RCGb INDEX: A TOOL FOR MAPPING THE DEGREE OF WEATHERING IN THE TROPICAL SOILS IN BRAZIL

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1. INTRODUCTION

In the Cerrado region the presence of classes of soils that possess perceptible mineralogical variations is common. Those classes cannot be separated with the methods adopted in the usual soil surveys.

The mineralogical variation of the soils is studied by means of the analysis of samples collected in the field. For mapping, the extrapolation of the punctual values used morphologic approaches of correlation with the topography, with the origin material, etc.

The discrimination of the soils with various contents of kaolinite and gibbsite is not reliable for field approaches. Though the variability of these two minerals can be assayed, a systematic sampling with high density of points would be necessary. This procedure would increase the cost of the projects.

That limitation has led to a search for new techniques and resources to increase the understanding of the pedologic covering. Recent progress in the acquisition of images of remote sensing has been introduced as an alternative to the usual method.

Now the studies related to the remote sensing change the actual paradigm, with the appearance of the hyperspectral systems sensor. The main difference between those two types of sensor systems is in the spectral resolution.

The hyperspectral sensor now in operation is AVIRIS (Airborne Visible/InfraRed Imaging Spectrometer), property of the Jet Propulsion Laboratory (JPL/NASA). It is an airborne system composed of four spectrometers that give images continually scan the reflected optical spectrum from 0.4 to 2.5 µm, in 224 bands, with widths of 10 nm approximately.

The obtained data by that sensor system allow the analysis of the reflectance spectra of the different targets that compose the scene. In these spectra they meet spectral features or absorption bands of the main mineral components of the soils. Those features result of quantum events, the interactions of the discreet electromagnetic radiation with the particles, the atoms and the molecules, in certain wavelengths.

The spectral analysis and the multispectral remote sensing data has been used for the detection of the occurrence of some of the main components of the tropical soils, as shown by Hlavay et al. (1977); Madeira Netto (1993); Madeira Netto et al. (1997) and others.

Those studies however have shown the possibility of the use of radiometric spectra for the definition of occurrences and mineral content variations.

One of the most important aspects in the understanding of the pedologic environments is the different weathering degrees of the soils. The knowledge of space variation of the mineralogy is important for different reasons: it permits to elucidate processes of genesis of the soils; it helps in the definition of more appropriate management systems; and it is an important factor for classification and mapping.

The present work presents the RCGb spectral index (Relation Kaolinite/Gibbsite), based on the method of three bands ratio (Gao et al., 1993). The method uses the spectra of pure minerals of the JPL spectral library (Grove et al., 1992) and validated the same spectra adopted by Madeira Netto being used (1993) for the construction of the IKi index. This method represents a new tool for mapping the weathering degrees of Brazilian tropical soils.

2. SPECTRAL CHARACTERISTICS OF THE MAIN MINERALS OF TROPICAL SOILS

Tropical soils are usually highly weathered, due mainly to warm and wet climate. Their mineralogy is characterized by a reduced number of components with kaolinite, iron and aluminum oxides as the most frequent minerals in the clay fraction and quartz in the sand and silt fractions. The amounts and proportions of these components are important for soil classification and management. The knowledge of reflectance spectra of these components is important for utilization of image spectroscopy for soil studies applications.

2.1 Kaolinite ($Al_2Si_2O_5(OH)_4$)

Kaolinite is the most frequent clay mineral found in tropical soils. Its reflectance spectra have characteristic sharp features in the reflected infrared region. The kaolinite presents its main spectra features associated to the molecular vibrations of the OH^- of its crystalline net. In the near infrared the most perceptible features are associated to the overtones of fundamental OH- stretching mode (2s) in 1400 nm and to combinations involving OH- stretching and Al-OH bending modes (d + s), in 2200 nm (Hlavay et al, 1977). Figure 1 presents the diffuse reflectance spectra of a kaolinite sample from Mesa Alta (New Mexico).

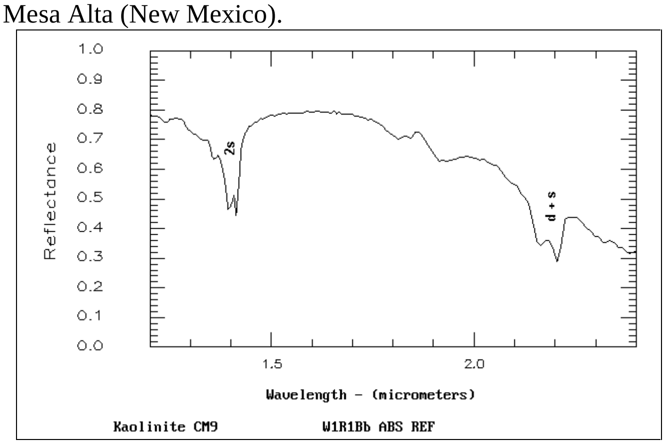

Figure 1. Diffuse reflectance spectra of a kaolinite sample, entitled CM9 of the USGS spectral library (Clark et al., 1993), from Mesa Alta (New Mexico), show absorption's band.

2.2 Gibbsite (Al_2O_3 $3H_20$)

Soils, which have been subject to pronounced alteration, like the oxisols located in the old erosion surfaces, may present a large amount of gibbsite on their composition. In some cases it may be the most important mineral in the clay fraction.

Gibbsite, as kaolinite, presents spectral features due to OH^- vibrations. In the near infrared gibbsite presents harmonic molecular vibrations (2s) close to 1550 nm and the combinations of the type d + s close to 2300 nm (Hunt et al, 1971). The bands of absorption of the water are shown to 1400 nm (2s) and to 1900 nm (d + s). Figure 2 presents the characteristic features of a gibbsite sample (HS423 of the library of USGS, Clark et al., 1993), from Brazil.

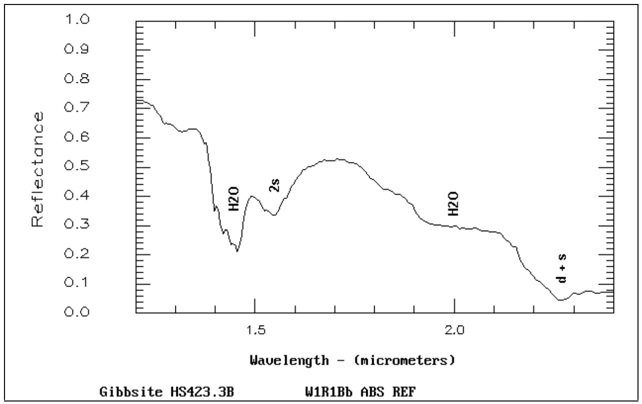

Figure 2. Characteristic features of a gibbsite sample (HS423 of the library of USGS), from Brazil.

3. DEVELOPMENT OF THE RCGb INDEX

For the development of RCGb we search for the spectral features of kaolinite and gibbsite to find an index that represents a Y scale similar or close to the Ki values. We used the spectra of the pure minerals of the JPL spectral library (Grove et al., 1992) entitled Kaolinite Well Ordered PS-1A and Gibbsite Synthetic OH-3A. Those spectra were resampling to the AVIRIS bands resolution. Later on, the spectra were integrated, by means of module spectral math, using 50% of each mineral for the formation of a spectrum, as it can be seen in Figure 3.

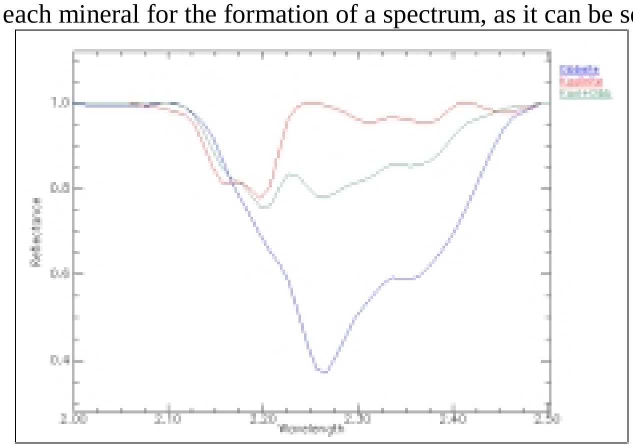

Figure 3. Spectra Kaolinite Well Ordered PS-1A (Kaolinite), Gibbsite Synthetic OH-3A (Gibbsite) (Grove et al., 1992) and the integration of 50% of each one to generate the spectrum Kaol+Gibb.

The proposed method is based on three points: the point at the beginning of spectral feature; the minimum reflectance point; and the point at the end of the spectral feature. To determine those points we used the procedure of continuum removed. The intensity of the spectral feature is directly proportional to the mineral content (Clark et al., 1990; Madeira Netto, 1993; Baptista et al., 1998).

For the elaboration of the index RCGb we also used the IKi index methodology (Madeira Netto, 1993), as can be seen in the equation 1.

$$RCGb = \frac{I_{kaol}}{I_{kaol} + I_{gibb}} \tag{1}$$

Therefore the procedure for the determination of Ikaol and Igibb was altered using the three band ratio procedure proposed by Gao et al. (1993). To determine the intensity of the mineral spectral features we use the average of the reflectance values at the beginning and at the end of feature minus the average of absorption points at the minimum reflectance. It’s worth noting that the kaolinite presents two points of minimum reflectance or an absorption doublet, which was used two points of minimum reflectance. Therefore Ikaol is determined in agreement with the equation 2.

$$I_{kaol} = \frac{(R_{2,127} + R_{2,226})}{2} - \frac{(R_{2,176} + R_{2,196})}{2} \tag{2}$$

where Ikaol is a value regarding intensity of the feature of the kaolinite, and R it is the reflectance value in the several wavelengths, adapted to AVIRIS bands.

The same procedure was adopted for the determination of the intensity of the absorption's feature of gibbsite, or Igibb, we just used a single point of minimum, as it can be visualized in equation 3.

$$I_{gibb} = \frac{(R_{2,226} + R_{2,335})}{2} - R_{2,266} \quad (3)$$

The reflectance value to 2,335 µm, was adopted as the terminal point of the gibbsite feature. It was determined by means of a heuristic method looking for the best adjustment. As can be seen in Figure 3 the gibbsite feature presents some internal inflection points before its end. These inflections are influenced by other elements or by the intensity of the noise.

An adjustment was also made to observe the determination of Igibb for laboratory spectra and for the AVIRIS data. Due to intensity of the noises in the final portion of the spectrum, we propose the use as the final point of the feature, the reflectance value at the first inflection at 2,286 µm for the AVIRIS data.

The model RCGb writing in the format ENVI® is presented in equation 4.

$$RCGb = (((b_1 + b_4)/2) - ((b_2 + b_3)/2))/((((b_1 + b_4)/2) - ((b_2 + b_3)/2)) + (((b_4 + b_6)/2) - b_5)) \quad (4)$$

Where b1, b2, b3, b4, b5 and b6 correspond respectively to the reflectance values in the wavelengths of 2,127 µm (band 186), of 2,176 µm (band 191), of 2,196 µm (band 193), of 2,226 µm (band 196), of 2,266 µm (band 200) and of 2,286 µm (band 202) (in the case AVIRIS data) or 2,335 µm (equivalent the band 207) (if laboratory spectra are used). The use of three band ratio procedure, besides the best Y scale adjustment, minimizes the noise found in the AVIRIS spectra.

Figure 4 presents the two integrated spectra, with the continuum removed, showing the six bands used in the RCGb spectral index.

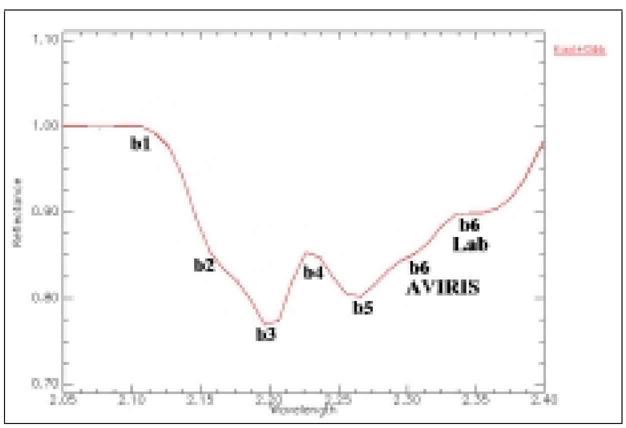

Figure 4. The six bands used in the RCGb spectral index.

4. SPECTRAL INDEX VALIDATION

To validate the RCGb spectral index we used the same spectra adopted by Madeira Netto (1993) for the construction of the IKi index, for 56 soil samples that corresponds to the surface and deeper horizons of 27 profiles of two main sources:

a) 25 samples, of the National Service of Survey and Conservation of Soils (SNLCS), corresponding to 14 profiles of representative Brazilian soils.
b) 31 samples of 13 profiles that belong to four toposequences studied in the area of Brasilia (Madeira Netto, 1993).

Of the 56 spectra. we removed four that presented opaque minerals. The influence of those minerals in the determination of the RCGb spectral index was discussed by Baptista et al. (2000a), using samples of the municipal district of Niquelândia, Goiás. The 52 diffuse reflectance spectra obtained in laboratory were resampled to the AVIRIS bands.

We performed the calculation for Ikaol and Igibb (equations 2 and 3) to test whether the same ones can be used for an individual analysis of the mineral contents. As shown by Madeira Netto (1993), those results indicate a linear relationship between kaolinite and gibbsite contents and the intensities of the absorption features.

For the kaolinite several factors influence the analysis, because Ikaol presents a low correlation coefficient (r=0,53) with the mineral contents. Madeira Netto (1993) accomplished a multiple lineal regression between Ikaol and the kaolinite and gibbsite contents that presented a high correlation coefficient (r=0,88), which shows that the gibbsite content affects the measures of intensity of absorption of the kaolinite.

On the other hand, for the gibbsite, inclusion of the kaolinite content in the regression didn't modify the correlation. As the clay fraction of the soils under heavy weathering consists mainly of kaolinite and gibbsite, we find a better degree of adjustment (r=0,91) considering the kaolinite contents in relation to the clay fraction. The hypothesis proposed by Madeira Netto (1993) is that gibbsite absorption interferes with the measure of Ikaol explaining such a low correlation coefficient.

For the gibbsite, Madeira Netto (1993) points out that Igibb can be used to calculate the content of that mineral in the latosols. The use of Igibb for determination of the gibbsite content was also tested and it presents a high correlation coefficient (r=0,81), as it can be seen in Figure 5.

Ikaol allows only estimating the kaolinite contents in relation to the fraction clay in a satisfactory way. The inclusion and the analysis of another parameters can drive a more precise estimate method for the kaolinite content of the latosols, by means of reflectance spectra (Madeira Netto, 1993).

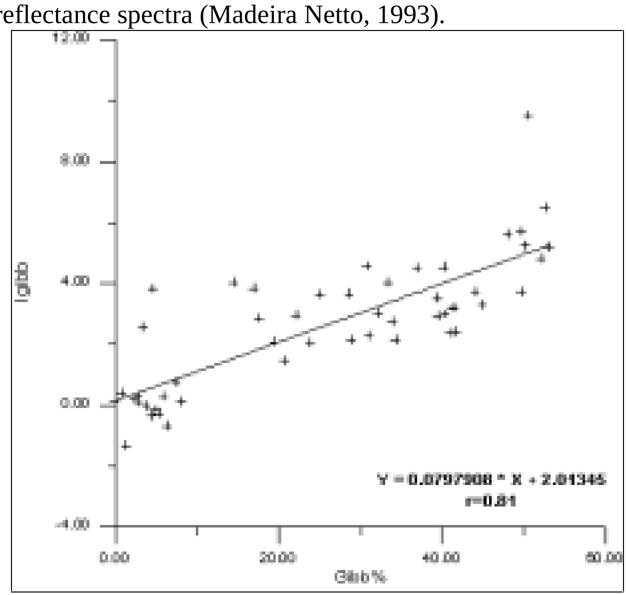

Figure 5. Linear regression between the gibbsite content (Gibb%) and Igibb for the 52 samples of Madeira Netto (1993).

We determined the values of band reflectance used in the determination of the RCGb spectral index, for each one of the 52 spectra. In addition, linear regressions were accomplished between the values obtained with the spectral index, when it is used as the dependent variable and the values of Ki as the independent variable. Table 1 presents the values obtained in the 52 spectra of reflectance of RCGb, with the values of Ki for each sample.

An important aspect to be understood in the analysis of the data is the correlation coefficients found. In the regression between the results of RCGb index and Ki values, the found correlation coefficient was quite high (r=0,93). Figure 6 presents the results of the linear regression.

Table 1. Values of RCGb and Ki for the 52 samples of Madeira Netto (1993)

Sample	RCGb	Ki
I1Ap	0.95	1.58
I1Bo4	1.00	1.56
I4Ap	1.08	1.58
I4Bo1	0.96	1.49
I3A2	0.94	1.55
I9A2	0.30	0.47
I9BA	0.32	0.51
I10A	0.45	1.03
I10BA	0.42	0.99
I11A2	0.42	0.22
I11Bo4	0.31	0.23
I13BA	0.95	1.91
I13Bo4	0.95	1.91
I17AB	0.43	0.74
I17Bo5	0.56	0.86
I20A	0.51	0.63
I20Bo1	0.51	0.53
I22Ap	1.02	1.45
I22Bo1	1.16	1.70
I23Ap	1.04	1.69
I23Bog2	1.09	1.65
A1Ap1	0.50	0.63
A1BA	0.57	0.68
A1Bo3	0.47	0.68
A2Ap2	0.71	1.12
A2BA	0.70	0.98
A2Bo2	0.64	0.92
A3Ap1	0.52	0.70
A3BA	0.61	0.68
A3Bo2	0.57	0.69
B1Ap1	0.47	0.52
B1BA	0.54	0.51
B1Bo3	0.42	0.51
B2Ap1	0.44	0.50
B2BA	0.48	0.63
B2Bo2	0.45	0.48
B3Ap1	0.55	0.82
B3BA	0.58	0.83
B3Bo2	0.44	0.71
C1Ap1	0.49	0.58
C1BA	0.55	0.53
C1Bo2	0.47	0.52
C2Ap1	0.65	1.00
C2BA	0.71	0.94
C2Bo2	0.62	0.91
C3Ap1	0.70	1.18
C3BA	0.75	1.15
C3Bo2	0.72	1.15
D1Ap	0.90	1.48
D2Ap	0.98	1.67
D3Ap	0.94	1.84
D4Ap	0.96	1.65

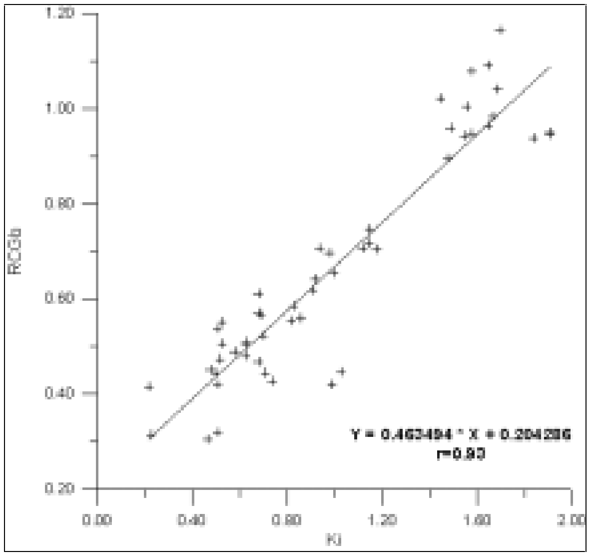

Figure 6. Linear regression between RCGb and Ki values.

5. RCGb INDEX TEXT IN AVIRIS DATA

The original radiance data was used in this stage, because, as it was pointed out by Baptista et al. (2000b), the radiance images present such good results as images corrected by the Green's method or by ATREM.

The RCGb spectral index was applied on two concatenated scenes of the AVIRIS data (Figure 7). This data was obtained on the same day with a difference of less than ½ hour between the acquisitions. The flight over Niquelândia (950816L3 - 10) was preceded by that over São João D'Aliança (950816L2 - 03).

The two images don't present clouds, and it was assumed that the atmospheric conditions would not have varied in a significant way between the images.

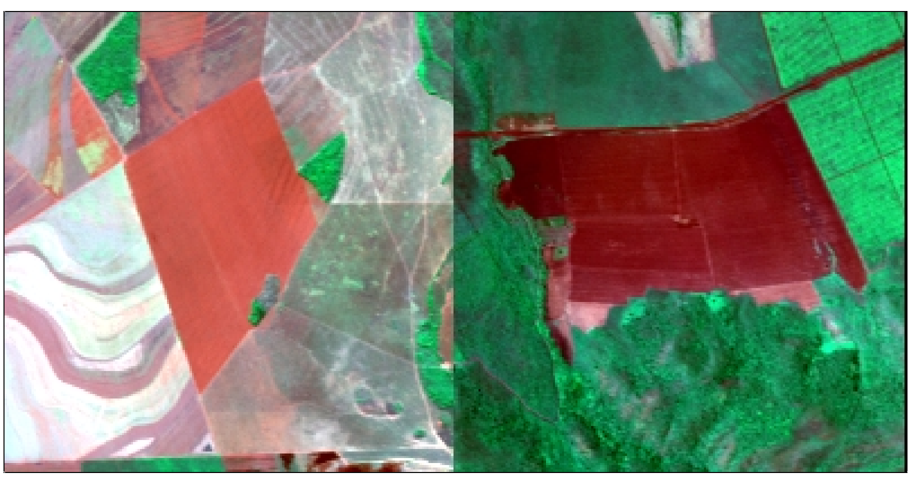

Figure 7. Concatenated AVIRIS images of the areas of studies showing the color differences of the soils due to the non-presence and the presence of opaque minerals respectively.

Figure 8 presents the gradual variation of RCGb for the two concatenated study areas.

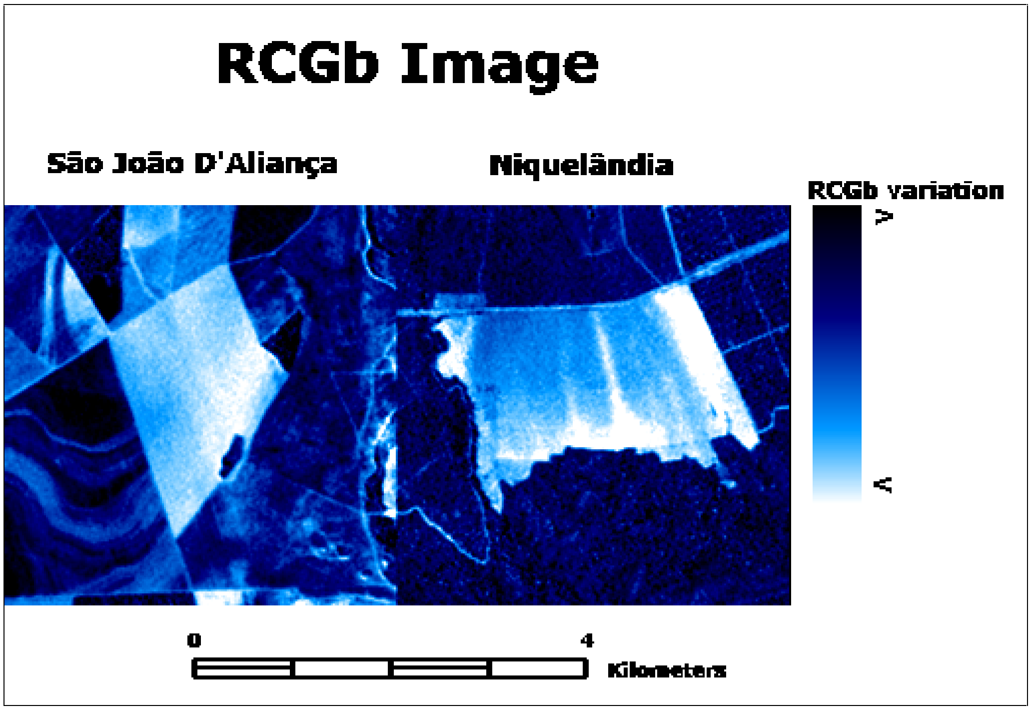

Figure 8. RCGb variation for the two areas.

For the analysis of Figure 8 it is important to know that for the kaolinite/(kaolinite+gibbsite) ratio, larger values, indicates more abundance of kaolinite and smaller values indicates a tendency of elevated gibbsite contents. It can be noticed that is a space variability of RCGb and not the homogeneity of soil classes as Figure 7 suggests.

This kind of processing of the AVIRIS data allows one a better slicing of the areas, because the result is not just based on color or on the morphology of the land but on a relationship of minerals by means of spectral analysis. It is noticed that the area of São João D'Aliança presents smaller variation of the kaolinite/(kaolinite+gibbsite) ratio, because it presents a less intense tonal variation than in the portion of Niquelândia.

In São João D'Aliança the clearest part of the studied area comes as a prolonged micro-dome that can be a structure slightly preserved of erosion processes. The darkest part of the area is a small concave depression, therefore more eroded and that can be a place of larger accumulation of water. This depression presents a small alteration, with less silicon and more aluminum. This is just a hypothesis to explain the difference of RCGb, but that is not the study object of this paper.

The clearest parts that appear in the Niquelândia scene indicate a higher local relief and present an inclination of those areas towards the darkest ones. They are higher either because a depositional process happens, since that area meets in Ultramafic's Unit and among them a altimetric significant variation happens in approximately 500 m, or for a process of differential erosion that exposed the areas with larger gibbsite contents.

6. CONCLUSIONS

The RCGb index has the advantage of generating very compatible Y scale values to Ki results, which facilitates the preliminary understanding of the soils stains exposed even before a field trip. Besides, once based on the three band ratio method (Gao et al., 1993), the RCGb spectral index minimizes the noises that happen in the laboratory spectra or of the AVIRIS images.

As the latosols genesis process is characterized by the removal of the Si and of exchangeable bases and posterior concentration of Al. The kaolinite represents the remains of silicon in those soils, and the kaolinite and the gibbsite presents aluminum in its structures, the RCGb index allows an understanding of the weathering degree of the Brazilian tropical soils.

This work showed that the RCGb index could minimize the time expended in the analysis and in the recognition process and mapping soils. To perform those two study areas in the traditional way it would be necessary to adopt a sampling matrix with regular spacing covering the whole area, which would increase the costs of the project.

It is also worthy of note that index works for exposed soils and that any covering types can obliterate the features turning it inefficient.

The use of the laboratory radiometry is fundamental for the construction of the spectral indexes and for posterior validation. That is the most fundamental methodological aspect used in this paper. If the study's objective is to derive indexes starting from the analysis of AVIRIS data or of any other spectroscopy data, the spectral analysis of the data obtained in the laboratory can be used in the study of themes for which no image data yet exists.

7. ACKNOWLEDGMENT

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