

# MINERALOGICAL DIFFERENTIATION IN WEATHERING PROFILES OF LATERITIC NI USING AVIRIS DATA, IN NIQUELANDIA - GO, BRAZIL

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## 1 INTRODUCTION

Improvement of prospective optical remote sensing techniques is important on account of the increase in operational speed and the low cost of total coverage of wide areas. In spite of the advances obtained in the study of the way the minerals spectrum behaves, the multispectral sensor presents limitations in relation to an accurate mineralogical identification. The hyperspectral sensor has come to fill this blank.

Even with the more complete information from hyperspectral sensors we must consider that in intertropical conditions, collecting information from rocks and orebodies is, in some cases, very difficult due to the intense weathering process and the eventual vegetation cover. Not much is known about the hyperspectral data for geological mapping and mineral prospection in such areas and it is a wide field of research.

Because supergenic accumulation is superficial and widespread in intertropical environment, it is more adequate for the use of this technique. Therefore, in this paper we try to evaluate the use of AVIRIS in the supergenic accumulation of lateritic nickel in Niquelândia town, Goiás State, Brazil.

## 2 GEOLOGICAL SETTING

Niquelandia lateritic nickel deposits lie in the central portion of Goiás's State, about 23 km north of the Niquelandia town (fig. 1).

The Niquelandia Complex is a well-exposed large layered intrusion in central Brazil that comprises an area of about 1,800 square km and has an estimated 10, 15 km in thickness. Studies of the geology (Ferreira Filho *et al.*, 1992) and petrology (Girardt *et al.* 1986) show many similarities between the Niquelandia Complex and well known Precambrian layered intrusions such as Bushveld and Stillwater. In contrast, (to??) these layered intrusions the Niquelandia Complex shows widespread tectonism and associated amphibolite to granulite facies metamorphism (Ferreira Filho *et al.*, 1992 and Ferreira Filho & Fawcett, 1992).

The stratigraphy of the Niquelandia Layer Intrusion (NLI) comprises four westward-dipping major units: a) the East Mafic Unit (EMU), b) the Ultramafic Unit (UMU), c) the Central Mafic Unit (CMU) and d) Serra do Borges Unit (SBU). This stratigraphy has a gradation from a more primitive base, where the accumulation of olivine and pyroxene are predominant, toward a more differentiated top, where plagioclase cumulates are predominant (fig.2).

The nickeliferous deposit of Niquelandia is the product of an ultramafic-alkaline massif weathering. The total of Niquelandia's nickel ore reserve is about 60 Mt.

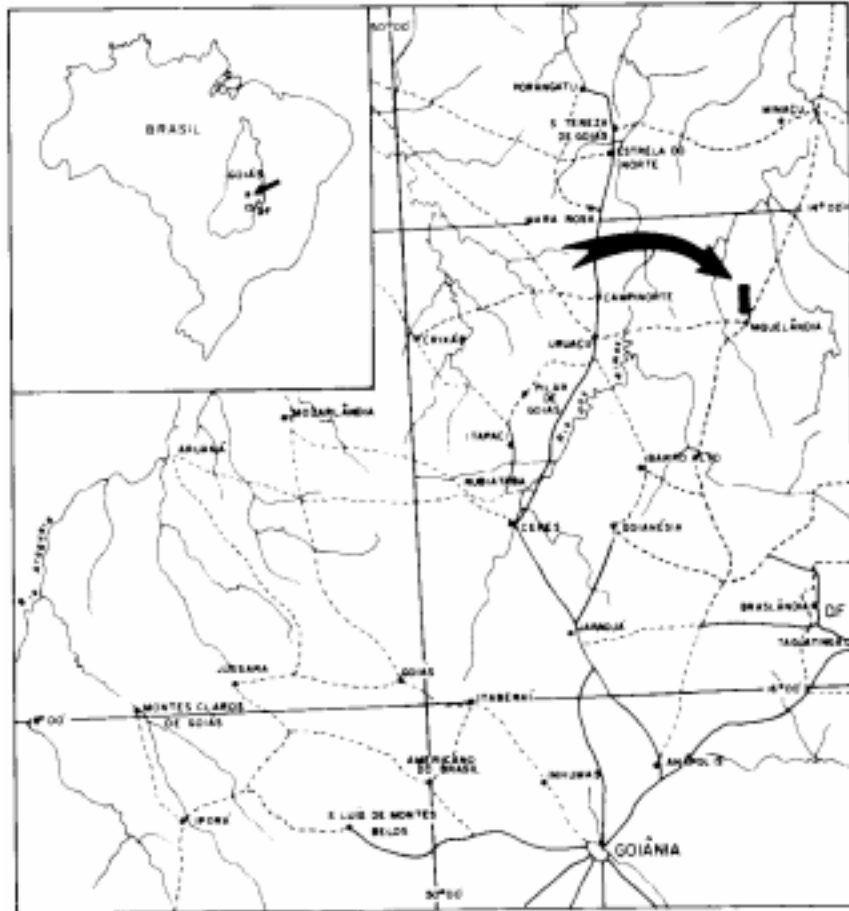


Figure 1. Study area

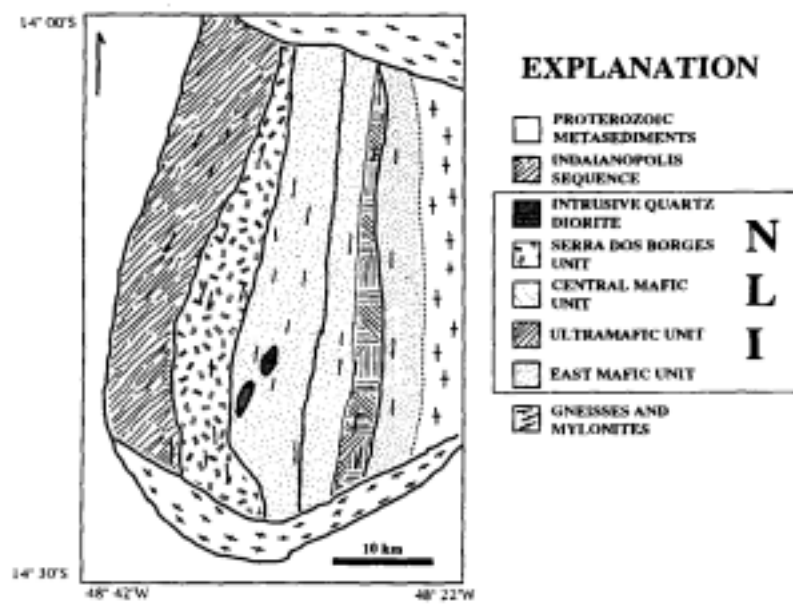


Figure 2. Geology of the Niquelândia Complex.

### 3 PEDOLOGIC PROFILE OF LATERITIC NICKEL

Deposits are located in the ultrabasic zone of Niquelandia Basic-Ultrabasic Complex as a result of the residual concentration developed by rocks weathering of this zone. The landscape consists of lowlands (Quaternary) and hills that are relicts of the South-American surface (Tertiary).

Weathering profiles are thick in the lowlands with five layers which appear to be identical to the profiles described as Santa Fé deposits; Goiás (Oliveira & Treccases, 1980) and Barro Alto (Costa, 1981):

1. Altered rocks – serpentized dunites which show quartz and garnierite veins. There is an important lack of density;
2. Coarse Saprolite – a zone with concentration of nickelliferous silicated minerals. These facies, which have no olivine, are mainly composed of amorphous silicates and garnierite;
3. Clay Fine Saprolite – a transition zone between the oxidated and silicated facies retains most of the minerals present in the coarse saprolite facies. There is an important increase of goethite;
4. Ferruginous Fine Saprolite – a material with a red-yellow color, where the goethite is the most important mineral and the grain size tends to fine; and
5. Red laterite – mainly composed of hematite and goethite. There are oolites and pisolites ferruginous concretions. Locally, these laterites grade to iron crust.

In the other words, the complete profile is composed of three main groups of horizons: a) saprolitic - partly composed of magnesian and iron silicates, b) limonitic - mainly composed of iron hydroxides, and c) red laterite and iron crust (fig. 3). In conclusion, we have from base to top a mineralogical variation basically from magnesian silicate which becomes more rich in goethite, and finally, in hematite.

The geochemical evolution of the lateritic profile in the lowlands leads leaching of Si and Mg and retention of Fe, Al Cr, Mn, Cu and Co. Ni shows an intermediate behavior. Ni is mainly associated with silicate phases mainly in the pimelite's minerals and amorphous Si-Fe products (Oliveira e Treccases, 1980).

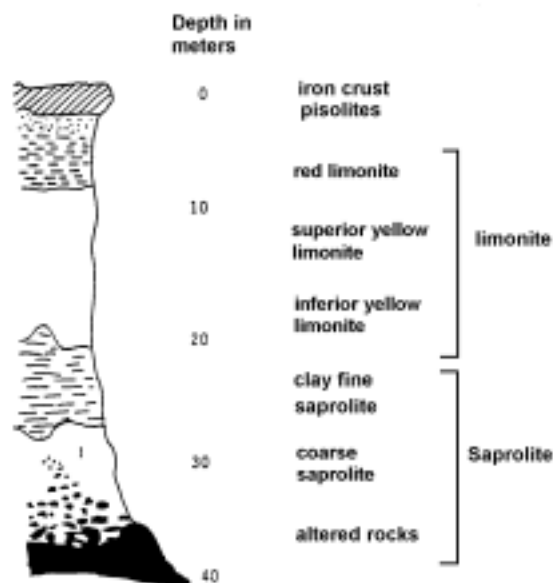


Figure 3. Typical alteration profile of the nickel-bearing deposits (Modified from Maquet *et al.*, 1981)

## 4 THE ORES

There are two types of ore: the garnierite and the oxidated ore (Pedroso & Schmatz, 1985). We used the X-ray diffractometry (powder method) in the mineralogical characterization of the samples, with  $2\theta$  between  $2^\circ$  and  $70^\circ$ , with a scan step of  $0,5^\circ 2\theta$ . A copper tube was used with a nickel filter in a Shimadzu XD-610 diffractometer.

Garnierites are basically silicates of nickel and magnesium, and they have a predominantly green color. Brindley *et al.* (1973) considered garnierites as the mixing of two kinds of silicates: serpentine type minerals and talc-saponite intermediate type minerals. They have an origin associated with the meteoric alteration of peridotitic rocks.

We used in this paper garnierite samples from the Votorantim Group Mine area, of Niquelândia, both mineralized and non-mineralized, green and white – green.

The X-ray diffractometry shows that the samples are mainly composed by pimelite  $(\text{Ni, Mg})_3 \text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$  a basic hydrated silicate of Ni-Mg from montmorillonite group. As trace we found talc  $(\text{Mg}_3 \text{Si}_4\text{O}_{10}(\text{OH})_2)$ , tosudite, antigorite  $(\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4)$  and lizardite  $(\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4)$ .

The garnierites with a white – green color have serpentine as the predominant mineral, and quartz, pimelite as secondary. Talc appears in small quantities. The white-green color is associated to the serpentine predominant in these samples.

The oxidated ore is mainly constituted by goethite with pimelite and talc in low proportions.

## 5 SPECTRAL BEHAVIOUR OF THREE MAIN GROUPS OF HORIZONS

A spectralradiometer GER (Geophysical & Environmental Research Corp.) model Mark V was utilized for determination of bi-directional reflectance spectra that work in the spectral interval of 300nm to 2500nm, with bands 2nm large in the 300 to 1000 nm interval, and 4nm large, between 1000 a 2500nm.

With the spectra of the sample we calculated the 2<sup>nd</sup> derivation to determine exactly the inflection points of the spectral feature, either caused by electronic transitions or molecular vibrations. The algorithm used was the one proposed by Savitzky e Golay (1964)

### a) Garnierite

The garnierite shows absorption bands that correspond to the transitions of the  $\text{Ni}^{2+}$ : 1100 nm, 660nm and 390 nm (Faye, 1974 and Maquet *et al.*, 1981). Another very important feature in garnierites is related to the absorption band of MgOH at 2300 nm. Hunt *et al* (1971) show this feature when they describe the spectral behavior of brucite.

The spectra obtained in the lab for the samples were submitted under the 2<sup>nd</sup> derivation analysis and showed the spectral features related to Ni at 613 nm,(and??) 1116nm; the features related to the vibrational transitions of brucite at 2300 nm, and the absorption bands caused by water in the mineral structure at 1400nm and 1900nm.

The absorption bands of Ni in the spectral curves of garnierite are strongly affected by the increase of goethite in the samples (fig.5). The interference in the Ni feature occurs with the increase of goethite and opaques. The MgOH is not very affected by the Fe oxides and hydroxides; therefore, it can be considered an important indicator of the garnierite, and also the silicated zone.

### b) Limonitic (Mainly composed of iron hydroxides)

The spectrum of oxidated ore is characterized mainly by goethite. The electronic transitions of  $\text{Fe}^{3+}$  are responsible by three absorption bands: 460 nm, 660 nm and 950 nm. The oxidated ore from the fine saprolite ferruginous horizon almost eliminates the Ni and MgOH features.

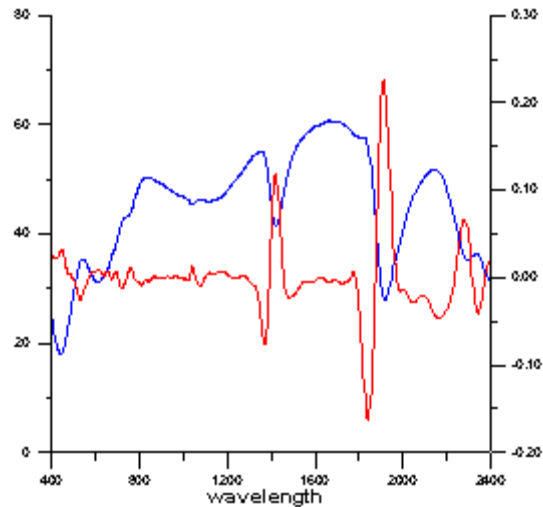


Figure 4 Bidirectional reflectance spectra (blue) and 2<sup>nd</sup> derivation (red) identifies the inflection point (garnerites samples).

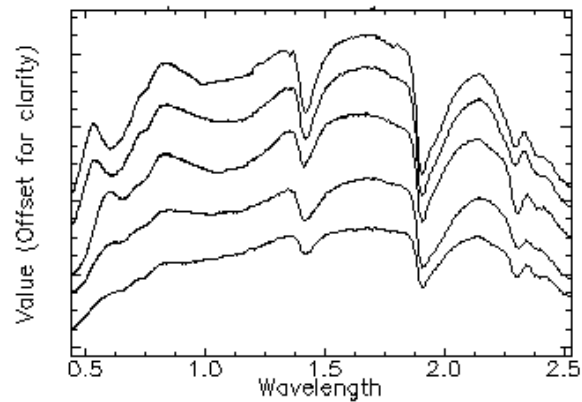


Figure 5 – Spectral behavior of garnerite obtained at lab with a crescent influence of Fe oxides from up to down.

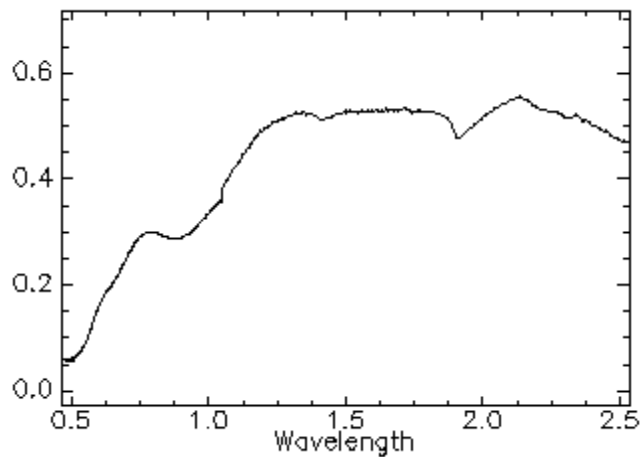


Fig. 6 – Spectral behavior horizon limonitic mainly composed of iron hidroxides.

### c) Red laterite and iron crust

The red laterite is composed of goethite, hematite, kaolinite, maghemite, and quartz. The spectrum is characterized by clay minerals of kaolinite group with a double feature at 2170 e 2200 nm.

## 6 HYPERSPECTRAL PROCESSING

We used the Green method for atmospheric correction and the methodology for analysis of hyperspectral data that is implemented from the software ENVI.

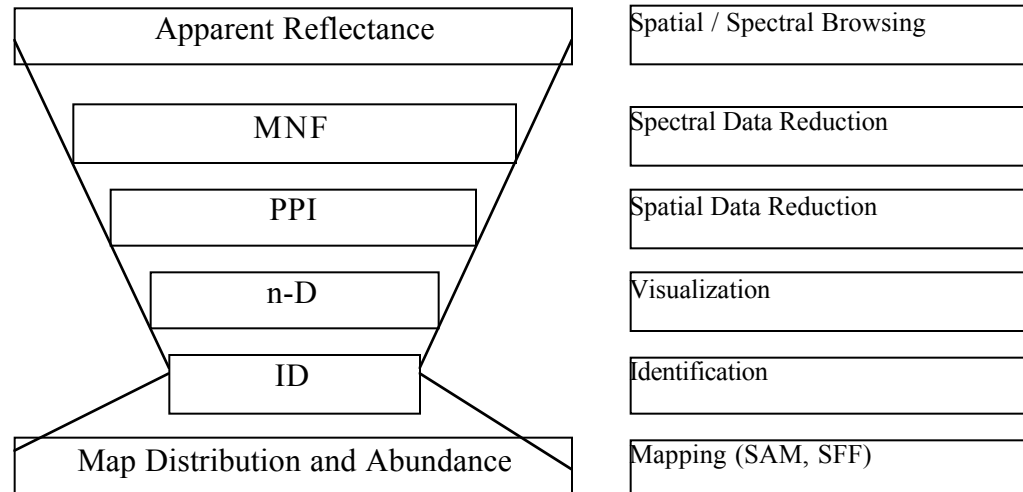


Fig.7 – Hyperspectral Processing with ENVI (ENVI®, 1997)

The Pixels Purity Index (PPI) was processed with the first fifteen principal components of the Minimum Noise Fraction (MNF). The PPI process was implemented with 4000 interactions. Hence we used the n-D to distinguish 4 pure spectral curves, three associated to the horizons of alteration profile and one related to the vegetal cover.

The spectra obtained from the silicated zone indicate a spectral behavior of mixing Fe oxide and garnierite. The Fe+3 features affected the feature related with the absorption band of Ni. On the other hand, the MgOH feature in the nickeliferous garnierites (pimelite) at 2300 nm is more evident in the spectra, being the principal parameter to discriminate this zone.

A sharp absorption band of Fe3+ in the visible and the lack of the MgOH feature in the infrared characterize the limonitic horizon. The curves are coherent with those found in the lab which describe a sample composed predominantly of goethite.

The spectra related to the red laterite horizon, which are more superficial, also show a strong concordance with those obtained in the lab. The main feature is the double feature of kaolinite, as mentioned above.

The fourth spectrum is related with the vegetation cover located around the region of the mine.

## 7 SPECTRAL MAPPING METHODS

The image classification was done using the continuum removal method and Spectral Feature Fitting (SFF) method. We used the absorption band of MgOH, AlOH, and the absorption band related to vegetation.

As a result, we have obtained a fit (scale/RMS) image with a sharp differentiation of the horizons from lateritic profile. In the figure 11, red characterizes the silicated ore, black indicates the limonitic zone, blue indicates the superficial red laterite, and green is related to the vegetation.

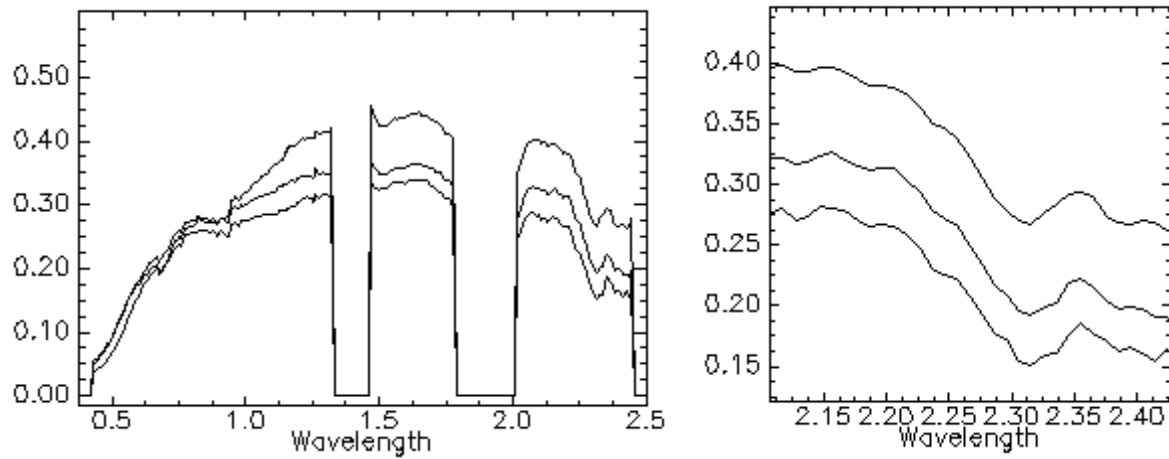


Figure 8 – Spectra of Saproilitic Partially Composed by Magnesian and Iron Silicates. The absorption feature of MgOH is prominent at 2300 nm.

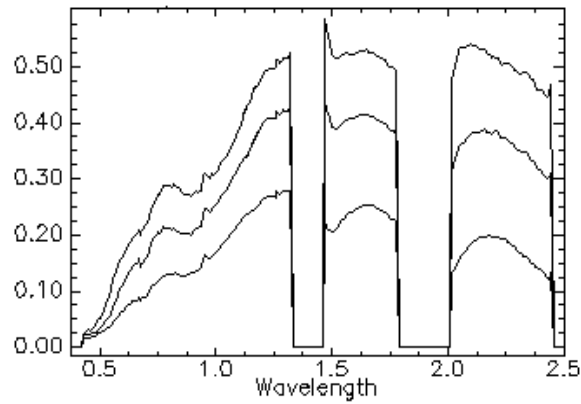


Figure 9 – Limonitic spectra, Mainly Composed of Iron Hydroxides

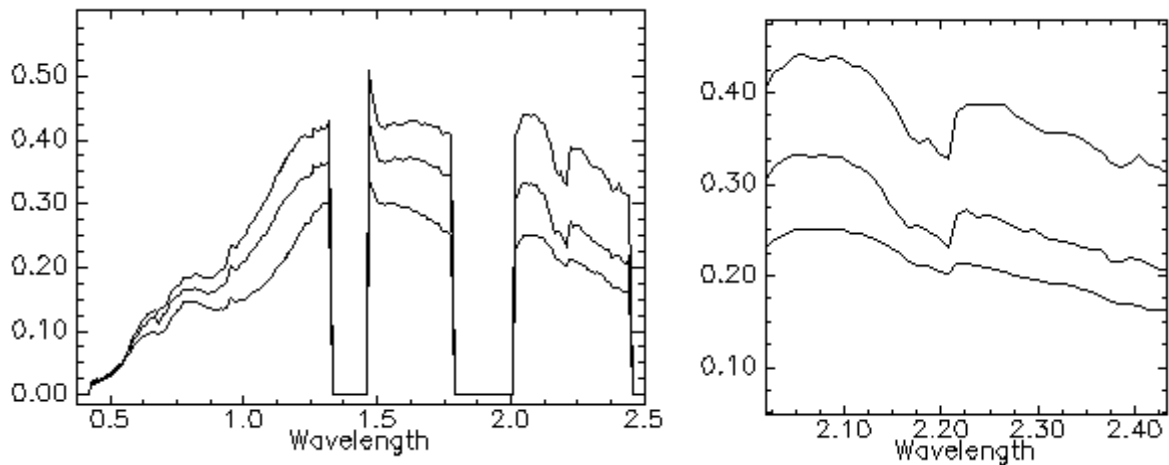


Figure 10 – Spectral curves of the red laterite horizon characterized by clay minerals of kaolinite group.

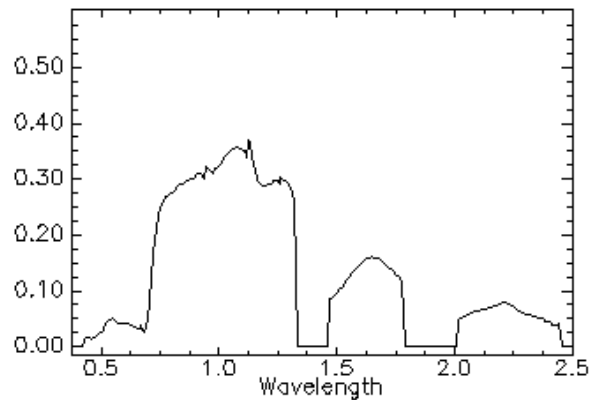


Figure 11 – Vegetation spectrum

## 8. CONCLUSION

The sensor ~~hi~~perspectral AVIRIS application in tropical weathering areas, ~~in~~ particularly ~~ly~~, ~~in~~ ultramafic rocks, presented a huge ~~performance advantage~~ in relation to the mineral detection. The results allowed the principals weathering horizon profiles to be defined. Features of pimelite, kaolinite, iron oxides and hydroxides characterized this weathering profile differentiation.

In addition, the good results in this work are due the mine exploitation that allowed the subsurface horizon profile exposition and also the lack of vegetation.

The AVIRIS data, as well as the lab-work-obtained spectra, were able to depict those features. This new technology showed a huge efficiency ~~to~~ ~~for~~ application in mineralogical maps of lateritic Ni.

Few works have been developed to analyze tropical regions. AVIRIS can be applied in the further works to identify and characterize others kind of supergene ore.

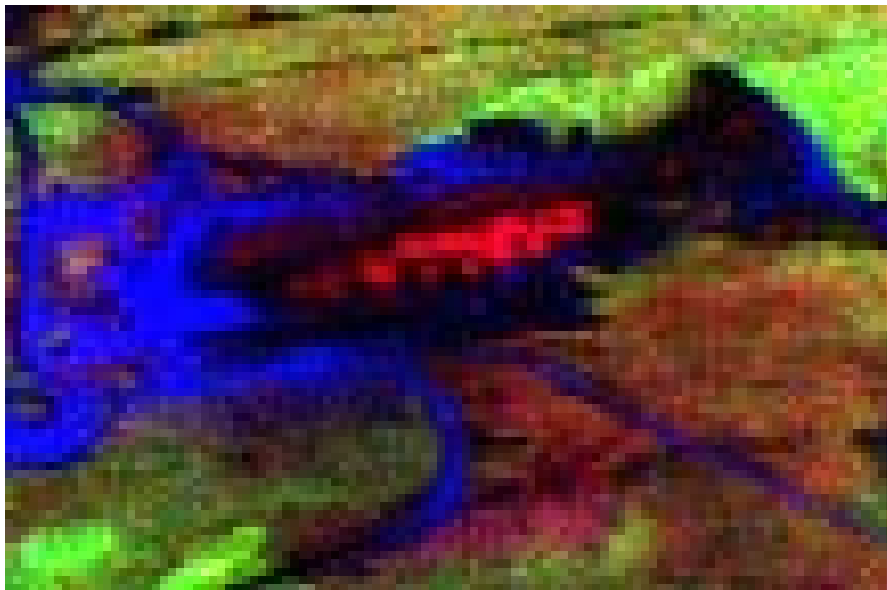


Figure 12 - Color composition image fit (MgOH, AlOH and chlorophyll).



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