanomagnetites) that occur in the more mafic volcanics. Opaques tend to lower the overall reflectance and to flatten the spectrum (A in Figure 2a). Absorption features under 1000 nm are possibly related to the presence of iron oxides and when less opaques occur, such as in B, C and D (Figure 2a), such features become prominent. The iron in minerals such as pyroxenes and olivines causes strong absorptions around 900 nm (Hunt *et al.*, 1974).

In Figure 2b, the spectra of samples E, F and G exemplify the variations along PC2 of Figure 1. It should be noticed that the three spectra have approximately the same albedo and the only difference among the curves is in the shape and slope. As a result, any time we plot spectra with the same albedo (same PC1 value), the curves show a spectral inversion from the visible (VIS) to the near-infrared (NIR): spectra with higher PC2 values (such as E in Figure 1) present a decreasing slope towards the NIR; spectra with lower PC2 values (such as G in Figure 1) present an increasing slope towards the NIR. As a result, NIR/VIS ratios have higher values as we go towards the bottom of Figure 1, and vice-versa.

In Figure 3a we show the correlation between spectral reflectance and the oxide composition of the 77 samples. For an adequate graphic representation, curves of correlation for MnO and P<sub>2</sub>O<sub>5</sub> were omitted. Figure 3a shows that the best negative correlations were obtained for FeO and CaO, whereas the best positive correlations were given by K<sub>2</sub>O and SiO<sub>2</sub>. Therefore, as the content of FeO and CaO increases, reflectances tend to decrease, but they will increase when K<sub>2</sub>O and SiO<sub>2</sub> contents also increase. Returning to Figure 1, the contents of FeO in the samples tend to increase in samples located towards the left, in association with the decrease in albedo.

The correlation with chemical composition was also obtained for the three groups: basic, acid and intermediary volcanics. Figure 3b shows the result of correlation for the silicic volcanics (rhyodacites and rhyolites). The best negative and positive correlations

were obtained for FeO and K<sub>2</sub>O, respectively. We will discuss, in detail, only the correlations for the rhyodacites.

In Figure 1, the rhyodacites are found in two subgroups: respectively in the left and the right side of the graphic. Petrologically, the rhyodacite samples from the left side have aphyric to subaphyric and hyaline to hypohyaline textures. Pheno- and microphenocrysts of plagioclase, pigeonite, augite, orthopyroxene and opaques (titanomagnetite and ilmenite) occur in the groundmass made up of glass, opaque microlites and accessory apatite. In the second group (right side), the microphenocrysts occur in a quartz-alkali feldspar felsitic groundmass. As a consequence, rhyodacites from the second group have more K<sub>2</sub>O and less FeO than those from the first group. This is in agreement with Figure 3b that indicates that reflectance will be higher when the sample has higher contents of K<sub>2</sub>O (positive correlation) but lesser contents of FeO (negative correlation).

These considerations are emphasized in Figure 4 that shows, for the rhyodacites, the variations in FeO, K<sub>2</sub>O and TiO<sub>2</sub> for samples H, I, C and D (Figure 1) with increasingly higher albedo. As the albedo increases from H to D (from left to right of Figure 1), the contents of FeO and TiO<sub>2</sub> decrease, but the contents of K<sub>2</sub>O increase. The TiO<sub>2</sub> content in the samples presents the same behavior as the FeO content because of the existence of a positive correlation between TiO<sub>2</sub> and FeO.

## CONCLUSIONS

Our preliminary results indicate that PC analysis of BRF determinations can provide some insights on the composition of volcanics from the Paraná Basin, in relation to their spectral discrimination. The analysis highlighted the relationships of FeO, SiO<sub>2</sub>, K<sub>2</sub>O, CaO and TiO<sub>2</sub> with reflectance. Because compositional variations are good indicators of the mafic/felsic character of the volcanics, their relationships with albedo and spectral shape and slope are important.

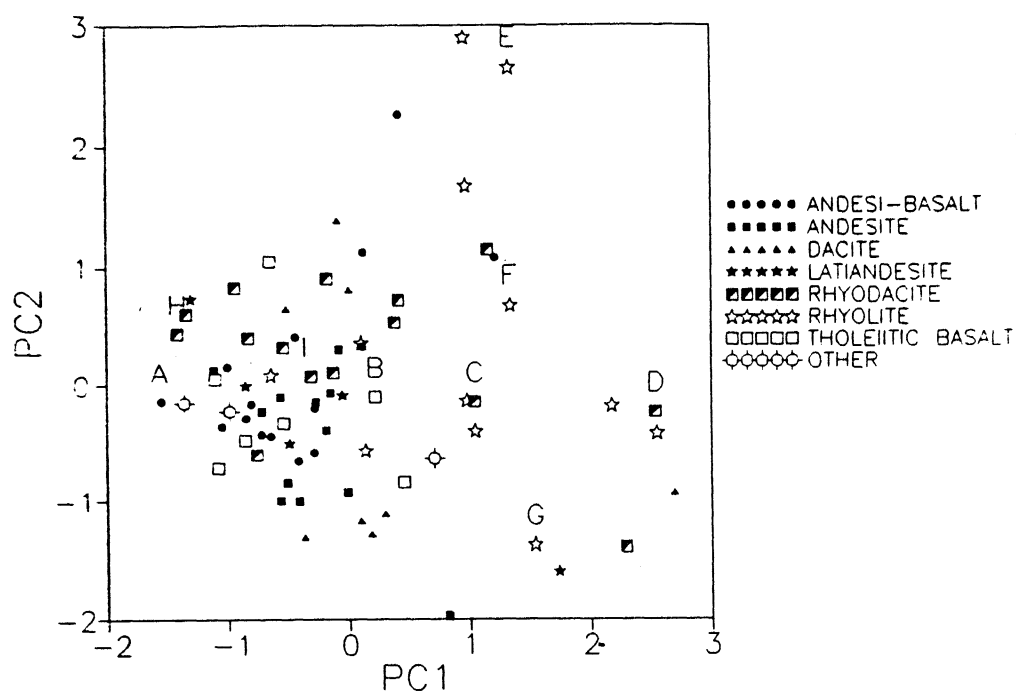
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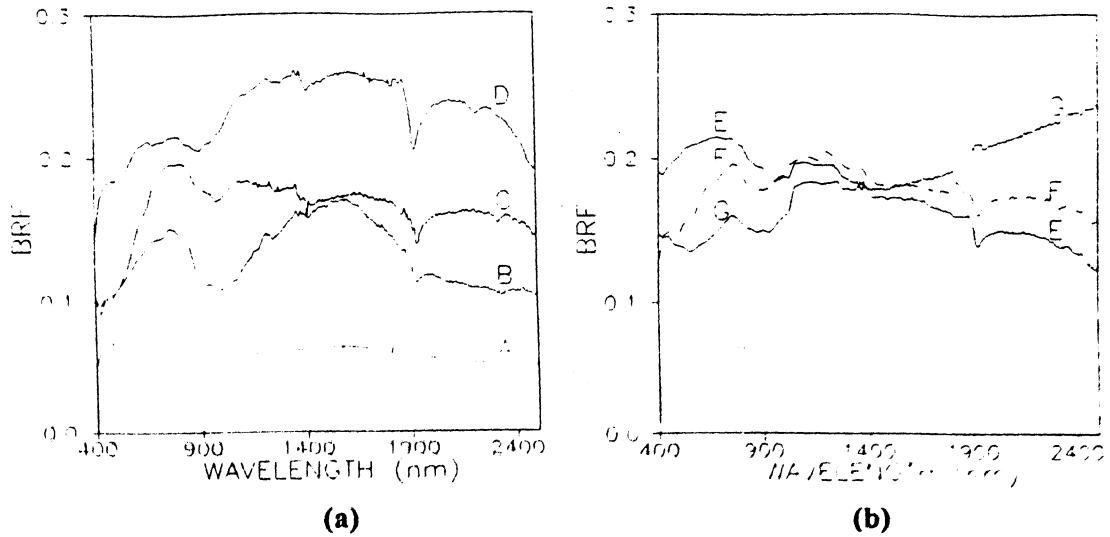
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**Figure 1- First two principal components scores of 77 volcanic rock samples from Paraná Basin. The albedo increases from the left side to the right side of PC1. The slopes of the spectra, represented by near-infrared/visible ratios, tend to increase from the top to the bottom of PC2. Spectra of samples A to G are shown in Figure 2.**

**Figure 1 - Les deux premiers "scores" des composants principales de 77 échantillons de roches volcaniques du Bassin du Paraná.**

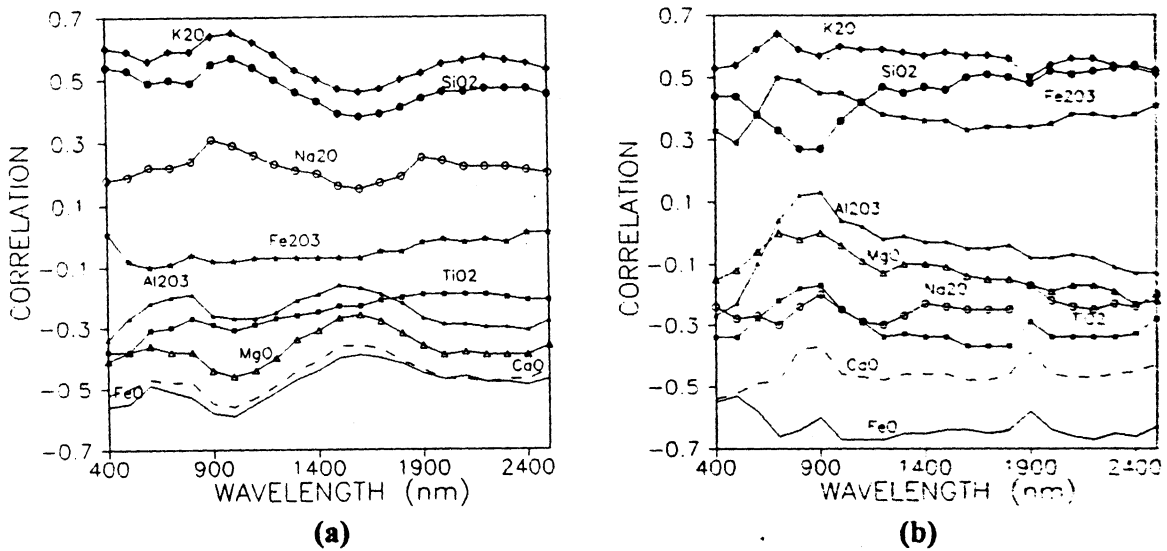
**Figura 1 - Los dos primeros "scores" componentes principales de 77 muestras de rocas volcánicas de la Bacía del Paraná.**



**Figure 2 - Spectra illustrating increasingly higher albedo along PC1 in (a), and the effect of spectral inversion along PC2 in (b). The volcanic rocks are: A = andesi-basalt; B = tholeiitic basalt; C,D = rhyodacites; E to G = rhyolites. The position of the samples in the PC space of Figure 1 is indicated by the same reference letters.**

**Figure 2 - Exemple de spectres de réflectance sur PC1 (albedo) en (a), et sur PC2 (inversion spectrale) en (b).**

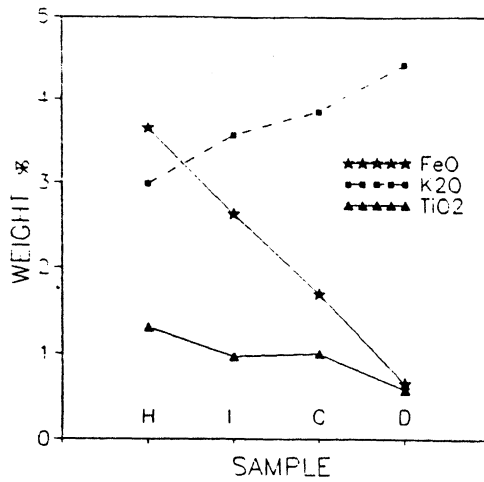
**Figura 2 - Espectros ilustrativos del crecimiento del albedo en PC1 (a), y del efecto de inversión espectral asociado a PC2 en (b).**



**Figure 3 - Coefficient of correlation between chemical composition and reflectance of 77 volcanic rock samples in (a), and of 27 acid volcanic rock samples in (b).**

**Figure 3 - Coefficient de corrélation entre la composition chimique et la réflectance de 77 échantillons de roches volcaniques en (a), et de 27 échantillons de roches volcaniques acides en (b).**

**Figura 3- Coeficiente de correlación entre la composición química y la reflectancia de 77 muestras de rocas volcánicas en (a), y de 27 muestras de rocas volcánicas ácidas en (b).**



**Figure 4 - Chemical variation (wt. %) of FeO, K<sub>2</sub>O and TiO<sub>2</sub> for rhyodacite samples positioned along PC1 axis in Figure 1.**

**Figure 4 - Variation chimique (%) de FeO, K<sub>2</sub>O et TiO<sub>2</sub> pour les échantillons de rhyodacites sur PC1 de la Figure 1.**

**Figura 4 - Variación química (%) de FeO, K<sub>2</sub>O y TiO<sub>2</sub> para muestras de "rhyodacites" posicionadas en el eje PC1 en la Figura 1.**