USE OF AVIRIS DATA FOR MINERALOGICAL MAPPING IN TROPICAL SOILS, IN THE DISTRICT OF SÃO JOÃO D'ALIANÇA, GOIÁS.

Gustavo Macedo de Mello Baptista[1], Éder de Souza Martins[1 & 2], José da Silva Madeira Netto[2], Osmar Abílio de Carvalho Jr.[1], and Paulo Roberto Meneses[1].

[1]Instituto de Geociências, Universidade de Brasília. E-mail: gustavom@cdsid.com.br

[2]Centro de Pesquisas Agropecuárias dos Cerrados (Embrapa / CPAC)

1. INTRODUCTION

Soil cartography in Central Brazil is available only in large scales. The increased agriculture pressure over these lands require basic soil knowledge obtainable in more detailed surveys. Data collected by hyperspectral sensors may represent a valuable source of information for soil scientists, mainly in the distinction of mineralogical classes.

Previous studies have shown the possibility to use indices developed from high-resolution diffuse reflectance spectra obtained in laboratory to estimate hematite content, and the Ki ratio (molecular ratio of SiO_2 and Al_2O_3). In this work we use AVIRIS data to verify the possibilities offered by hyperspectral data to differentiate tropical soils mineralogy.

AVIRIS data from São João D'Aliança district, Goiás state (950816L2 scene 3) after atmospheric correction and reflectance transformation were used. Field work was conducted to sample the main soil units. The location of the sampled points was obtained with a GPS, which allowed the precise plotting in the image. Samples were air-dried and sieved to 2 mm before being used for laboratory determination of 400 to 2500 nm spectral reflectance. X ray diffraction of these samples were also obtained.

Most of the scene considered was covered by crop residues, pasture and native Cerrado vegetation with only a few hundred hectares of bare soils. The bare soil areas were considered in this work. Kaolinite, goethite and quartz were present in all samples. Gibbsite and hematite were also present in some sampled soils. Features attributable to kaolinite, gibbsite, hematite and goethite were clearly detected in the spectra obtained in the laboratory and in the AVIRIS data. The occurrence of these minerals was confirmed by the X-ray diffraction data.

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 ($Al_2SiO_5(OH)_4$)

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). The Figure 1 presents the diffuse reflectance spectra of a kaolinite sample from Mesa Alta (New Mexico).

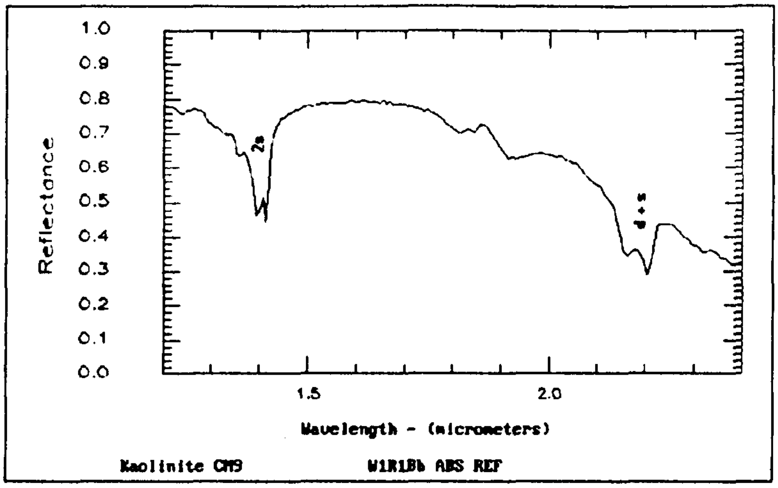

Figure 1. Diffuse reflectance spectra of a kaolinite sample, entitled CM9 of the USGS spectral library, from Mesa Alta (New Mexico), show absorption's band.

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

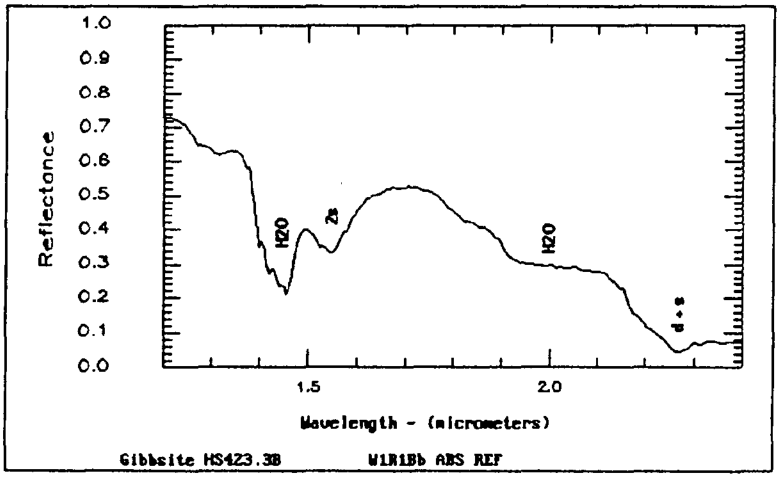

Figure 2. Characteristic features of a gibbsite sample (HS423 of the library of USGS), from Brazil.

2.3 Goethite (FeOOH) and Hematite (Fe_2O_3)

Goethite (FeOOH) and hematite (Fe_2O_3) are the most frequently occurring ferric iron (Fe^{3+}) minerals found in tropical soils. They result from the oxidation of iron present as Fe^{2+} in primary minerals in the soil forming process. The predominance of one or other of these minerals has been related to pedoclimatic factors and the understanding of their occurrence is important in the study of tropical soils.

These iron oxides have different reflectance features in the visible and near infrared spectra. Some of these features are responsible for their colors: red for hematite and brown-yellow for goethite. Sherman and Waite (1985) showed that the difference between the colors of those two minerals is determined by the transition 2(6A1) => 2(4T1), that happen in 480 nm for the goethite and 530 nm for the hematite.

The figure 3 shows the diffuse reflectance spectra of a goethite (a) and hematite (b). The goethite sample (WS222 - USGS spectral library) it is coming of Superior it Mines, Marquette, Michigan, while the one of hematite (GDS27 - USGS spectral library), is a synthetic sample (Baker Analyzed Reagent).

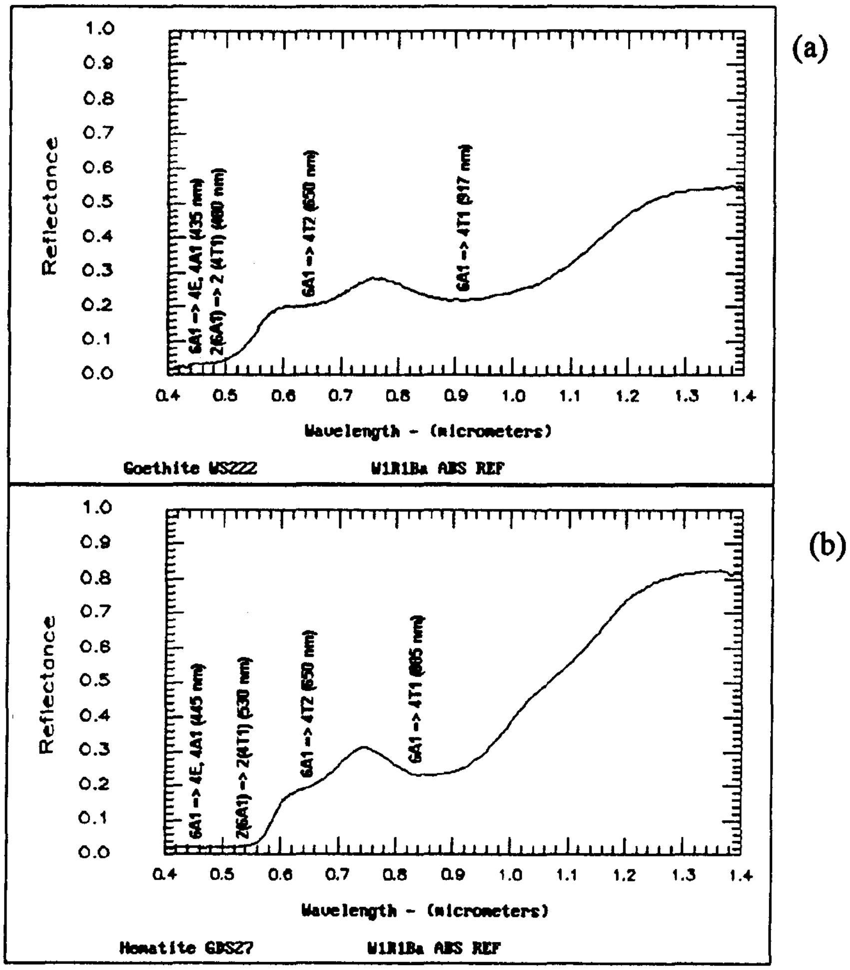

Figure 3. Diffuse reflectance spectra of a goethite (a) and hematite (b).

2. METHODOLOGY

The adopted methodological steps are subdivided in 3 stages: atmospheric correction and reduction of AVIRIS radiance to scaled surface reflectance; gathering of soil samples in the field; and spectro-radiometry and X-ray diffraction analysis of soil samples.

The image of São João D'Aliança district, Goiás state (950816L2 scene 3) was selected, due to the presence of bare soil areas associated to topographical variations.

2.1 Atmospheric Correction and Reduction of AVIRIS Radiance to Scaled Surface Reflectance

This was done at INPE (National Institute of Space Researches - São José of Campos, São Paulo) using Green's method (Green et al, 1991), counting with the participation of Dr. Robert O. Green in the determination of the correction parameters.

That method is based on the model of radioactive transfer MODTRAN. According to Clark et al (1995) the correction is accomplished by adjusting the oxygen, carbon dioxide and water levels of each pixel. Although it spends 50 times more computer time than other models, this method is considered as one of the best procedures for atmospheric correction and derivation of scaled surface reflectance from AVIRIS data.

2.2 Soil Sampling

Field work was conducted to sample the main soil units. At the time of the AVIRIS flight most of the soil surface was covered by crop residues, which limited the bare soils to two fields: one represented by a uniform flat (slope < 3%) area with clayey Dark Red Latosol (points 1 and 2). The other by a gently sloping (<8%) area with clayey Dark Red Latosol (point 7), sandy loam Red Yellow Latosol (point 6), Cambisol (point 4) and Quartz sands (points 3).

Soil Samples
AVIRIS 950816L02-03

Figure 4. Soil samples sites.

2.2 Radiometry and X-ray Diffraction Experiments

The radiometry experiments were accomplished in Embrapa/CPAC, being used a radiometer GER (Geophysical & Environmental Research Corp.), model MARK V. That instrument has a spectral range of 300 to

2500 nm, with spectral bandwidth of 2 nm in the 300 nm to 1000 nm region and 4 nm in the 1000 to 2500 nm region.

X-ray diffraction data were obtained for the powder, between 2 and 80° 20, with step of sweeping of 0.02° 2θ using an apparatus with a Cu tube and a Ni filter. The quantification of the minerals was obtained with the aid of an analysis program - Jade for Windows®.

3. RESULTS

The spectral results will be presented considering two wavelength intervals: 450 nm to 1100 nm, visible and near infrared and to 2000 nm at 2400nm, short wave infrared.

The mineralogical composition of the A horizon of the sampled soils, is presented in table 1.

Table 1. Mineral composition of the A horizon of the sampled soils

Samples	Hematite (%)	Goethite (%)	Kaolinite (%)	Gibbsite (%)	Quartz (%)
1	7.8	2.9	47.7	26.1	15.5
2	8.5	3.4	37.9	30.0	20.3
3	0.5	0.8	3.3	0.0	95.4
4	1.5	1.3	17.4	4.5	75.3
5	2.0	0.4	11.9	2.3	83.4
6	1.3	1.2	10.2	2.5	84.8
7	4.0	0.6	29.3	10.8	55.4

Except samples 3 and 6, all the others presented more than 70% of hematite composing the free iron oxides. The sample 3 present more goethite than hematite and the sample 6, very seemed values.

Sample 1, 2 present the highest values of gibbsite, showing a high weathering degree. Sample 3, a Quartz Sand (Quartzpsament), presented no gibbsite. In samples 3 to 6 kaolinite clearly prevails over gibbsite. Sample 7 presented an intermediate value gibbsite. These variations in the kaolinite/gibbsite proportions are a good example of the variability of the weathering degree usually found in Central Plateau of Brazil.

Figures 5 to 10 present X-ray diffractograms and reflectance spectra (2000 to 2400 nm) obtained in the laboratory and with AVIRIS for selected samples. Sample 1 presented high kaolinite and gibbsite values as evidenced by the diffractogram (10° to 20° 2θ) of figure 5. The spectra of figure 6 show the features that can be attributed to kaolinite and gibbsite in the data obtained in laboratory as well as with AVIRIS. Similar results are observed for sample 2 (figures 7 and 8). It is important to note that variations in the intensities of the features attributable to kaolinite and gibbsite in samples 1 and 2 in the diffractogram are also found in the reflectance spectra. Results for the sample 3 (Quartzpsaments) with low contents of kaolinite and absence of gibbsite are presented in figures 9 and 10 showing agreement between X-ray and reflectance data. Madeira Netto (1993) has reported a good correlation between the intensity of absorption of kaolinite and gibbsite measured in diffuse reflectance spectra and contents of those minerals in latosols. This author has also derived an index from kaolinite and gibbsite intensities of absorption that correlates strongly with the ratio of kaolinite and gibbsite contents in the soil which is very useful for estimating the weathering degree of soils from reflectance data. Since a very limited amount of data is available, these relationships could not be tested for AVIRIS data. However the trends observed, indicates the potential of this hyperspectral images for quantification purposes of those important minerals.

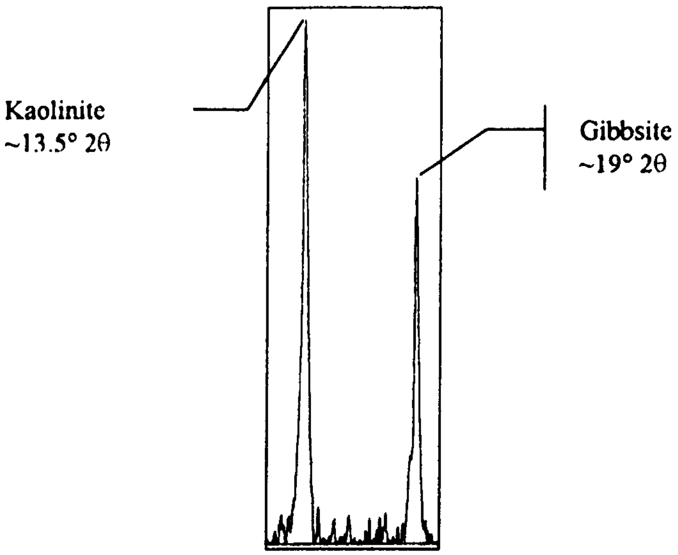

Figure 5. Diffractogram of soil sample 1.

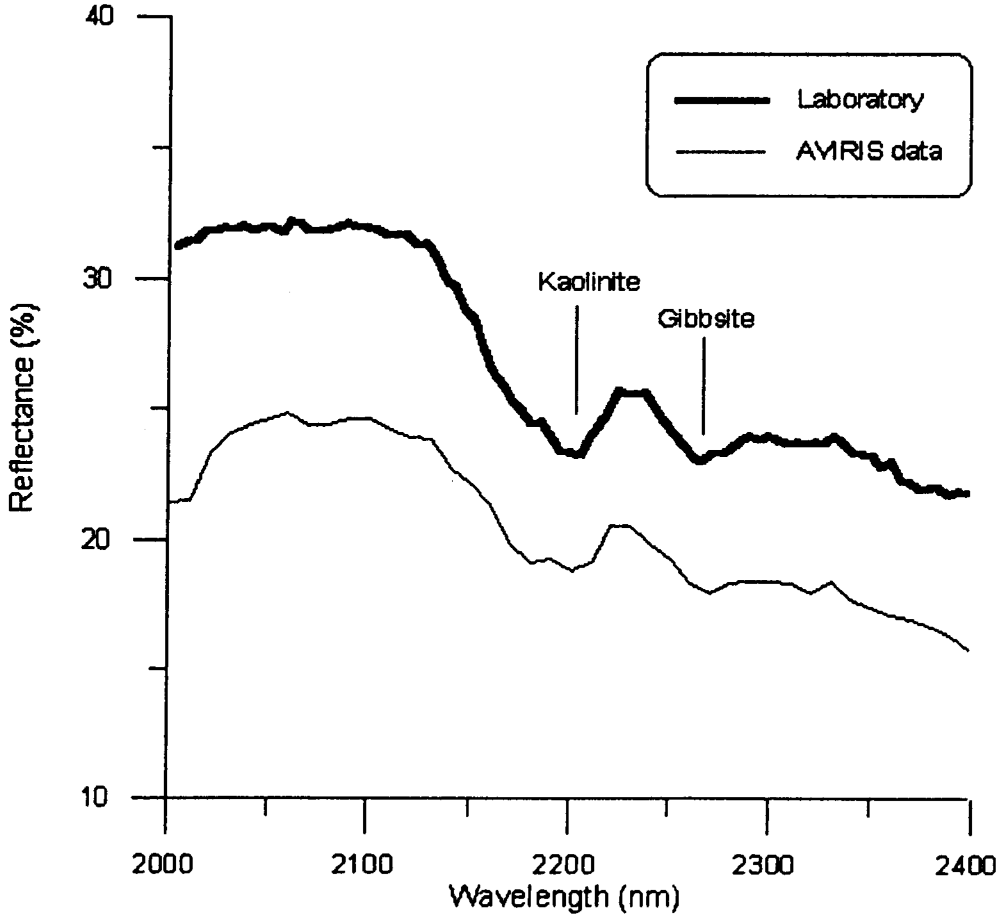

Figure 6. Spectral curves of soil sample 1 in short wave infrared region.

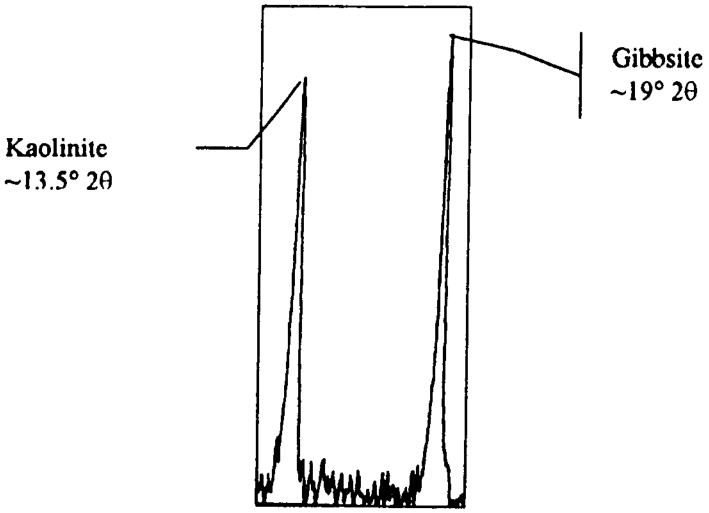

Figure 7. Diffractogram of soil sample 2.

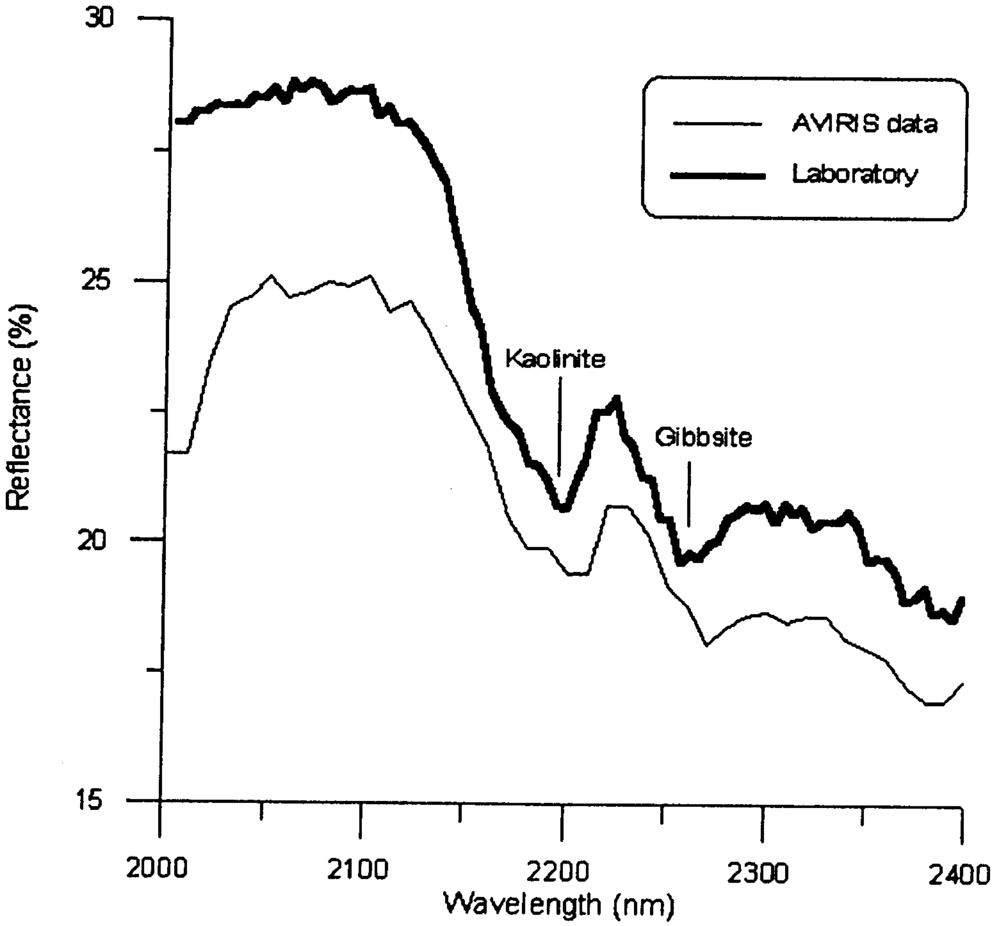

Figure 8. Spectral curves of soil sample 2 in short wave infrared region.

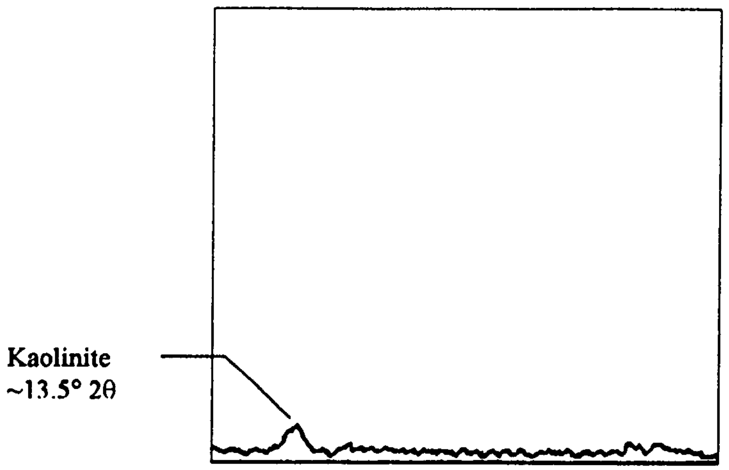

Figure 9. Diffractogram of soil sample 3.

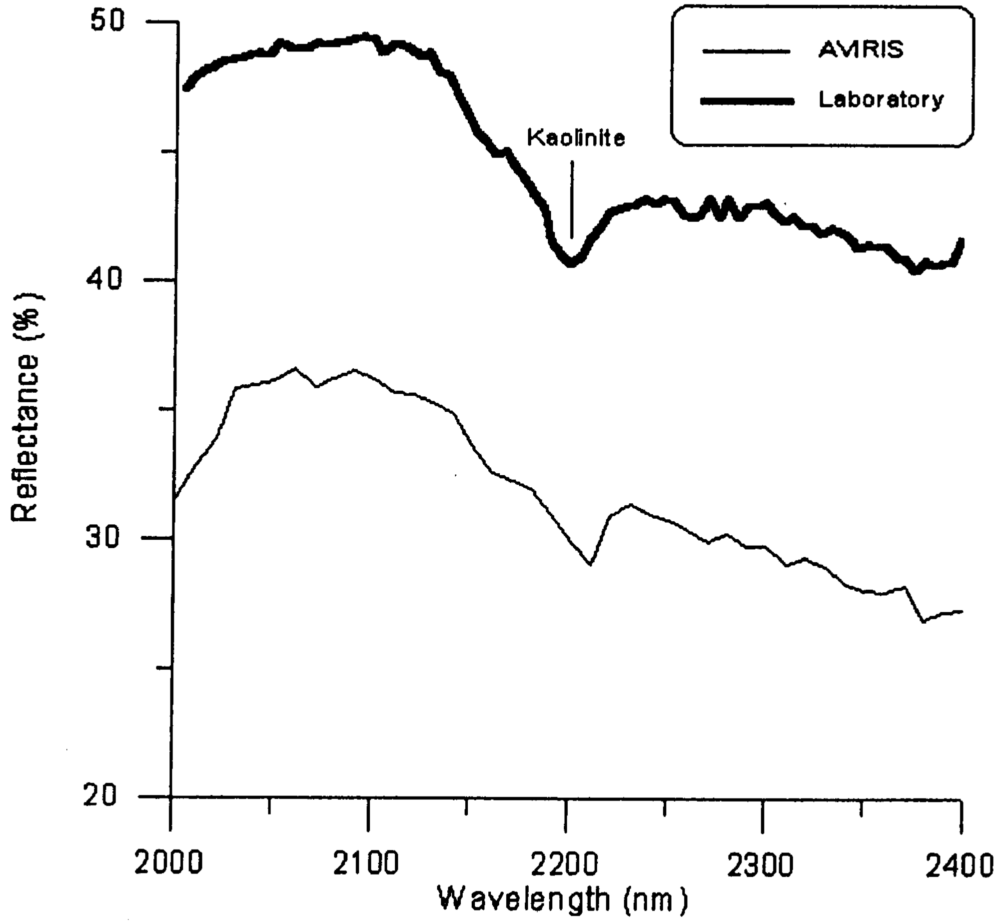

Figure 10. Spectral curves of soil sample 3 in short wave infrared region.

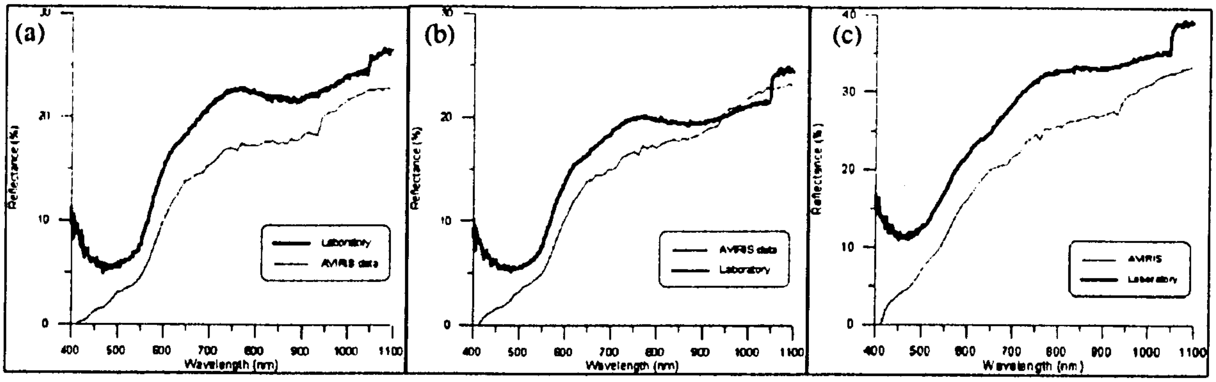

Figure 11. Spectral curves of soil samples 1 (a), 2 (b) and 3 (c) in visible and near infrared region.

Figure 11 shows the visible to near infrared spectra (400nm – 1100 nm) of point 1, 2 and 3 obtained with GER – MARK V spectroradiometer and with AVIRIS. The general shapes of the curves obtained in the laboratory are similar to the ones reported by Valeriano et al (1995) for the corresponding soil types. The strong feature observed at 1050 nm is due to detector change during data acquisition. The other features are due mainly to Fe^{3+} electronic transitions: close to 450 and 900 nm in a broad concave shape and an inflection close to 650 nm. The position of the minima close to 450 nm is the determining factor for the differences in soil color and are related to the goethite / hematite relative composition (Madeira Netto, 1997). The spectra obtained by AVIRIS present a clear difference from the ones obtained at laboratory mainly in the 400 nm to 500 nm range. Can be noticed that the reflectance values at 400 nm are set to 0 for all the spectra. This apparent abnormality seems to be the origin of the discrepancies observed in the blue-green wavelength. The features centered at ~650 nm and ~900 nm can also be observed in the AVIRIS spectra, although the intensities are not as strong as in the MARK V spectra.

4. CONCLUSIONS

AVIRIS spectral data may be a valuable aid in the study of tropical soil mineral components, mainly in the wavelength range where the characteristic features of kaolinite and gibbsite are present.

In relation to the iron oxides, a problem was detected, in the blue/green region, where the data of AVIRIS don't correspond to the spectral data obtained in laboratory. Two hypotheses are considered: a problem with the sensor system, because the first 4 bands present reflectance values equal to zero, for all the pixels of the image; or a problem in the processing of atmospheric correction, that can have suppressed the information of the first 4 bands.

The next steps will be adopted in that exploration of the potentialities of AVIRIS will include to increase the number of the samples and of soil types covered, more precise chemical and mineralogical studies, in order to define procedures useful in the mineralogical mapping for a better understanding of the pedologic environment.

5. ACKNOWLEDGMENTS

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