METHODOLOGICAL APPROACH IN LITHOLOGICAL DISCRIMINATION BY DIGITAL PROCESSING: A CASE STUDY IN THE "SERRA DO RAMALHO", STATE OF BAHIA

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ABSTRACT

This is a report of the first part of one of INPE's project that studies problems related to lithologic mapping in several tropical environments of Brazil, by computer-assisted techniques applied to digital images. Some enhancement techniques and thematic classifications have been combined and applied in the lithological discrimination of metasediments of the Bambuí Super Group (Upper Proterozoic) in the region of "Serra do Ramalho", representative of a widespread transitional environment between semi-arid and temperate conditions, in the SW portion of the State of Bahia, Brazil. A proposed preliminary methodological sequence is here discussed in detail for imagery obtained during the dry season. Color Composites of stretched original data, Band-Ratioing and Principal Components allow lithological discrimination through grey level and tonal gradations of several metasedimentary sequences, to a degree superior to reconnaissance mapping. Unsupervised (K-Means classifier) and Supervised (Maximum Likelihood classifier) were also applied, and the spatial distribution of the limestone sequence, host to a fluorite mineralization, have shown satisfactory results for the purposes of this research. However, the effects of vegetation cover and of human activities mask and limit in several ways, lithological discrimination in this kind of environment.

1. INTRODUCTION

The importance of orbital remote sensing techniques as an essential tool in geologic mapping in countries with large inaccessible areas and continental dimensions like Brazil, can be better viewed under the context of the country's present day knowledge and needs.

According to Salomão (in Fernandes, 1983), a study based on the percentage of mapping done up to 1980 (Table 1) and the rate of mapping carried out in that year, indicates that it would be necessary 270 years to map all the country at a 1:250,000 scale; 551 years at the 1:100,000 and 1,322 years at the 1:50,000 scale.

TABLE 1

RELATIONSHIP BETWEEN THE % OF BRAZILIAN TERRITORY COVERED BY GEOLOGIC CARTOGRAPHY AT SEVERAL MAPPING SCALE: (SOURCE: SALOMÃO IN FERNANDES, 1983)

MAP SCALE	% OF BRAZIL WITH GEOLOGICAL MAPS
1:250,000	32.6
1:100,000	4.2
1: 50,000	2.0

Since mineral exploitation is directly related to the degree of geological mapping, it is obvious that Brazil might be placed in a position of dependence on external sources for its basic mineral needs very shortly, if it does not revert present day trend. The authors believe that remote sensing techniques offer relatively fast, cheap and accurate way by which the existing gap on geological knowledge can be bridged.

The availability of successive LANDSAT passes over Brazil since 1972 has open up new investigation possibilities in geological research of the Brazilian territory through the analysis of their spatial (texture and land forms), spectral (gradations in grey levels and tone) and temporal/seasonal attributes. INPE is concerned in directing its studies in the analysis of the best remote sensing approach in each morpho-climatic region of South America. The fact that the LANDSAT information is digitally formatted in magnetic tapes makes the use of computers in the analysis of the large volume of information found in multispectral and multitemporal data, particularly convenient.

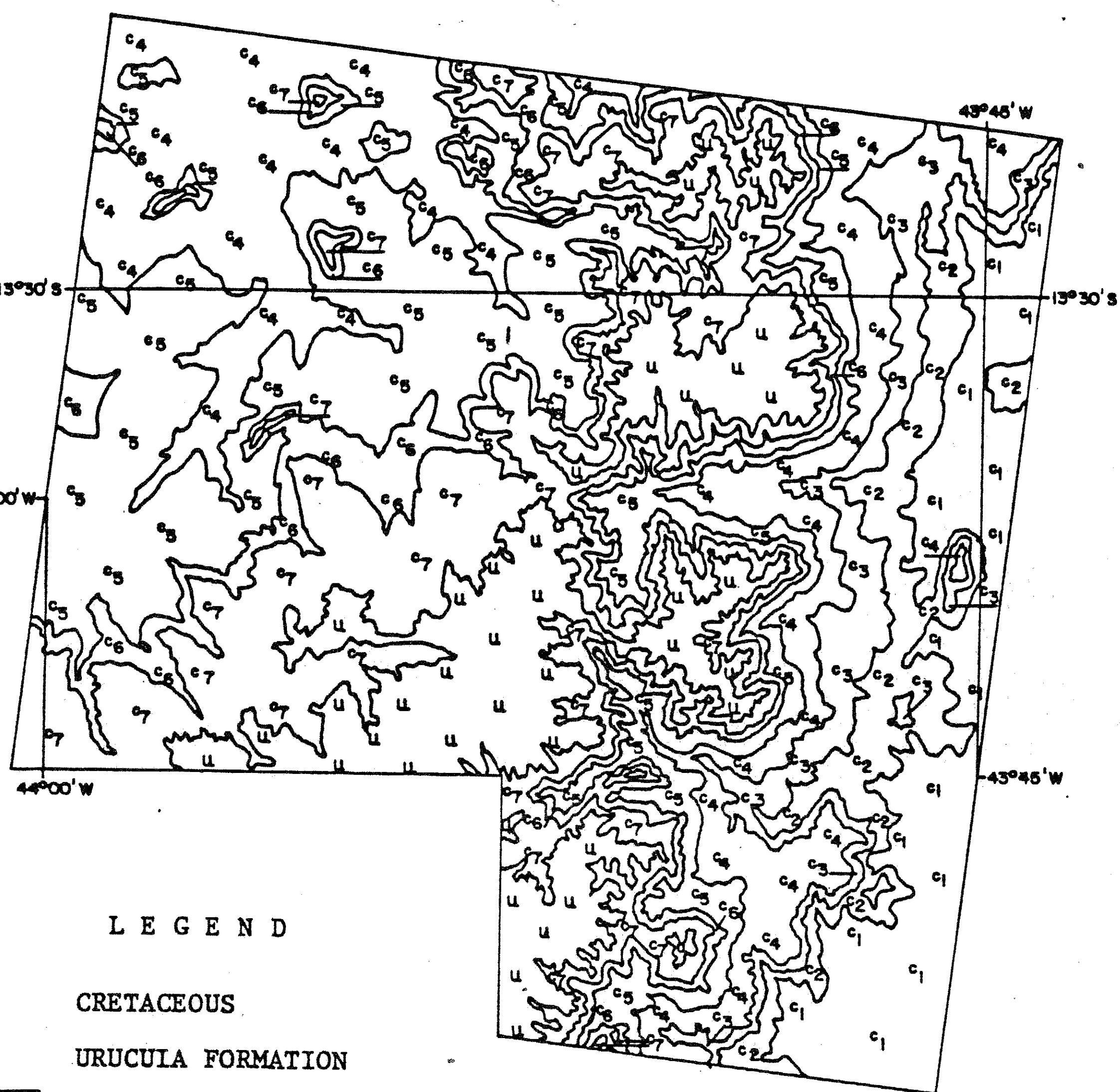
The use of costly and time consuming computer assisted treatments requires serious considerations to be given to the ultimate objective of the geological study in question, the characteristics of the surface imaged, and the seasonal aspects of the phenological behaviour of plant species, soil conditions (moisture, physical-chemical, etc.) and sun-surface-sensor geometry. The analysis of these aspects contributes to the definition of the most adequate sequence of digital treatment to explore either the spectral or the spatial characteristics of orbital imagery of a particular region.

Within this context, the main goal of this work is to test a methodological sequence of digital image processing of LANDSAT data, in the lithological discrimination of relatively flat-lying metasedimentary sequences that present interesting rock-soil-vegetation associations, typical of large areas in central Brazil. The present analysis is based only on the spectral attributes of the images.

Since only imagery from the dry season has been analysed up to this point, seasonal variations (solar illumination conditions and soil-vegetation spectral changes) have not been explored for additional geological information. As a continuation of this study, LANDSAT digital data from rainy season and several additional digital processing techniques (Canonical Transformation and Digital Filtering) will be analysed subsequently in this same area. Other test areas representing diversified environments and geology in the Brazilian territory are presently under study.

2. CHARACTERISTICS OF THE TEST AREA

The test area selected in this research is the "Serra do Ramalho", located in the southwestern corner of the state of Bahia. The Plateau is formed by a sedimentary sequence of the Upper Proterozoic Bambuí Group and the Cretaceous Urucuia Formation (Figure 1). Along the eastern part of the Plateau, important fluorite deposits have been studied in detail(Secretaria de Minas e Energia-SME/Companhia Baiana de Pesquisas Minerais-CBPM - 1976).



LEGEND

CRETACEOUS

URUCUIA FORMATION

u	Sandstones

UPPER PRECAMBRIAN

BAMBUÍ GROUP

c_7	Limestones and shales, siltites
c_6	Outcropping gray limestones
c_5	Limestones and shales, siltites
c_4	Siltites, shales and limestones
c_3	Dolomites and dolarenites
c_2	Outcropping gray limestones
c_1	Dolomites and calcarenites

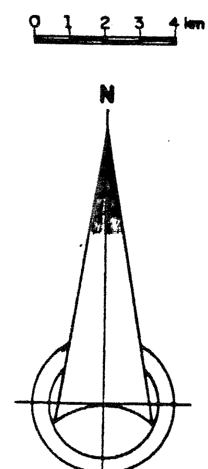


Figure 1 - Simplified geological map of part of the Serra do Ramalho corresponding to the area covered by the images that are discussed in the text.
(Adapted from C.B.P.M., 1975)

The region is characterized by a transitional zone from a semi-arid to a temperate environment and by three distinct vegetation types associated to the topography: a) the eastern low areas adjacent to the left margin of the São Francisco River, dominated by xerophytic species of about 10 meters high and relatively large amount of dry biomass during the winter season; b) up the slopes of the Plateau, the vegetation degenerates into smaller trees with lesser amounts of dry biomass (Figure 2); c) and finally, at the highest portion of the Plateau, where the Urucuia Formation is found, predominates a savannah type of vegetation known as "cerrado" (Figure 3). This vegetation is characterized by small twisted trees which remains green throughout the dry winter season. The reason for this behaviour is a sandy soil of high permeability that developed on top of the Urucuia Formation and which retains some moisture at depth, whereas the soils derived from the limestone are richer in nutrients but present a deficit of water available to the plant during the dry season.

Fig. 2 - Partial view of the vegetation cover over the C_4 unit (Bambuī Group) during the dry winter season.

The region was mapped at the scale of 1:50,000 during the Fluorite Project of Serra do Ramalho (SME/CBPM, op. cit.). The Bambuī Group was formally subdivided into seven units, while the Urucuia Formation remained one. The fluorite mineralizations are confined to the C_2 unit of the Bambuī Group, a dark grey limestone layer.

The C_1 unit is found in the lowlands east of the Plateau, and few outcrops are found interspersed in a reddish argillaceous soil that support vegetation cover with large amount of biomass. The C_2 limestone unit occurs in a narrow strip west of C_1 and is well-represented by numerous large dark grey lapies where only some cactus species are found (Melocactus bahiensis (Br. et R); Melocactus sp; Cereus jamacaru (P.DC.). The C_3 dolomitic unit shows a well-defined deep red soil that contrast with the light yellow soil from the C_4 unit. Furthermore, small pelitic plates are common in the later.

In panchromatic air photos, the C_4 unit is easily identified by the "half-orange" shaped relief and a conspicuous dendritic drainage pattern.

Fig. 3 - View of the vegetation cover (Cerrado) over the Urucuia Sandstone Formation, during the dry winter season.

The C_5 unit is characterized by the predominance of calcareous layers from which originated soils that vary from brown to red, someplaces covered by colluvium from the Urucuia Formation or by a layer of dry leaves. This blanket effect by the leaves is also found in units C_1, C_3, C_4 and C_7 as observed in Figure 2, for instance. Units C_3, C_4 and C_5 support a vegetation cover of medium sized plants, usually devoid of leaves during the dry spell. The C_6 unit is apparently very similar to the C_2 unit, however it supports the slopes of the Plateau. Overlapping the C_6 unit, there is a C_7 carbonaceous shale very similar to C_5, but hidden in many places by Urucuia colluvium.

The Urucuia Formation at the top of the Plateau consists of a red sandstone, someplaces associated to limonites and argillaceous siltites.

3. METHODOLOGICAL SEQUENCE: DISCUSSION OF RESULTS

The flow chart presented in Figure 4 is proposed for lithological discrimination in tropical semi-arid to temperate environments, exploring mainly the spectral characteristics of the MSS LANDSAT imagery. The examples and discussion that follow are based only in one LANDSAT pass of June 14, 1975 which corresponds to the dry season. However, the same steps in digital image processing can be suggested in a multitemporal approach based on the results from another research developed at INPE in the semi-arid environment of the Caraíba Copper Province, in the region of the Bahia State(Paradella, 1983).

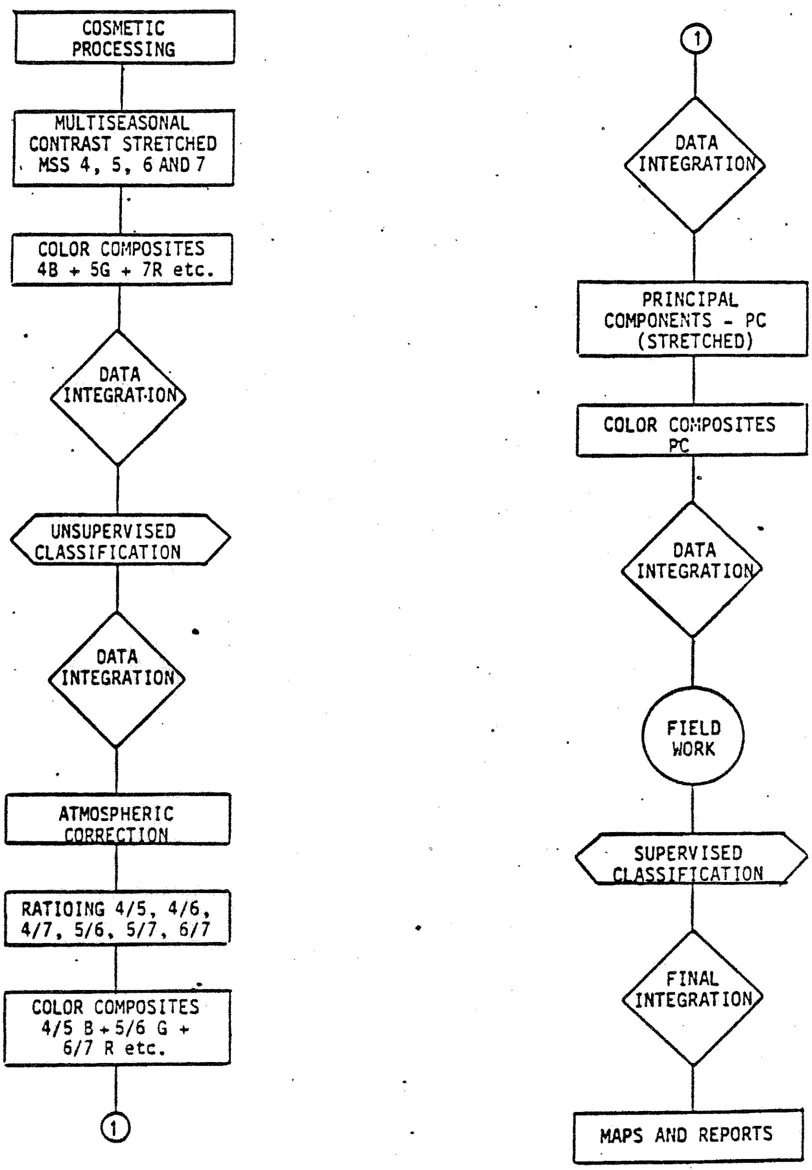


Fig. 4 - Flow chart of suggested steps in lithological discrimination by digital processing in a semi-arid environment.

All the computer processing done in this study was realized in a General Electric Image 100 with a PDP 11/45, at a video scale of 1:100,000 in INPE's Laboratory of Digital Image Processing in São José dos Campos, São Paulo State.

3.1. LINEAR CONTRAST STRETCH AND COLOR COMPOSITE OF STRETCHED MSS-IMAGES

In the first step the area was enlarged to the video scale of 1:100,000 and Linear Contrast Stretch was applied. Enhancements by contrast stretch are the most commonly used processing technique for geological applications. However, it is not a consensus that linear stretch is the most adequate function for geological investigations (Goetz et alii, 1975). In the present study, the analysis of the Stretched Original Bands provides information about the influence of green vegetation cover and human activities over the scene radiation and permits the delineation of the spatial distribution of some rock units represented by distinct rock-soil-vegetation associations.

The use of Color Composites of stretched bands, as the one shown in Figure 5, helps to define the lithological contacts. Basically, this is due to the characteristics of the human eyes, which are able to discriminate with greater facility and accuracy color hues than grey levels. Furthermore, color-composites are also a convenient way to show in one scene multispectral variations of the target, without losing the spatial relationships of the image.

Fig. 5 - Color Composite of Contrast Stretched bands 4, 5 and 6 with colors blue, green and red, respectively. Scale ≅ 1:300,000.

In Figure 5, the outcrops of the C_2 unit are shown in blue at the right side of the photo and the scarps of the C_6 unit are clearly defined by a dark blue, narrow and sinuous band in the central part of the photo. The tonal contrasted light-green/dark-green region, in the upper left corner of the photo, shows approximately the lithological contacts of units C_4/C_5. The Urucuia Formation appears in red shades and agricultural land-uses are distinct straight bordered geometric figures in very light tones.

3.2. UNSUPERVISED CLASSIFICATION

At this point, an unsupervised classification with a K-Means algorithm (Hartigan, 1975) was done with the objective of defining the major spectral classes in the area and eventually other classes, exploring thus its potential in discriminating subtle clusters which in visual analysis usually are not evident to the photointerpreter (Figure 6).

In Figure 6, the units C_2 and C_6 are represented by yellow; Urucuia Formation by light-blue; C_4 is magenta, which someplaces represents also the C_7 unit; and C_5 is represented by dark-brown color. The agricultural land use is portrayed both in dark blue and white. The remaining two classes in black and light-brown do not correspond to any recognizable thematic class, but someplaces they coincide with shadowed areas.

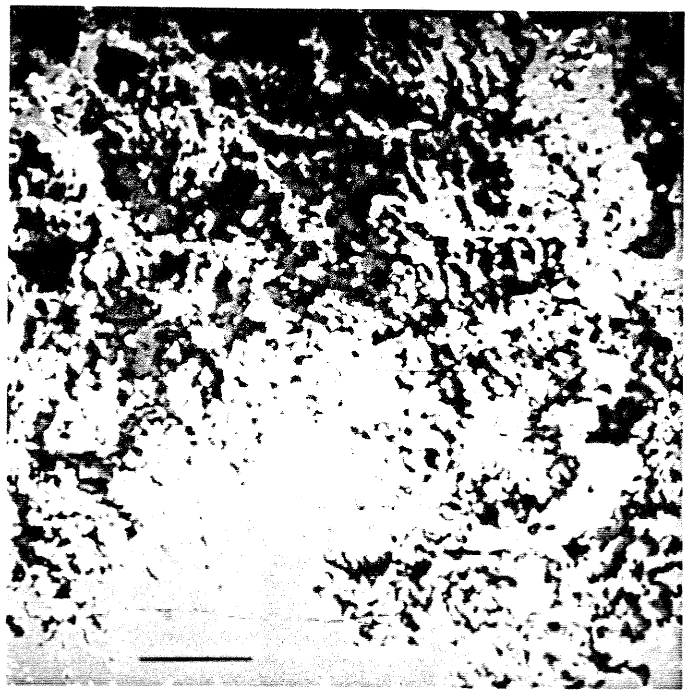


Fig. 6 - Eight thematic classes obtained by unsupervised classification with K-Means algorithms. Scale ≅ 300,000.

3.3. BAND RATIOS AND COLOR COMPOSITE STRETCHED RATIOS

Band-ratioing has been widely used in geologic interpretations in a varied set of problems (Rowan et alii, 1974; Blodget et alii, 1978; Paradella, 1983; Almeida Filho, 1984). This is due to the fact that band-ratios can emphasize small spectral differences among targets that have spectral signatures with different spectral slopes (Rowan et alii, 1977).It can also be mentioned that targets easily separated in their original channels might become indistinguishable in ratio images, particularly if they have similar spectral-reflectivity slopes. For this reason, it is recommended that in geologic photointerpretations, ratio images and original channels be always analysed prior to the elaboration of color-composite band-ratios (Figure 7).

Moreover, this technique tends to decrease the differences in spectral response of the same unit due to topographic effects related to the illumination conditions (Kowalik, 1981). In this sense, there is a restriction in the use of ratio products for direct photointerpretation in respect to the loss of the familiar spatial features in the scene due to the elimination of shadow effects. This can be partially corrected by the use of a "hybrid" color composite of ratio images and an original MSS channel, such as band 6 or 7.

The analysis of stretched original band-ratios and of color composites of ratios in the test-area, made possible the check of the spatial distribution of the units C_2, C_4, C_6 and C_7 and additionally improve the definition of their lithological contacts. Nevertheless tone patterns that characterize the units C_1, C_3 and C_7 couldn't be extracted with such an approach. It is relevant to mention in respect to the analysis of the original ratio data that: units C_2, C_6 and Urucuia Formation are clearly defined through MSS 5/6; the spectral contact between units C_4/C_5 on the upper left side of the area is well-defined by the MSS 4/7; human activities in the area of the unit C_4 on the eastern border of the Plateau, is shown on MSS 4/7 and 5/7. The most important aspect of these products was observed on MSS 4/5 where spectral differences between C_2/C_6 were easily noted.

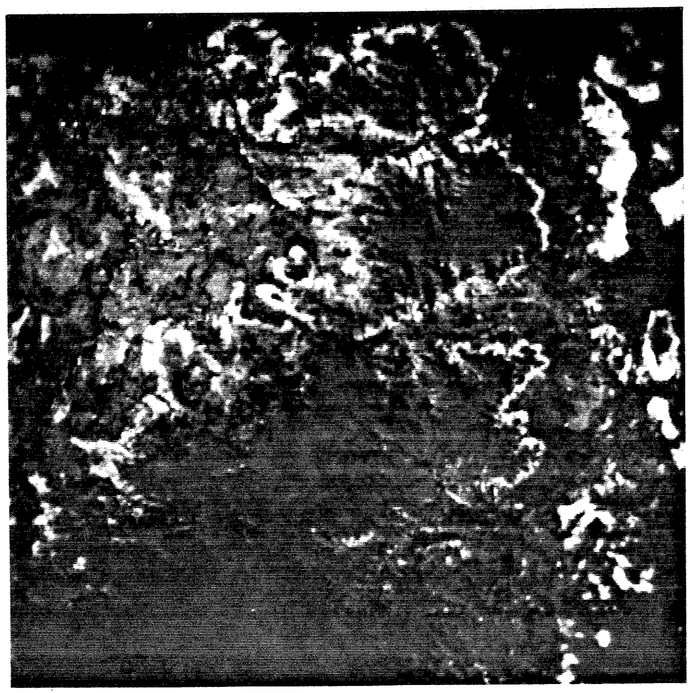


Fig. 7 - Band ratio stretched color composite using MSS 4/5 with blue, MSS 5/6 with green and MSS 5/7 with red. Scale ≅ 1:300,000.

3.4 - CONTRAST STRETCHED PRINCIPAL COMPONENTS

Several remote sensing articles have shown the use of Principal Components of MSS LANDSAT data in geological applications (Blodget et alii, 1978; Santisteban and Munoz, 1977; Paradella, 1983). The technique assumes that the variance is a measure of the amount of information in the original scenes, so the algorithm computes one orthogonal linear transformation C, in such way that $Y = Cx$,where x is the original channel, C is the matrix of linear transformation and Y is the new channel or principal component. This kind of transformation tends to concentrate all the information of the original channels in another set of axis that are uncorrelated and orthogonal between themselves. In addition, with this transformation most of the original information is concentrated in the first two components.The Color-composite of stretched principal components is shown in Figure 8.

The visual analysis of these products (individual PC and Color Composites) shows results that agrees with the band-ratio products. In this sense it is important to mention the spectral lithologic contact between units C_4/C_5 in the 1st PC and the regions of occurrences of units C_2, C_6 and Urucuia Formation, well-defined in the 2nd PC. Based on Figure 8 it is possible to see the spatial distribution of the main lithological units in the area, which are: units C_2 and C_6 in light tones; unit C_4 in pale green-brown tones; units C_5 and C_7 in light green gradations, and Urucuia Formation in heavy red tones. Human activities are well-characterized by nuances in dark and light blue-green tones. The distribution of the units C_2 and C_3 presents ambiguities in spatial distribution with part of C_4.

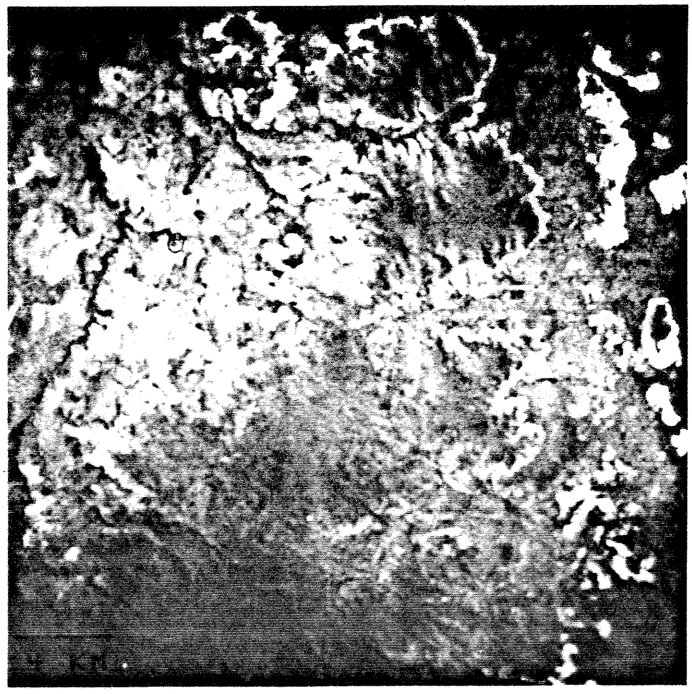


Fig. 8 - Color Composite of Stretched Principal Components (1^{st} PC with blue, 2^{nd} PC with red and 3^{rd} PC with green).

3.5. FIELD WORK AND SUPERVISED CLASSIFICATION

Based on the results obtained from the analysis of processed products and taking in consideration the flow chart of Figure 4, field work would be planned only after checking several aspects of spatial distribution and contact relationships indicated by color patterns. For instance, the green vegetation cover determines the spectral response of the C_1 unit and part of C_3 and C_4, specially along the eastern border of the scene. The spectral responses from the partly green vegetation cover in the test area can be extracted by a relatively simple visual analysis of the products (such as R 5/7). The distribution pattern of the C_2 unit can be thought as a true outcrop map of this unit, which is very important for fluorite prospection purposes.

In the NW portion of the test area, in the region of the C_4/C_5 contact, the influence of vegetation cover is attenuated. Along the western border of the area, the contacts of C_4, C_5 and part of C_6 are indistinguishable because of the Urucuia Formation colluvium and associated "cerrado" vegetation.

Finally, the Supervised Classification (Figure 9) was made possible only after appropriate choice of sampling areas selected on the basis of the field work and analysis of previously processed images.

4. CONCLUSIONS

The proposed methodological sequence, advancing through the analysis of products of increasingly interpretative complexity, was satisfactory in view of the purposes of this research. In general, standard color composite of three original LANDSAT bands was sufficient in the delineation of the most conspicuous lithologic units within the test area. Since this product can be also obtained by photo-optical means, it has the advantage of being cost-effective and time-efficient. Even though it has the added advantage of easy dissemination in the geologic community, its use is restricted at the moment to a standard 1:250,000 scale produced by INPE in Cachoeira Paulista, SP.

Fig. 9 - Illustration of Supervised Classification (Maximum likelihood algorithm) of the C_2 unit (Bambuí Group) which hosts fluorite mineralizations.

In situations of detailed work that requires scales of 1:100,000 or greater, the products obtained by Ratioing, Principal Components and Thematic Classifications are more appropriate, when analysed with the original LANDSAT data. However, they envolve costly and time consuming digital processing techniques not widely available in Brazil.

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