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Raimundo Almeida-Filho
National Institute for Space Research-INPE
Caixa Postal 515
São José dos Campos-SP, Brazil

Raimundo M. G. Castelo Branco
Department of Geology
University of Ceará
Fortaleza-CE, Brazil

Abstract

Landsat Thematic Mapper images and aerial photographs were used in the detection of kimberlite-derived materials in the Redondão test site. In this area kimberlite-derived soils show a flora constituted mainly by grasses and shrubs, which differ from the surrounding savanna-park ("cerrado") vegetation cover. Band-ratio images were able to distinguish kimberlite-derived materials by enhancing areas with different vegetation covers. However, the coarse spatial resolution of Landsat TM images compared with the spatial variability of the study area, and the removal of topographic shadowing effects on ratio images blurred several landscape features. To increase discrimination, Landsat Thematic Mapper ratio images were merged with digitized aerial photographs through intensity, hue and saturation (IHS) colour transforms. The resulting merged colour composite highlighted the spatial and spectral features of the study area permitting an accurate definition of the kimberlite-derived materials within the Redondão diatreme.

1. Introduction

The search for kimberlitic bodies usually raises both scientific and economic interests. Kimberlites are the geological source of diamonds and may yield primary or, more frequently, secondary (alluvial) diamantiferous deposits. However, kimberlites are not detectable easily because of the small outcrop sizes (in most cases less than 150 metres in diameter), and the effect of weathering. This is particularly true in tropical conditions, where kimberlitic pipes are deeply weathered.

Over the past decade remote sensing techniques have been used as a tool for prospecting kimberlite throughout the world (Woodzick and McCallun 1982; Marrs et al. 1984; Pin-Qing 1987). This is based on the observation that kimberlites usually show specific soil-vegetation associations, which may contrast with surrounding areas. The present study aims at evaluating the merged use of Landsat Thematic Mapper (TM) images and aerial photographs in the location of kimberlite-derived materials, using the Redondão diatreme as a test site.

2. General characteristics of the study area

The study area is located in the Gu The near the town of Santa Filomena, Southern Piauí State, (Figure 1). The region has a semi-humid climate, characterized by two seasons: a summer rainy season (October to March) and a winter dry season (April to September), with average annual precipitation of 1100 mm. The mean annual temperature is around 28^{o} C. The region has the typical savanna-like vegetation (cerrado) of Central Brazil, characterized by trees with twisted trunks and branches, shrubs, and a grass mat covering the soil. Except for the

grasses, which become dry during the dry season, the "cerrado" vegetation is green throughout the year. The main species identified in the study area are: Curatella americana, Qualea grandiflora, Stryphnodendron barbatimao, Carapa guianensis, Magonia pubescens, Xylopia emarginata, Pterodon polygaliflorus, Annona coriacea, Caryocar brasiliense, Luehea grandiflora, Panicum equinoleana, and Panasco sp.

FIGURE 1

Redondåo was the first kimberlite diatreme identified in Brazil (Melo and Porto 1965). So far, about ten kimberlitic bodies have been found in this region, most with diameters larger than 500 metres (Castelo Branco 1985). Commercial primary diamond deposits associated with these pipes are still unknown, although diamantiferous placers have been manually exploited by prospectors since the 1940's. As this region is a poorly known kimberlitic province, new bodies might be discovered. The Redondåo diatreme was chosen for study because it is the largest and the best known among the kimberlitic bodies of the region.

The Redondåo pipe intrudes Paleozoic sedimentary rocks on the Guaribas plateau, which comprise Carboniferous sandstones, siltstones, shales and conglomerates of the Piauí Formation; as well as sandstones, siltstones, shales, and cherts of the Permian Pedra de Fogo Formation (Castelo Branco, 1989). Analysis of satellite images and airborne synthetic aperture radar (Castelo Branco 1986) shows that the Redondåo kimberlite is located at the intersection of two regional lineaments, which may be related to deep-seated faults: the Transbrasiliano lineament (Schobbenhaus et al. 1975), oriented Northeast, and the Serra do Boqueirão-Balsas

lineament (Cunha and Carneiro 1972), oriented Northwest. The regional geological relationships suggest that the emplacement of the Redondåo pipe occurred in the Cretaceous, being related to the Mesozoic tectono-magmatic activation of the South America Platform (Almeida 1972).

The Redondåo diatreme forms a coarsely circular crater-like topographic feature, about 1100 metres in diameter, and 40 to 50 metres deep relative to the Guaribas plateau. Within the crater relief is hilly, resulting from dissection by the Mateiro river which drains the area from east to west. Intense weathering has developed deep argillaceous soils widespread over large areas within the crater. Kimberlite-derived materials within the Redondåo diatreme are completely serpentinized, occurring as a light greenish breccia-like groundmass. Rare typical kimberlite minerals (e.g., pyrope-rich garnets) have been found trapped in this breccia-like material. Garnet-lherzolite xenoliths have also been reported (Svisero et al. 1977). Figure 2 shows a recent geological map of the Redondåo area (Silva et al. 1972; Castelo Branco 1989).

FIGURE 2

The vegetation cover associated with the areas of kimberlite-derived soils comprises grasses and shrubs, constituting a serpentine-like flora (Brooks 1972). This grass-shrub land is different from the savanna-park vegetation (cerrado) that occurs in the areas of sedimentary rocks in the Guaribas plateau (Figure 3). This is particularly true during the dry season when the grass cover is dry all over the area, while the "cerrado" foliage remains green.

FIGURE 3

3. Remote sensing data

Two types of remote sensing data were used in this study: digital Landsat Thematic Mapper (TM) images and panchromatic aerial photographs on the scale of 1:60,000. Landsat TM images (Path 220, Row 67) were acquired under a solar elevation angle of 44^{o}, on August 7, 1984, at the peak of the dry season. The Landsat TM images (visible bands) were corrected for atmospheric scattering using shaded areas as reference (Sabins 1987). Taking into account the characteristics of the study area, only TM 3 (0.63 - 0.69 m), TM 4 (0.76 - 0.90 m), and TM 5 (1.55 - 1.75 m) bands were selected. The TM 3 and TM 5 bands were chosen because they are sensitive to chlorophyll and leaf water content, respectively. They can therefore be used to differentiate between vegetation and bare soil. TM 4 band is correlated negatively with TM 3 and TM 5 bands (considering the spectral response of the green vegetation), and is useful for green biomass estimates through band-ratio techniques.

Aerial photographs covering the study area were digitized, producing a fine spatial resolution panchromatic image with pixel size of 3 by 3 metres.

Through a least squares first-degree polynomial rectification algorithm, the Landsat TM images and the digitized aerial photographs were geometrically co-registered and transformed to the Universal Transverse Mercator (UTM) coordinate system, using as reference a topographic sheet of the region, at a scale of 1:50,000.

In addition to these remote sensing products, a detailed topographic map of the study area was produced using as reference the same topographic sheet, complemented with data derived from a stereoscopic pair of aerial photographs. This map was then digitized and transformed into a raster form, creating a digital elevation model (DEM). This product was utilized to produce different perspective views of the study area, by matching it with both enhanced Landsat TM images and digitized panchromatic aerial photographs.

4. Image enhancement and results

Taking into account the characteristics of the vegetation cover in the study area, TM 3/4 and TM 5/4 band-ratios using images from the dry season were used to enhance the kimberlite target areas. Ratios between negatively correlated bands have been shown to be very useful for discriminating subtle changes in vegetation density that can be related to bedrock lithology (Raines et al. 1978; Almeida-Filho 1984). Figure 4 shows the TM 5/4 ratio image covering the Redondão diatreme and the surrounding area. The light grey tones correspond to areas of kimberlite-derived materials (k) with a less dense vegetation cover compared with the savanna-park vegetation. On the other hand, the areas of sedimentary rocks in the Guaribas plateau (Gb) appear in darker grey shades, since trees of the savanna-park remain green during the dry season. Visual comparison showed the TM 5/4 ratio image to be more effective in discriminating the target area than the TM 3/4 ratio image. This may be due to a better spectral separability between bare soils and vegetated areas in the mid-infrared band compared with the visible band.

FIGURE 4

Though the areas of kimberlite-derived materials are enhanced, several landscape features in the study area remain unseen in Figure 4, because of the coarse spatial resolution of Landsat TM images in relation to the spatial variability of the study area, and the relief subduing effects of the ratio images.

To improve the quality of the data, forward and reverse intensity, hue and saturation (IHS) colour transforms were applied using the Landsat TM images and the aerial photographs, since this technique permits the merging of images from different sensor systems (Haydn et al. 1982). In the first step, IHS images were obtained from a RGB (red, green and blue) colour composite using TM 3/4 ratio image, TM 4 band, and TM 5/4 ratio image, respectively. In the reverse transform, the intensity image was replaced by the panchromatic aerial photograph and transformed back into RGB colours. The resulting multisensor image kept the spatial resolution of the aerial photograph and the spectral characteristics (hue and saturation) of the Landsat TM images. Figure 5 is an IHS reverse colour composite showing in reddish hues the areas of kimberlite-derived materials within the Redondão diatreme. Due to the good spatial resolution, this product shows details of the landscape of the Guaribas plateau, with accurate definition of the target areas. Comparison of Figure 5 and Figure 2 shows that the areas of kimberlite-derived materials (k) correspond to the recent geological map of the study area.

FIGURE 5

Conclusions

Combined use of adequately enhanced Landsat TM images and aerial photographs in digital format clearly discriminates areas with particular soil-vegetation associations that are in turn related to the occurrence of kimberlite-derived materials. The results obtained in this study show that remote sensing techniques may be a potential tool to complement traditional methods in searching for kimberlites in the study region. To cope with this task, however, target areas should be of a size compatible with the spatial resolution of the sensor systems and show contrasting soil-vegetation associations relative to the surrounding area.

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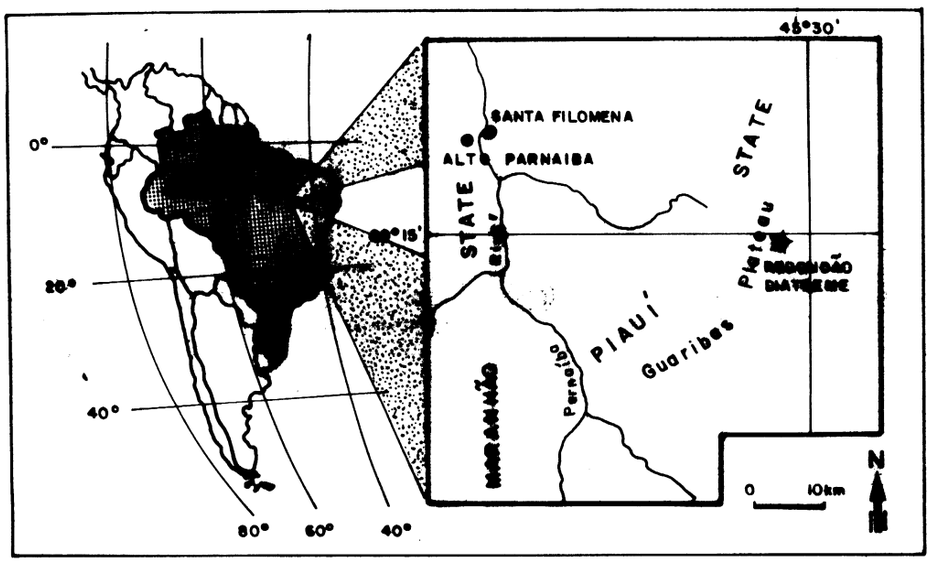

Figure 1. Location of the study area.

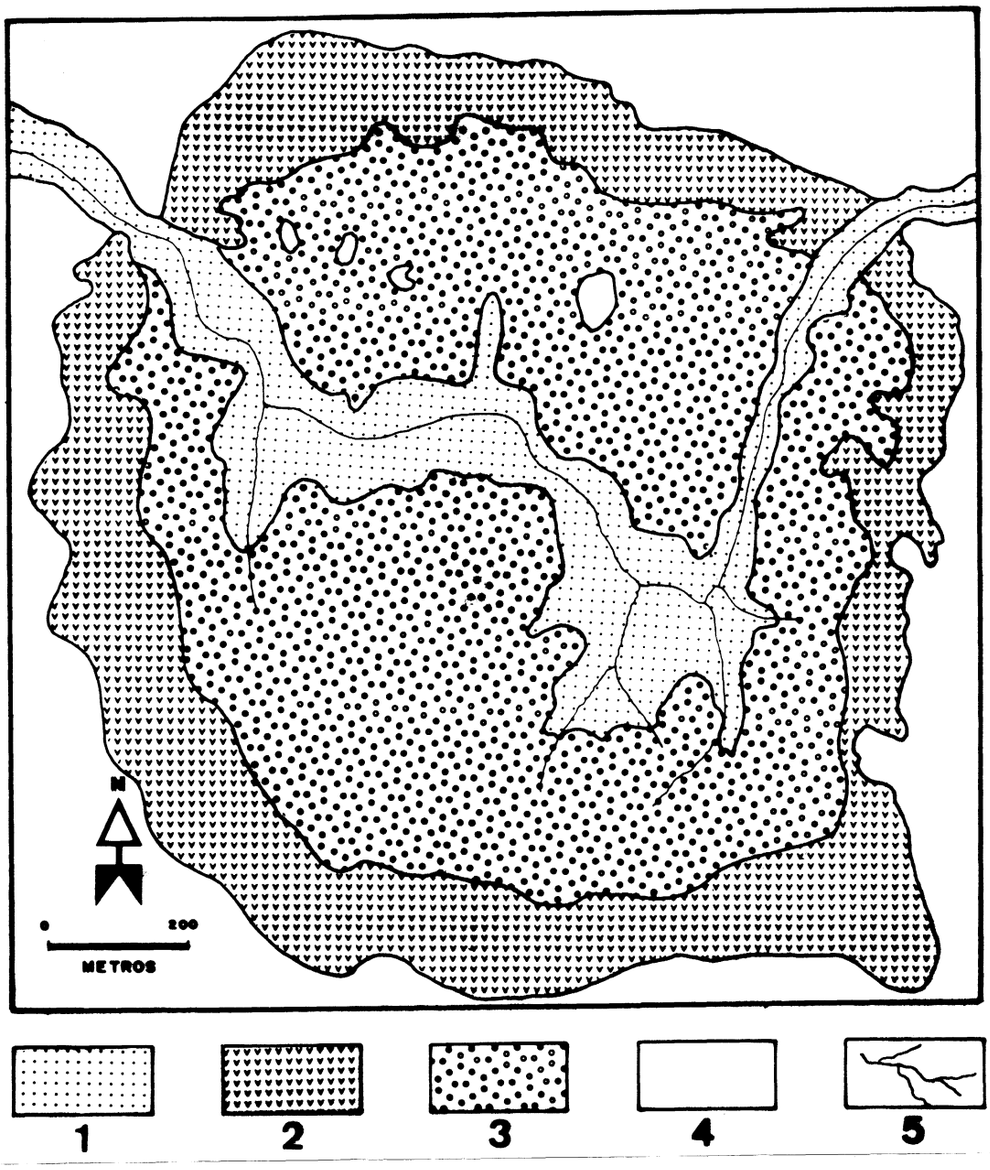

Figure 2. Geological map the Redondão (After Silva et al. 1972; and Castelo Branco 1989): 1 - Alluvial Deposits; 2 - Colluvial Materials; 3 - Kimberlite-Derived Materials; 4 - Pedra de Fogo Sandstones; 5 - Drainage.

Figure 3. Panoramic view of the vegetation in the study area during the dry season: in the foreground predominance of dry grasses associated with the kimberlite-derived materials; and in the background the "cerrado" vegetation associated with the sedimentary rocks in the Guaribas plateau.

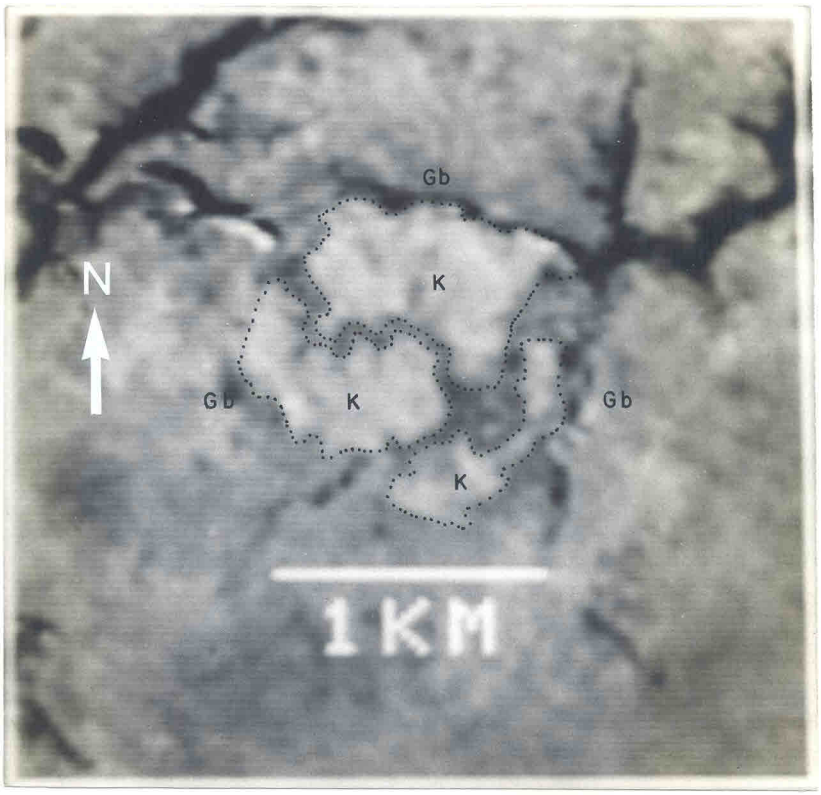

Figure 4. Landsat TM 574 ratio image showing the areas of kimberlite-derived materials (k) within the Redondão diatreme, and of sedimentary rocks in the Guaribas plateau (Gb).

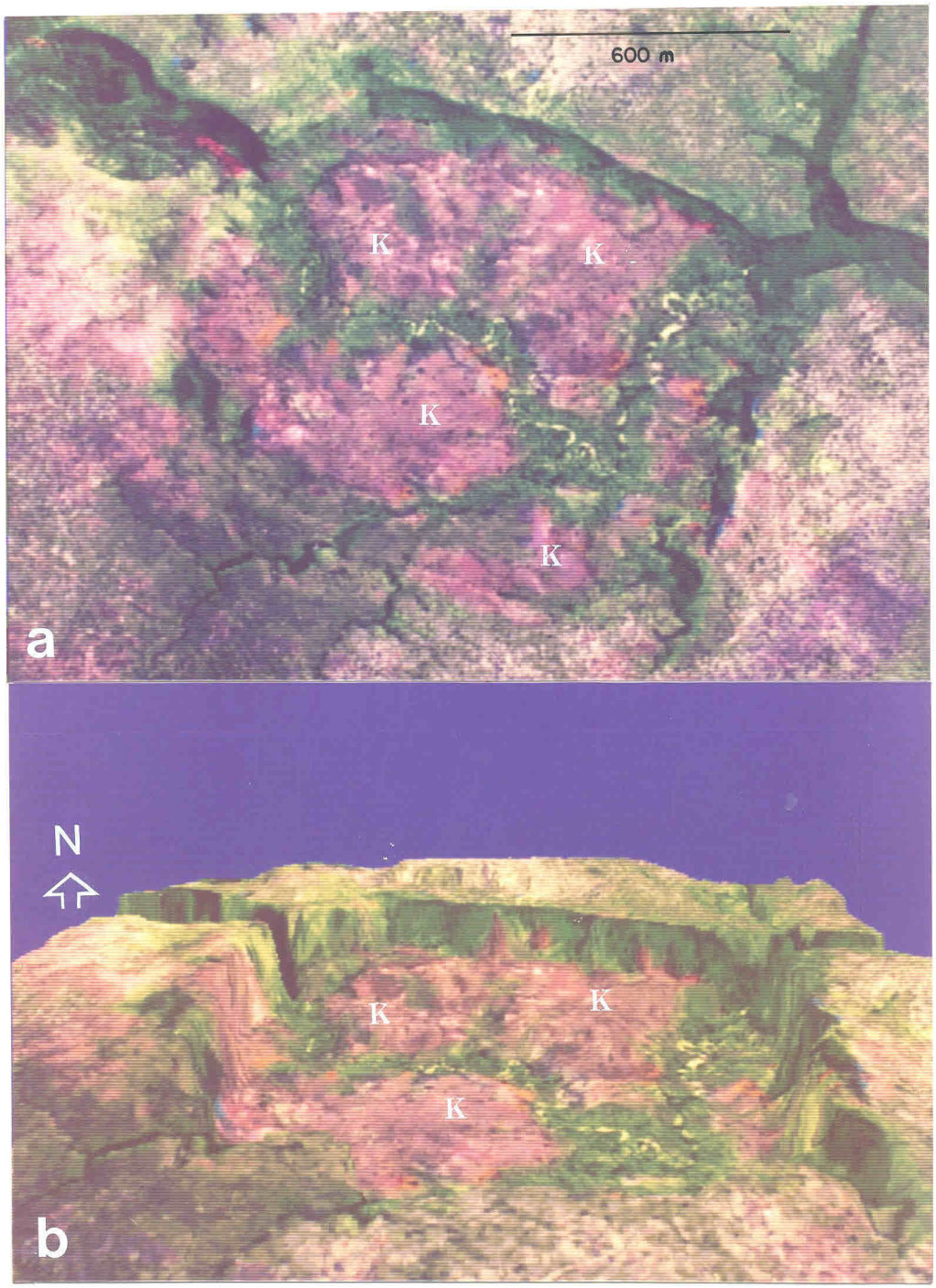

Figure 5. Areas of kimberlite-derived materials (k) within the Redondão diatreme, enhanced by an IHS hybrid color composite (5a); and a south to north perspective view of the study area using the same colour composite merged with topographic data (5b).