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Reflectance spectra of tropical vegetation as a response to metal enrichment in the substrate of west-central Puerto Rico

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ABSTRACT. **The northwest – southeast belt of Eocene rocks in west-central Puerto Rico contains a number of well-documented porphyry copper deposits. These deposits are characterized by felsic stocks and larger envelops of hydrothermally altered rocks that make these ideal targets for recognition from space-borne platforms. In the tropics, these deposits are usually hidden under thick soils and vegetation that complicate their recognition. The well-mapped geology of the belt and the well-documented mineral deposits allowed us to carry out an experimental study in which leaf reflectance of tropical vegetation growing on mineralized and barren substrates is compared. Leaves were collected from the top of canopies and the reflectance spectra between 400 and 800 nm were determined in the laboratory with a GER 1500 radiospectrometer. *Spathodea campanulata* (Tulipán africano) showed a reduction of reflectance around 550 nm and a shift towards larger wavelengths of the infrared plateau ('redshift').**

1. INTRODUCTION

At least eight porphyry copper type mineral deposits are described in west central Puerto Rico. These deposits occur associated with small stocks (300 to 1000 m in diameter) of tonalite and quartz diorite porphyry of Eocene age, and are characterized by hydrothermal alteration. The belt includes economic porphyry copper deposits, as well as low-grade uneconomic and barren intrusive bodies. Thanks to detailed geological mapping by the US Geological Survey (USGS) and mining companies (Nelson and Tobisch, 1968; Mattson, 1968; Barabas, 1982: Cox and Briggs, 1973: Cox, 1985). The extend of these deposits is well-known and the range in economic potential makes this belt a target to experimentally distinguish the deposits using satellite images (Figs 1 and 2).

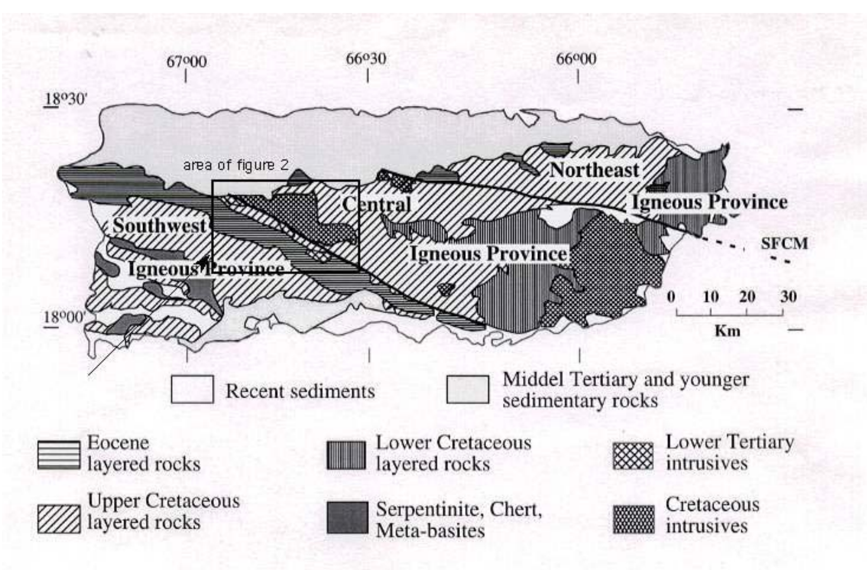

Figure 1: Geologic sketch map of Puerto Rico (based on Briggs and Akers, 1965; Cox and Briggs, 1973).

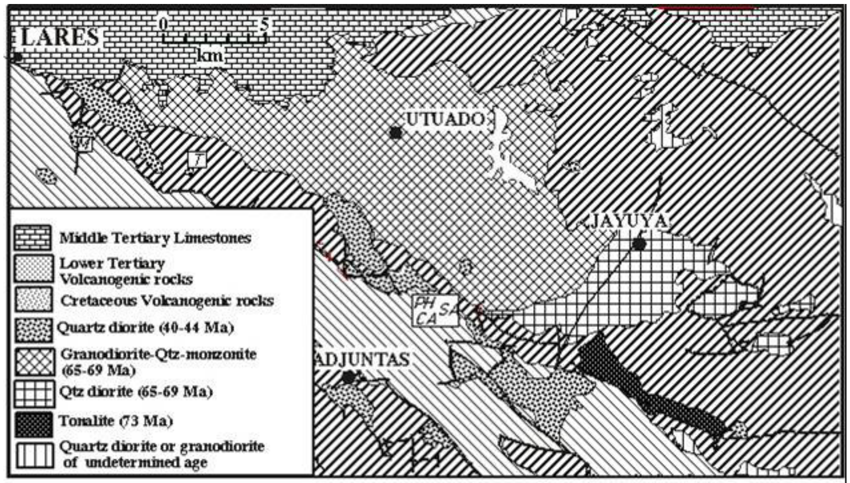

Figure 2. The geology of west central Puerto Rico (based on Barabas, 1982, modified by data from Smith *et al.*, 1998) with the location of deposits mentioned in the text. M = Matilde stock, T=Tanamá, PH=Piedra Hueca, CA=Cala Abajo, SA=Sapo Alegre.

2. Remote sensing of porphyry copper deposits

Porphyry copper deposits usually consist of a porphyritic felsic stock with chalcopyrite in stockwork veinlets in a hydrothermally altered stock and the adjacent country rock (Cox, 1986). The mineralization is usually surrounded by a much larger hydrothermally altered envelop, that forms a much bigger target than the ore zone (Fig. 3). The presence of this much larger hydrothermally altered envelop, with distinct concentric alteration zones, makes porphyry copper type deposits ideally suited for exploration using remote sensing (e.g., Abrams and Brown, 1985). Unfortunately often, but especially in the tropics, these alteration zones are hidden under dense vegetation. Therefore many studies dealing with remote sensing and mineral exploration focus on the optical properties of the vegetation cover and the use of the spectral properties of the vegetation to discern the conditions of the substrate (Goetz *et al.*, 1983).

Vegetation responds in three different ways to anomalous geochemical conditions of the substrate, a taxonomic response, a structural response, and a spectral response (Mouat, 1982: Milton and Mouat, 1989). The taxonomic response refers to the growth, or non-growth, of plant species depending on substrate geochemical conditions. Structural responses include morphological (dwarfism, colour changes), phenological (disturbance in natural rhythmic senescence), and physiological (chlorophyll synthesis) changes in plants due to the substrate conditions (Lepp, 1981; Van Assche and Clijsters, 1990). Spectral response includes all the effects of taxonomic and structural responses on the optical characteristics of the vegetation.

This study focused on changes of the leaf reflectance spectrum due to metal induced stress. Labovitz *et al.* (1983) demonstrated that the metal

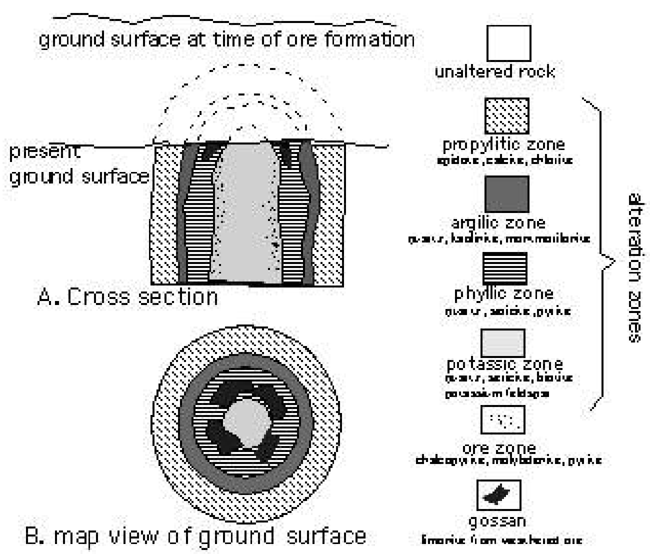

Figure 3. Schematic cross section (A) and map view (B) of a porphyry copper deposit, illustrating that the hydrothermal envelop makes a larger target for exploration (after Lowell and Guilbert, 1970).

content in the soil changed the leaf reflectance especially in those parts of the spectrum used for chlorophyll content and leaf water absorption, and that variation in trace metal content was associated with leaf reflectance. Collins *et al*. (1983) distinguished a distinct shift in the spectral position of chlorophyll bands in forests affected by metal-induced stress. This shift was confirmed by growing trees under controlled conditions of metal contamination (Chang and Collins, 1983). These studies were carried out in temperate climates and their applicability to the tropics is unknown.

The presence, in the same belt, of potentially economically mineralized to barren felsic stocks allowed for the experimental observation of leaf reflectance differences. Reflectance spectra from native plant species growing on known mineralized stocks and on barren stocks were determined to be used in the future interpretation of airborne or spaceborne data. Because satellite images only observe the top surface of the trees, leaves on the top of the canopy were sampled and analyzed to determine their difference in the reflectance spectra.

3. Methods

Leaves from the top of the canopy were sampled, rolled in aluminum foil, packed in zip-lock bags and stored on ice to be taken to the laboratory for reflectance measurements. In the laboratory the leaves were analyzed using a LI-COR integrating sphere attached to the GER 1500 spectroradiometer. The present reflectance of the leaves was calculated based on the reflectance of a diffuse white standard made of polytetrafluorlethylene (PTFE).

For this study two main areas were selected, a) a dry area north of the Cordillera Central containing the Tanamá deposit and the barren stock in barrio Matilde (Nelson and Tobisch, 1968), b) a wet area in the Cordillera Central with the Piedra Hueca and Cala Abajo deposits (Mattson, 1968) (Fig. 2). For this first approach published soil analyses were used, for Piedra Hueca and Cala Abajo (resp. >2000 ppm Cu, and 600-2000 ppm Cu, from Learned and Boissen, 1973) and for Tanamá (97 ppm Cu, Colon *et al*., 2003). Leaves were sampled from bamboo (*Bambusa vulgaris*), flamboyán (*Delonix regia*), and yagrumo (*Cecropia peltata*), pomarrosa (*Eugenia jambos*), and tulipán africano (*Spathodea campanulata*).

Two types of leaves (*Delonix regia* and *Bambusa vulgaris*) had to be discarded because they were to small to measure with the GER 1500 spectroradiometer, other leaves were not useful because of their limited occurrence. The only tree common to barren, uneconomic as well as economic deposits was the tulipán african tree (*Spathodea campanulata*). The metal content of the soils was determined using Atomic Absorption Spectrometry (Colon *et al*., 2003) or from published analyses (Learned and Boissen, 1973).

4. Results and Discussion

This study was a first attempt to study the effect of copper content on the reflectance spectrum of trees typical occurring in Puerto Rico. Because the locations of the porphyry copper deposits in Puerto Rico are so well known, these deposits allow us to determine the best parameters for distinction of this type of deposit in heavily vegetated tropical terranes using remote sensing. Leaves from the top of the canopy were sampled and leaf reflectance spectra were measured to determine the changes in the spectral position of chlorophyll bands due to metal induced stress as demonstrated by Collins *et al*. (1983). Of the leaves collected, only those from the tulipán africano (*Spathodea campanulata*) could be used. The tree occurred abundantly on both barren as well as mineralized substrates. In addition, their leaves were large enough to be measured in the laboratory. The tulipán africano (*Spathodea campanulata*) produces a wide crown of 20 to 40 m in size. Vegetation of this size is visible using IKONOS images with 4 m resolution, but also in images with poorer resolution, like Landsat TM with a 30 m resolution.

The results are summarized in Fig. 4. The initial results show that with an increasing copper content there is a reduction in reflectance at about 550 nm and a shift of the infrared plateau towards higher wavelengths (“red shift’).

This study showed that the *Spathodea campanulata* (tulipán africano) is sufficiently wide-spread to be used and showed changes with the differences in Cu content of the substrate. This study will have to be backed up by more robust studies, in which soil analyses and leave reflectance are compared, especially a study of copper content of the young leaves in the top of the canopy and the relation with the copper content of the substrate. Future investigations should include a wider variety of plant and or tree species. Additional data may be gained from a tree growing experiment, where tropical trees, including tulipán trees, are grown with a controlled content of metal in the substrate as was done by Chang and Collins (1983).

Our preliminary results show that the reflectance curves of the studied tropical vegetation is affected by the metal enriched soils. This demonstrates the potential of remote sensing tools for the future analyses of these area. We are now developing new studies to refine the appropriate techniques.

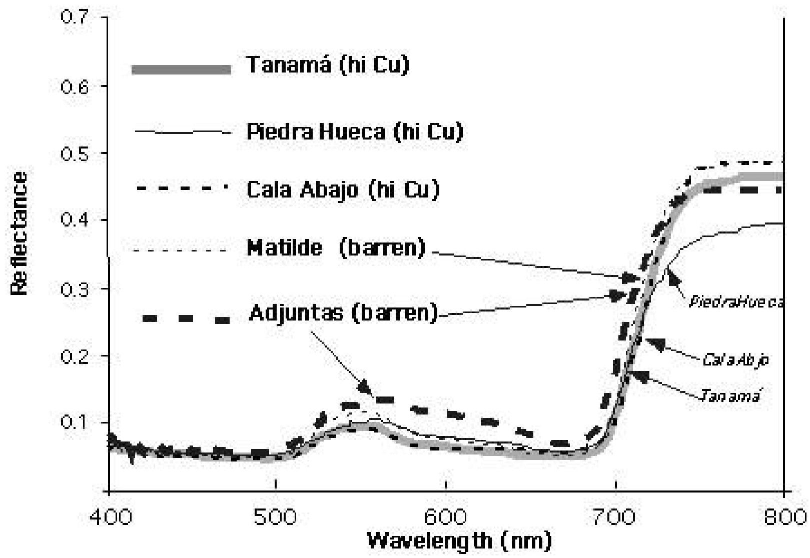

Figure 4. Reflectance of tulipán africano *(Spathodea campanulata*) taken on the Tanamá, Piedra Hueca, and Cala Abajo deposits (all economic deposits), the Matilde stock and barren rocks in Adjuntas. The graph shows that around 550 nm the leaf reflectance of trees on copper bearing substrates is reduced, whereas just above 700 nm, the reflectance shows a shift to the higher wave lengths ('red shift') for leaves of trees on copper bearing substrates.

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