Extr. SPOT 1 : Utilisation des images, Toulp. bilan, résultats ... Paris, nov. 1987

SPOT IMAGES AND GEOCHEMICAL MAPPING OF LATERITIC COVERS IN SOUTHERN MALI

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ABSTRACT

A detailed geochemical mapping of superficial formations in South Mali, is compared with recent high resolution SPOT satellite images. The two main landscape features standing out in SPOT images are expressed by thematic indices derived from multispectral data. They reflect the distribution of vegetation cover and the distinction between silty clay soils in the valleys and ferruginous duricrust exposed on plateaus. Detritic material accumulation at the periphry of duricrust plateaus is evidenced by a geochemical halo of zirconium and quartz at their periphery, and by a narrow strip of high reflectivity with sparse vegetation cover on Spot images. Distribution of vegetation on duricrusts is related to their kaolinite content. These relationships,either direct or indirect, existing between radiometric response and geochemical composition of superficial formations appear very useful for geological and mineral exploration of lateritic covers.

1. INTRODUCTION

The main purpose of this study is to compare the multispectral and geochemical patterns of lateritic covers, in relation with geology, landscape morphology and distribution of weathering facies. Another objective is to show the contribution of high resolution remote sensing data, for detailed mapping of superficial formations in tropical countries where a very thick and widespread lateritic mantle creates a major obstacle to the application of direct surface exploration methods.

This study was realised near the village of Dagadamou in South Mali, where a detailed geochemical survey was carried out for base metal and gold mineralizations by BRGM and DNGM (Cottard et al. 1981 a-b). About 1000 samples were collected on a regular grid of 100x200 m, and analyzed for major and trace elements. This large number of informations collected on a relatively small area of about 25 km² is compared with SPOT remote sensing data acquired in april and november 1986.

2. PRESENTATION OF STUDY AREA

The village of Dagadamou is located in the Kangaba district, between the Niger valley and the border line with Guinea. In this region the tropical climate of sudanian type is characterized by two contrasted season with a mean annual rainfall of 1250 mm. Vegetation cover is a clear forested savanna with large stretches of grass and bare lands on plateaus where massive ferricrete is outcropping.

Landform characteristic features correspond to high plateaus of ferruginous duricrust dissected by broad bottom flat valleys. In the western part of the area plateaus are higher with monoclinal top surfaces limited by an erosion scarp, while their shape is more rounded in the East. An overburden of fine sand and clay material is accumulated in the valleys and in the lowest parts of plateaus.

The facies of the underlying basement rocks corresponding to the metamorphic volcano-sedimentary formations of the Siguiri unit (Bessoles, 1977, Bassot et al. 1981), are not well known due to the lack of exposure. Many quartz veins are observed in the lateritic profile , sometimes in relation with gold mineralizations (Freyssinet et al., 1987).

3. ANALYSIS OF SPOT IMAGES

3.1 Characteristics of SPOT data

SPOT images used in this study correspond to a stereoscopic pair of oblique views in multispectral mode. The first image is an eastern view with 25° incidence, acquired on 5 April 1986 at the end of the dry season. The second image was taken on 29 November 1986 from the West with 21° incidence, about one month after the end of the humid season. After standard corrections (level 1B), the radiometric values in the three spectral bands XS1, XS2 and XS3 are given for pixels of 20 x 20m (Begni, 1982; Baudoin, 1982).

Registration of SPOT image with geochemical base map was achieved by visual superposition, using roads and drainage network as reference landmarks. After rotation, the window of 225 x 275 pixels corresponding to the study area was selected. A close fitting was obtained between the two SPOT images due to the moderate relief variations (≈40m) on this small area and to the presence of some permanent easily identifiable pixel units on both views.

3.2 Comparison and interpretation of SPOT images in April and November

A synthetic representation of multispectral information is given on color composite picture of the three channels XS1, XS2 and XS3, presented in annex for the two acquisition dates. The main geomorphological units are easily identified by color variations corresponding to their difference of spectral signature. A sharp contrast can be noticed between lateritic duricrust cover exposed on plateaus and silty clay superficial deposits accumulated in topographic depressions and on valley floors or "flats". However, if the same general features are visible on both images, many important changes in their radiometric response can also be noticed between April and November. Statistical parameters of reflectance distributions given on Table I indicate that intensities registered in November are systematically lower than in April and the same spectral bands are only slightly correlated between the two dates (Table II).

Table I : Statistical distribution parameters of intensities measured in the three spectral bands XS1, XS2, XS3 on SPOT images of Dagadamou area.

Date	Channel	Mean	Standard deviation	Minimum	Maximum
5 April	$XS1_a$ $XS2_a$ $XS3_a$	86.9 85.1 87.4	3.9 5.1 8.1	69 61 53	111 118 124
29 November	$XS1_n$ $XS2_n$ $XS3_n$	38.4 31.0 42.5	1.9 3.1 7.0	32 21 20	51 48 63

Table II : Correlation coefficients matrix between intensities in the three spectral bands for the two acquisition dates.

Date		5 Avril			29 November		
	Channel	$XS1_a$	$XS2_a$	$XS3_a$	$XS1_n$	$XS2_n$	$XS3_n$
5 April	$XS1_a$	1.00					
	$XS2_a$	.95	1.00				
	$XS3_a$	.39	.38	1.00			
29 Novem	$XS1_n$	.19	.23	- .29	1.00		
	$XS2_n$	.16	.22	- .32	.89	1.00	
	$XS3_n$	- .00	- .03	.34	- .06	.05	1.00

Distribution of vegetation, characterized by a red color corresponding to higher reflectances in near infrared channel XS3 and relatively low intensities in the visible channels XS1 and XS2, is clearly visible. The highest density of vegetation corresponds to the gallery forest outlining the drainage network. In November at the beginning of dry season, vegetation is also more widespread in the valleys than in April. On duricrust plateaus, vegetation is less abundant and characterized by discontinuous patches of wooded savannah. In many areas, bands of vegetation alternate with bare ferricrete exposure, and form a striped pattern stretching in the NW-SE direction. This distribution pattern can be considered as the expression of lithological structures preserved in the lateritic cover. That is also well evidenced by the classical vegetation index I_v (Roquin et al., 1987).

$$I_v = (XS3 - XS2) / (XS3 + XS2)$$

In April, due to a less extensive vegetation cover, silty clay soils of valleys are characterized by a higher albedo in visible bands XS1 and XS2 than the ferricrete exposed on plateaus. A better discrimination was given by a synthetic index taking into account the color contrast related to the abundance of ferruginous oxides in superficial materials. This duricrust index was expressed as I_c (Roquin et al., 1987).

$$I_c = 3(XS1) - XS2 - 100$$

One can also notice a narrow strip of high reflectivity outlining the margin of plateaus. This transition zone without much vegetation seem to correspond to the bottom slope accumulation of fine silty clay materials washed out from the surface of plateaus during humid season.

4. ANALYSIS OF GEOCHEMICAL DATA

4.1 Presentation of geochemical data

The 1062 samples of superficial material collected on a regular grid of 100 x 200m were analyzed for major and trace elements by plasma emission spectrometry. The following elements: SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, MnO, TiO_2 (in oxide percentage) and P, Ba, V, Cr, Co, Ni, Cu, Zn, As, Ce, Y, Sr, Zr, Nb and Mo (given in ppm), present significant variations at the background level. Normative mineral composition for hematite, goethite, gibbsite, kaolinite, quartz and the ratio RHG = Hematite/(Goethite + Hematite) were also estimated from the major element concentrations (Roquin et al., 1987).

Four main sample categories have been distinguished according to major element composition and field observations :

- 271 samples of aluminum rich ferricrete;
- 189 samples of quartz rich ferricrete;
- 184 samples of gravelly soils corresponding to the superficial dismantling of the ferricrete;
- 228 samples of soils developed on sandy clay deposits accumulated in "flats".

4.2 Analysis of background differentiation between sampling media

The geochemical background differentiation was characterized by comparing distribution parameters of each element between the four sampling facies. The median value of an element distribution is considered as a robust estimator of its background level and the two extreme percentiles (5% and 95%) indicate its variation range. A differentiation index, D_i, was thus calculated as the difference between within group and global median values relative to the global range of variation for the element considered.

$D_i = 100 \times (\text{Median group}_i - \text{Median}) / (\text{Pct } 95 - \text{Pct } 5)$

According to their mode of differentiation, five groups of elements and minerals can be distinguished (fig. 1).

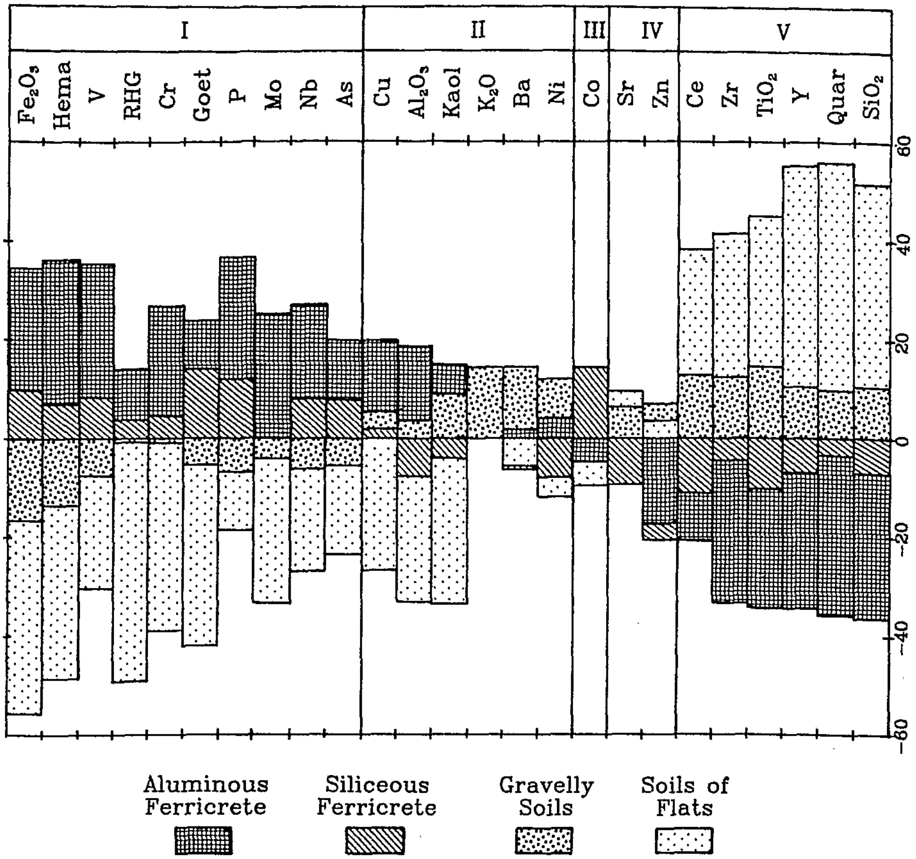

Figure 1 : Classification of elements and normative minerals according to their background differentiation index D_i, for the four types of sampling facies.

- Elements of group I (Fe_2O_3, hematite, V, Cr, goethite, P, Mo, Nb, As) present decreasing background levels from aluminous to siliceous duricrust to gravelly soils and soils of flats.
- Elements of group II (Cu, Al_2O_3, kaolinite, K_2O, Ba, Ni) differ from the preceding ones by higher contents in gravelly soils than in siliceous duricrust samples.
- For group III (Co), the highest background is observed in siliceous duricrust and a similar trend can be noticed for Mn whose 95% percentile is also higher in this facies.
- The two mobile elements Sr and Zn, corresponding to group IV, present a rather complex behaviour, with a background slightly higher in gravelly and flats soils than in duricrust samples.
- Elements of group V (SiO_2, TiO_2, Zr, Ce, Y and quartz), show a background differentiation opposite to the first group. They are accumulated in soil samples and particularly in soils of flats and depleted in duricrust samples. This asssociation is characteristic of heavy minerals (monazite, zircon, rutile, anatase, ilmenite...) accumulated with quartz in sandy covers of the valleys.

The same trends of differentiation are also evidenced by a study of correlations between elements corresponding to geochemical and mineralogical associations.

Another representation of these geochemical patterns is given on the maps of elements distribution, illustrated in annex for aluminum and zirconium. The main differentiation correspond to the contrast of composition between outcropping ferricrete on plateaus and silty clay soils in valleys. Extension of plateaus is delineated by high background levels in Fe_2O_3, Al_2O_3, Cr, V, P, Cu, As, Mo, Nb, goethite, hematite and kaolinite. On the contrary, flats are enriched in quartz, SiO_2, TiO_2, Zr, Ce and Y. There is no indication of another kind of differentiation related to a change of lithology in the underlying bedrock.

A halo of high concentration in zirconium and less extensively in quartz contents can also be noticed around ferricrete plateaus. this feature is particularly noticeable in the west part of the area and is clearly related to the narrow strip of high reflectivity already noticed on SPOT images. This feature confirm the presence of a pedological differentiation at the periphery of plateaus corresponding to the bottom slope accumulation of detritic materials with further leaching of fine clay particles.

5. COMPARISON BETWEEN GEOCHEMICAL AND RADIOMETRIC DATA

In order to precise the relationship existing between radiometric signature of superficial lateritic formations and their geochemical and mineralogical composition, correlations between the two data sets were also studied. For this purpose, every pixel corresponding to a sampling site was first sampled on SPOT image and the radiometric data were merged with the geochemical data file.

Correlations of element concentrations with duricrust and vegetation indices, which provide a good summary of multispectral information, have already been presented for SPOT data collected in April (Roquin et al., 1987). Here, the same radiometric duricrust index was considered , because it is much better in April when the vegetation cover is less abundant, than in November. A new synthetic index was devised in order to allow for the obliteration of information by bush fires. This index, Iv_{max}, correspond to the maximum of the standardized values ($m = 100$, $s = 10$) of the two vegetation indices from April and November.

Elements and normative minerals correlation coefficients (higher than 0.1), with the two indices, Ic_{avr} and Iv_{max}, have been plotted on diagrams given for the whole sample set and separately for each sampling facies (Fig. 2).

On the diagram of correlation coefficients for the whole set of background samples (with no concentrations higher than m+3s for any element), elements are clustered in three main groups corresponding to their geochemical background differentiation pattern (Fig. 2) :

- Quartz and silica, with their associated trace elements Ti, Y, Zr and Ce, are positively correlated with the vegetation and duricrust indices;
- On the contrary, in the iron group, goethite , hematite , V, P, Nb, As, Mo and Cr show negative correlations with both indices;
- The kaolinite or aluminum group is scattered on a wider range of intermediate values. At one extremity, the less mobile elements enriched in the ferricrete, Al, Cu and kaolinite, are characterized by negative correlations with the duricrust index; at the other end, a positive correlation is observed for the more mobile elements Ba, Sr, Zn, Mg and Ni, preferentially concentrated in gravelly soils and soils of flats.

Quite different relationships are observed when they are considered separately, within each facies (Fig. 2).

In the duricrust facies (aluminous, siliceous or gravelly), a permanent feature correspond to the positive correlation of aluminum and kaolinite and some associated trace elements with the vegetation index. Such a kind of affinity between vegetation and kaolinite content of ferricrete was already noticed in western Africa (Maignien, 1958). An opposite behaviour is observed for quartz, silica and associated trace elements which are positively correlated to the duricrust index and opposed to the vegetation index.

However, in soils of flats, geochemical composition is reflected in a different way by the two radiometric indices. Ba, Ce, Mn, Sr and Co are positively correlated with vegetation index and negatively correlated with duricrust index. This relation suggest that manganese concretions, which are very effective to scavenge trace elements such as Co, Ba, and Ce, are more abundant in environments favorable for vegetation.

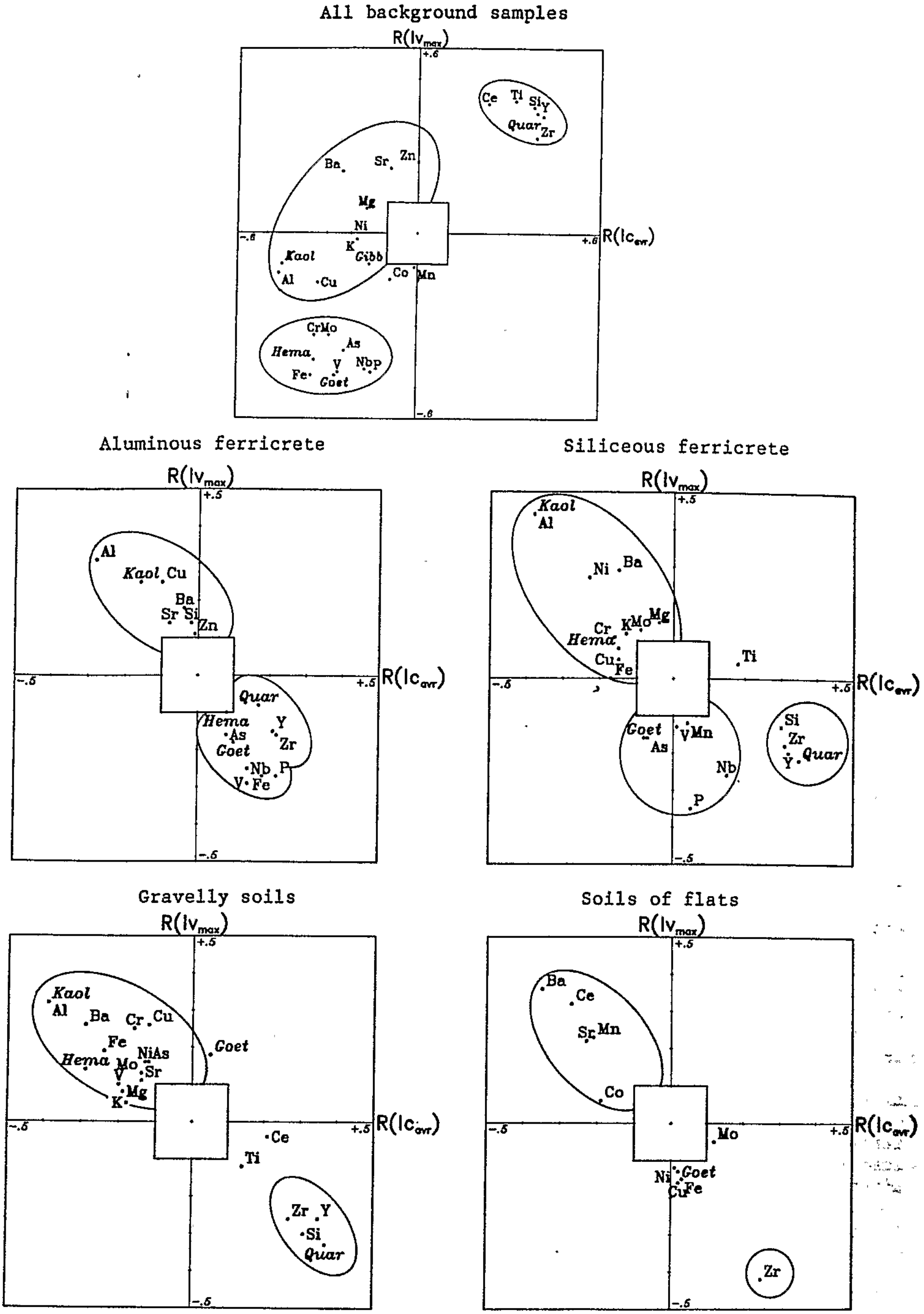

Figure 2 : Diagrams of elements and normative minerals correlation coefficients with duricrust index of April (Ic $_{avr}$), and maximum vegetation index (Iv $_{max}$).

On the contrary, zirconium in soils of flats, is correlated with the duricrust index and opposed to the vegetation index. This, again, points out the correspondence between the geochemical halo of Zr surrounding many plateaus and the halo of high reflectivity without vegetation observed on Spot image.

6. CONCLUSION

The differentiation of superficial formations, dominated by the contrast between ferruginous duricrust on plateaus and silty clay soils in valleys is the result of the geomorphological and geochemical evolution of the landscape. Two different features of this evolution are clearly illustrated on both SPOT images and geochemical maps.

- The residual character of the lateritic profile is indicated by a structural control marked by the striped pattern of vegetation distribution on duricrust plateaus.
- Superficial mechanical dispersion of detritic materials, accumulated in the valleys, is characterized by a halo of high reflectivity corresponding to accumulation of quartz and zirconium at the bottom slope of duricrust plateaus.

Multispectral information provided by SPOT images appears to be very efficient to describe the differentiation and spatial organization of superficial formations of the lateritic cover.

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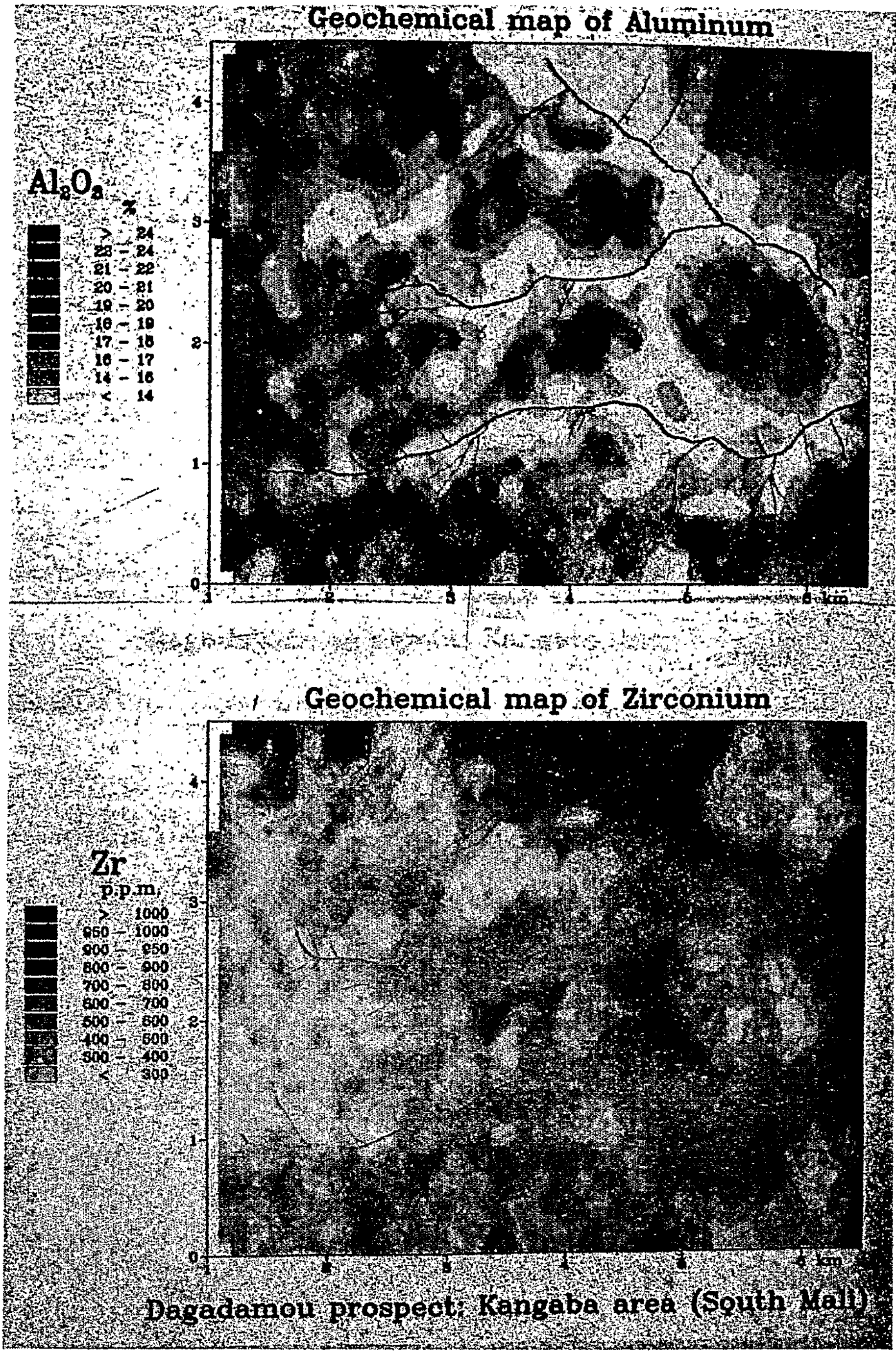

FIGURE 1 - GEOCHIMICAL MAP OF ALUMINIUM AND ZIRCONIUM

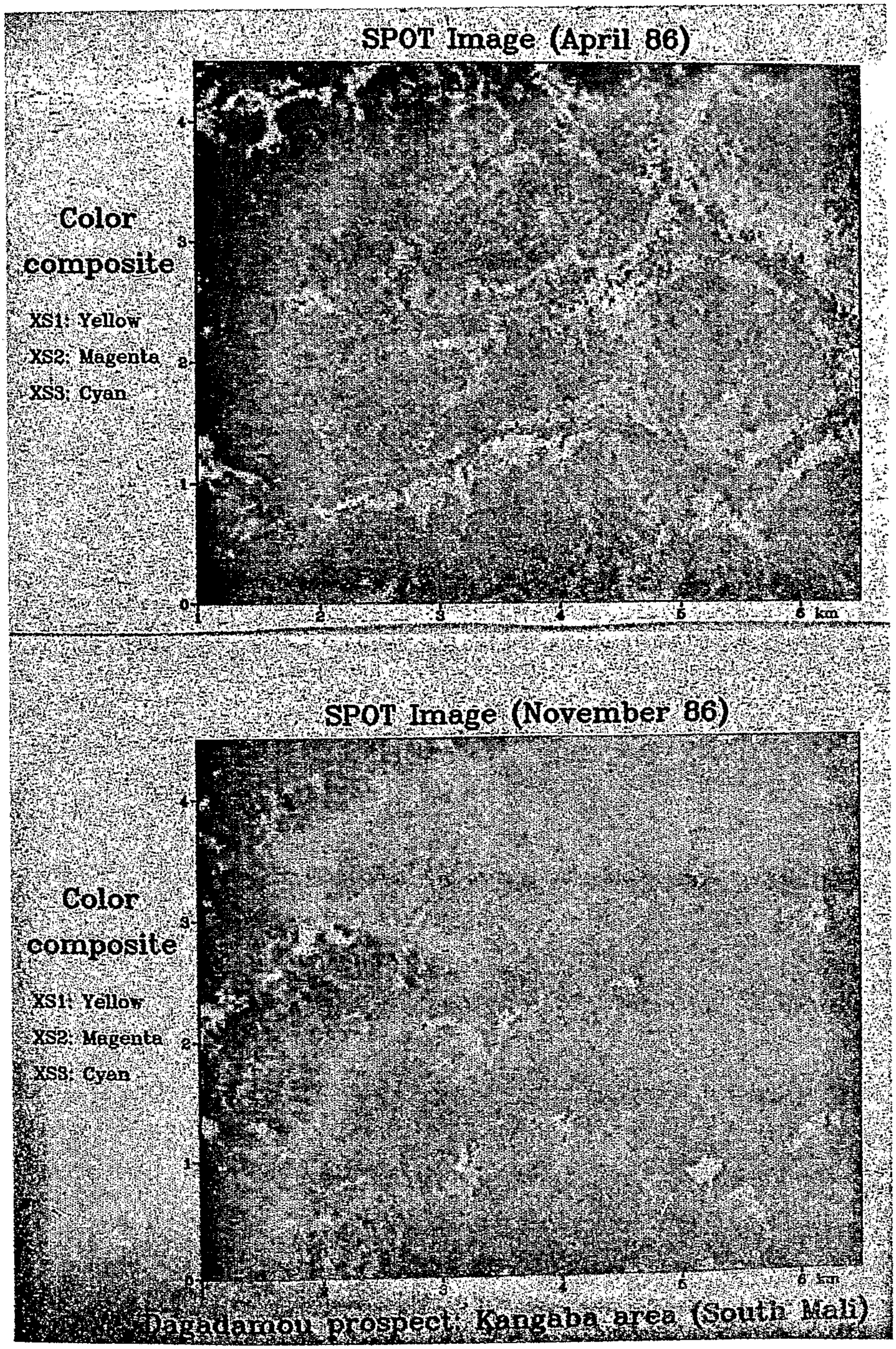

FIGURE 2 - COLOR COMPOSITE OF SPOT IMAGES FOR APRIL AND NOVEMBER