MULTISEASONAL VARIABLES IN DIGITAL IMAGE ENHANCEMENTS FOR GEOLOGICAL APPLICATIONS

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ABSTRACT

The problems related to the effects of multiseasonal variables on scene radiation are presented under two aspects: solar illumination geometry (topographic relief versus solar angle of elevation and of azimuth) and variations in radiance due to seasonal changes of the surface cover. Examples of enhanced multiseasonal orbital imagery illustrate the influence of multiseasonal changes in their spatial and spectral attributes, and consequently in their application to structural geology and lithological discrimination. Shadow effects associated with appropriate solar elevation and azimuth effects are shown to enhance the spatial attributes but not the spectral. In this case, variations in illumination conditions should be minimized by selecting images with high solar elevation and by the use of techniques that minimize illumination conditions. Moreover, multiseasonal imagery should be used in the identification of spectral contrast changes of rock-soil-vegetation associations which can provide evidences of related lithological units and structural features. Thus, the extraction of maximum geological information requires, at least, a fall/winter and a spring/summer scene from which spatial, spectral and multiseasonal attributes can be adequately explored.

1. INTRODUCTION

Experience gained from analysis of a large number of LANDSAT scenes from differing morpho-climatic surfaces indicates that there is no single approach to treat digital images which is optimum for geological applications. This is due to the fact that data registered by orbital sensing devices are strongly dependent on several ambient variables.

As can be seen from Figure 1, geological information is generally obtained only indirectly from vegetation, soil and geomorphological characteristics as well as from drainage and shoreline patterns. Since the spectral behaviour of these elements and the related electromagnetic radiation - EMR (downwelling and upwelling) are affected by climate and illumination, specially in the case of passive sensors, imageries acquired throughout the year are substantially influenced by seasonal variations because of the phenological behaviour of the vegetation cover, soil moisture and the solar illumination geometry (sun - surface - sensor).

As a consequence, the spectral and spatial attributes of orbital imagery will vary accordingly. Those varying conditions tend to modify the spectral contrasts among vegetation - soil - rock associations with serious implications in digital image treatments and the subsequent interpretation in lithological discrimination and of structural features. In such cases, where the information is derived from the spectral characteristics, it becomes important to reduce the variability due to changing illumination conditions so that vegetation - soil - rock associations would be better distinguished. On the other hand, when the analysis is based upon the spatial attributes, shadow effects have to be taken into consideration in both structural geology and lithological discrimination.

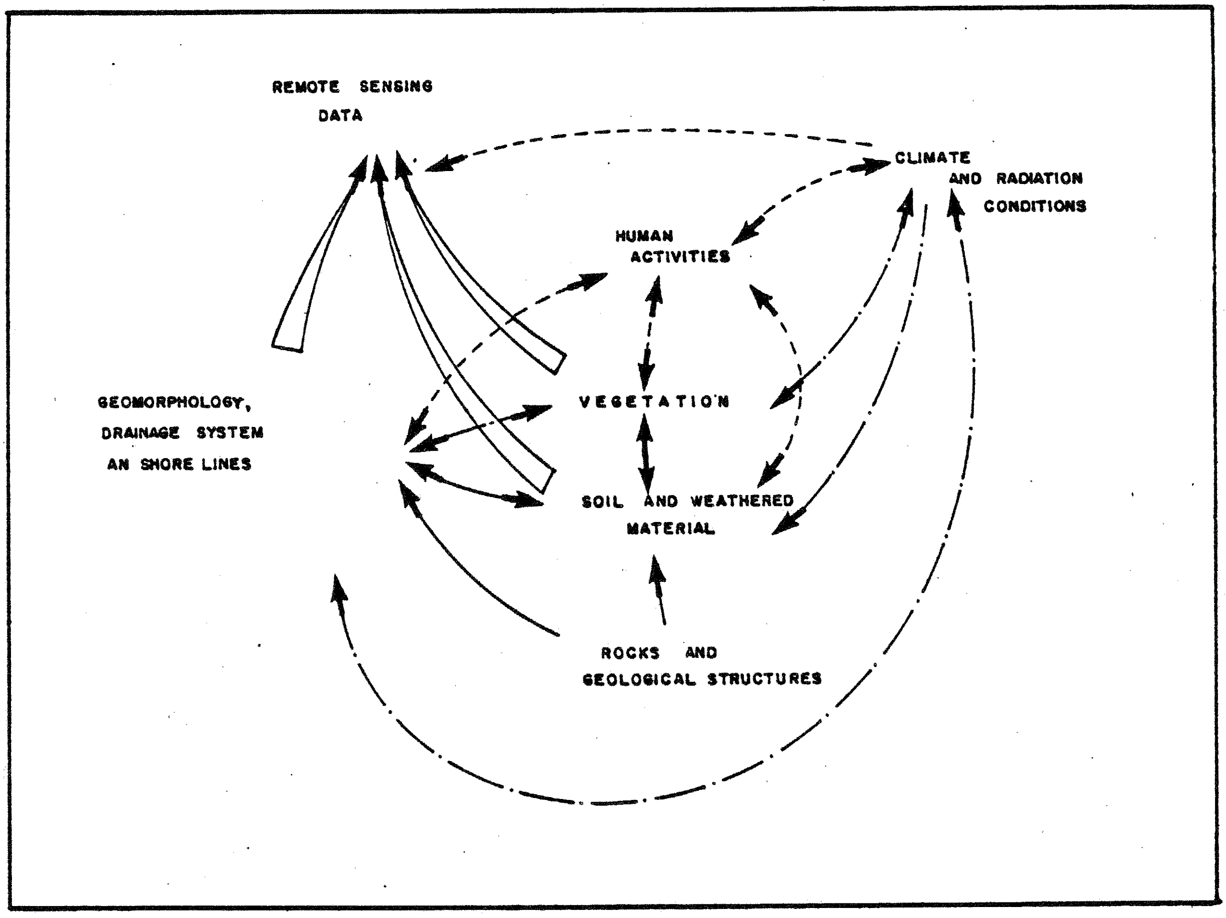


Fig. 1 - Main elements that contribute to a remote sensing data collection system.

In this report, the problems related to the effects of multiseasonal variables on scene radiation are presented in two topics of discussion which will follow: the illumination geometry (sun - slope - sensor) and the multiseasonal spectral behaviour of the surface cover.

2. TOPOGRAPHY VERSUS ILLUMINATION CONDITIONS

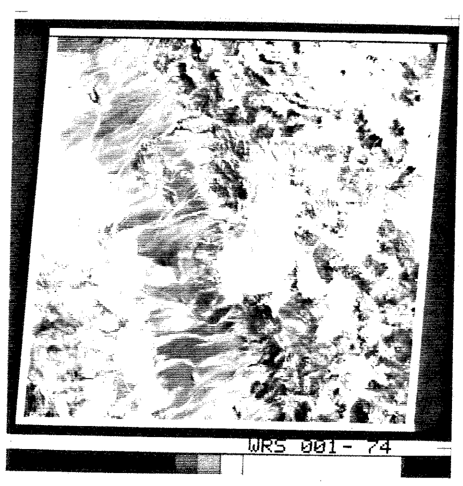
In general, the upwelling radiation from a given terrestrial surface varies according to the time of the day and year, the atmosphere along the sun's rays and the changes in the physical and chemical properties of the surface.

The daily and annual variation comes from the changes in the sun's position, given by the solar elevation and azimuth, in relation with the orientation of the surface.

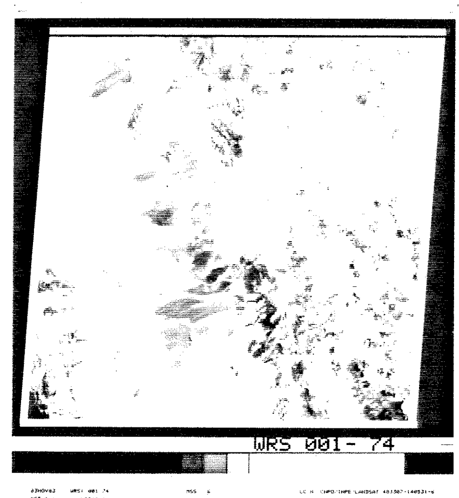
A variation which is easily illustrated is the one derived from the changes in solar elevation, such as Figure 2, which shows a sequence of four LANDSAT scenes taken in the Andes from July (winter) to November (spring). Since the area is devoid of significant vegetation, the observed sequential gradation in grey level from one image to another comes mainly from changing illumination conditions.

a

b



c



d

Fig. 2 - LANDSAT (MSS 4 - band 6) images of the Andes, obtained under different illumination geometry (sun - target - sensor): a = Jul. 30, 83; b = Aug. 31, 83; c = Oct. 2, 83; d = Nov. 3, 83. Scale ≅ 1:3,700,000.

Imagery from spring and summer (Figure 2 c and d) are taken under higher solar elevation which results in a higher radiance and subdued shadow effects than imagery from fall and winter. In this case (Figure 2 a and b), the image appears darker when the same grey level gradations are used in producing the images, and the geomorphological features, important photogeology elements in visual interpretation, are enhanced by favorable illumination conditions (Hackman, 1977; Walker and Trexler, 1977).

Moreover, the intensity of solar radiation on sloping surfaces is governed by the relationship between the solar ray direction and the strike and dip of the slope, being stronger when the slope is normal to the incident light beam. Figure 3 illustrates the manner by which the same geologic unit can have different radiation values related to the slope position and illumination direction: A represents the usual solar illumination conditions in which the light falls on a horizontal surface; B represents an area of stronger illumination because the slope is almost perpendicular to the sun's rays; and C represents an area of shadow and where the slope is illuminated by diffuse light.

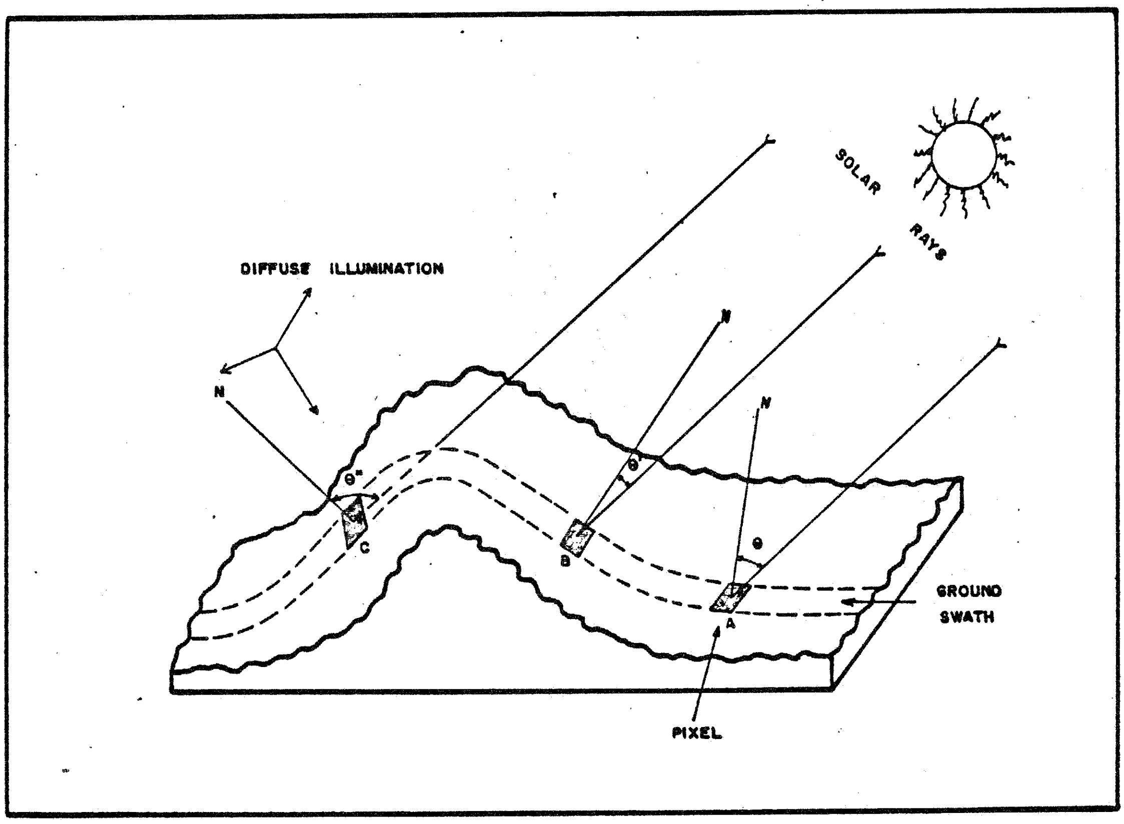


Fig. 3 - Variation in scene radiation of the same geologic unit, due to changes in the relationship between the incidence angle and the sloping surface direction.

Thus, the orientation of the topographic features relative to solar azimuth and elevation has strong effect on the intensity of the signal received by the sensor. In practice, however, the solar elevation effect is usually more noticeable than the azimuth. As an example, Figure 4a shows a LANDSAT band 7 of a spring scene (October) of a large N25^{o}E anticlinal structure. In the winter scene (July), Figure 4b, the details of the structure and associated faults as well as the intrusive body located in the northwestern portion of the image are very clear because of the favorable low solar elevation (28^{o}).

3. VEGETATION COVER AS A SEASONAL VARIABLE

When the goal of data analysis is the determination of tonal variations related to the spectral behaviour of rock - soil - vegetation associations, the vegetation cover becomes a very important component of analysis. Obviously, the vegetation cover, when not related to the lithology underneath, becomes a limiting factor in the use of remote sensing products in lithological discrimination (Siegal and Goetz, 1977). However, for this purpose, multiseasonal data has to be searched for geobotanical indicators not easily identified in a single analysis of only one scene.

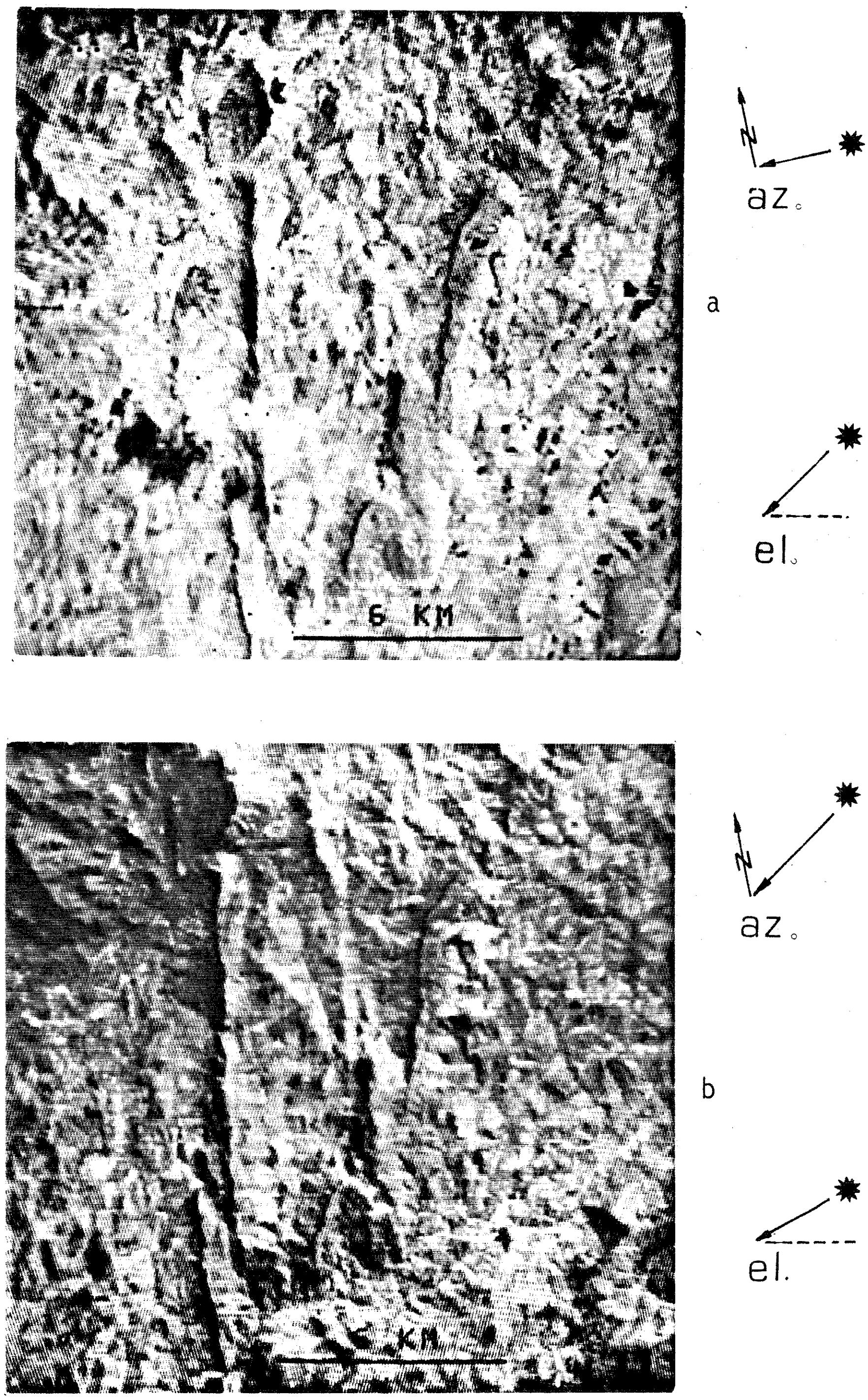


Fig. 4 - LANDSAT (MSS, band 7) images of the southwestern dipping anticline of "Serra Dourada" (State of Goiás). On the top (a), an October spring scene (solar elevation of 43º and azimuth of 87º) and on the bottom (b), a July winter scene (solar elevation of 28º and azimuth of 54º). Both images were enhanced by linear contrast stretch.

Numerous articles have been written of mineralized zones or lithologies related to geobotanical indicators, such as plant density,selective species growth, water and heavy metal stresses, and physiological changes (Bølviken et al. 1977; Horler et al. 1980; Lyon, 1975; Almeida Filho, 1984). However, in orbital imagery, the most significant environmental element of Figure 1 is the one related to geologically derived soil properties that affect vegetation density and greenness, and consequently the amount of scene reflected radiance. Such relationship is often seen in surface conditions controlled by geological structures, such as the alignment of vigorous vegetation growth along faults, or in regions where soil properties are related to lithologies or mineralized zones.

As a simple example, Figure 5 shows bands 5 and 7 from a LANDSAT pass over the state of Goiãs, in the dry (June) and rainy (February) season. The sketch of the geology of the same area is shown in Figure 6.

In the rainy season, the greater amount of green biomass associated to the calcareous Bambui Group makes very evident the contact between the Bambui and the Precambrian gneiss of the Goiãs Basal Complex and metasediments of the Arai Group. The Bambui Group presents a lighter tone in band 7 and a darker tone in band 5, than the Basal Complex and the Arai Group. The calcareous formations develop a soil richer in nutrients but not very permeable and quite dry during the dry season. The dense vegetation it supports responds very quickly to the rain.

In contrast, the sandy soils derived from the Arai Group and Basal Complex are more permeable, and support the typical savannah type of Central Brazil, called "Cerrado".

In the dry season, the greater contribution of exposed soil and rocks, the yellowish dry grass of the "Cerrado" and the dry biomass of the trees, make the differentiation between the adjacent lithologies almost imperceptible, except when delineated by topography.

4. DIGITAL ENHANCEMENTS

The most commonly used digital treatment that explores the spatial attributes of the image, for geological applications, is the Contrast Stretch technique applied to the near infrared channel. As indicated in item 2 and illustrated by Figure 4, the criteria for selecting the most adequate image for this purpose is low solar elevation and appropriate sun's azimuth. Obviously, the same rules apply to Digital Filtering and Principal Components, two other techniques not yet widely used in the analysis of the spatial attributes of an image.

In such analysis there is a preference for the near-infrared over the visible channel because in the former there is more contrast among segment of scenes representing surfaces in different directions and specially between shadowed and non-shadowed areas (see Figure 3). By comparing Figures 5a and 5b which show enhanced winter scenes (low solar elevation), it can be observed that band 7 (Figure 5b) has more structural details than band 5 (Figure 5a).

However, to complement the geological information derived from the spatial attributes, the spectral and multiseasonal attributes have necessarily to be also considered.

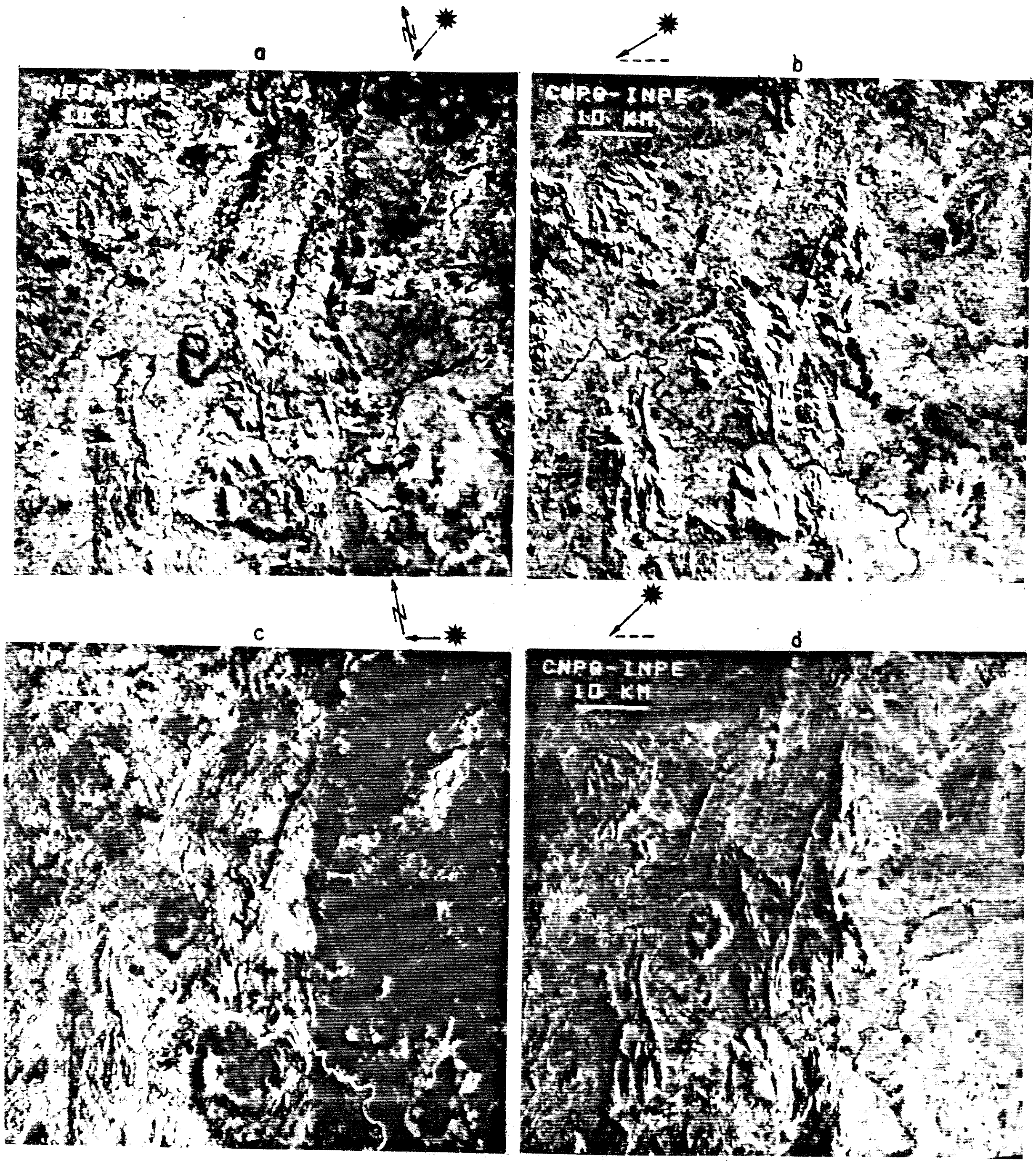


Fig. 5 - Multispectral images from the State of Goiás, Central Brazil:

a = band 5 taken in the dry season (June,77; solar elevation of 33° and azimuth of 50°).

b = band 7 taken in the dry season.

c = band 5 taken in the rainy season (February, 77; elevation of 44° and azimuth of 98°).

d = band 7 taken in the rainy season.

Contrast stretch enhancements have been applied to all these images.

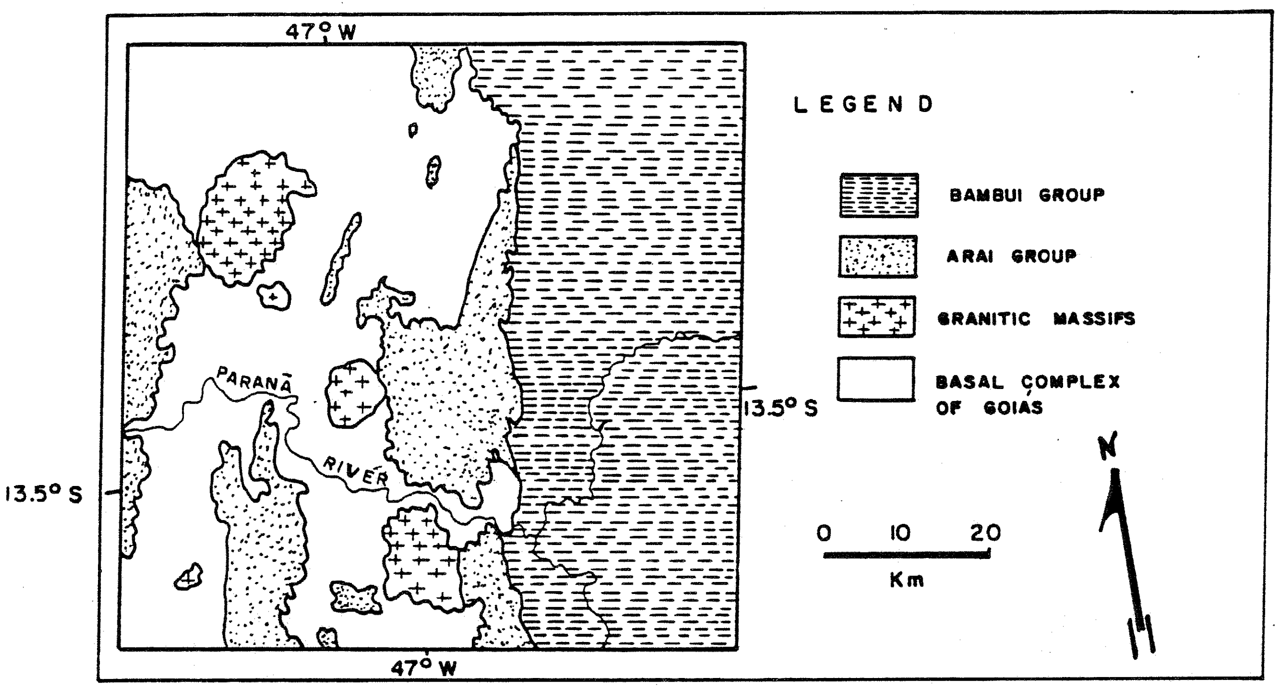


Fig. 6 - Geologic sketch of the area around the town of Monte Alegre de Goiãs, Goiãs State.The geographic area is the same as in Figure 5.

To explore these attributes, several digital enhancement techniques are available: Contrast Stretch, Band Ratioing, Principal Components, Canonical Analysis, and Color Transformations.

However, for these purposes, orbital imagery should be selected on the basis of two considerations:

a) High solar elevation that minimizes shadow effects and provides stronger solar illumination, as indicated by Figure 3.In lithological discrimination through spectral characteristics of an image, the situation described by Figure 3, in which a given geologic unit presents variable spectral response according the slope direction,is a hindrance that has to be attenuated (Almeida Filho and Vitorello, 1981). A simple solution, in this case, is the use of Band Ratioing, an enhancement technique that creates a product less dependent on the variations of illumination conditions, as illustrated in Figures 7a and 7b. Another product that possibly displays lithologically related spectral information with a minimum of dependence on illumination,is the Second Component of a Principal Component (Figures 7c and 7d)and perhaps of a Canonical Transformation.

b) Identification of changes in scene radiation related to seasonal variation which affects plants and soils through changes in precipitation, temperature and wind.

The examples shown in Figure 7, of Band Ratioing and Principal Component, in the dry and rainy seasons, display the variability in information usually found in the analysis of multiseasonal imagery, but very seldom in just a single image.

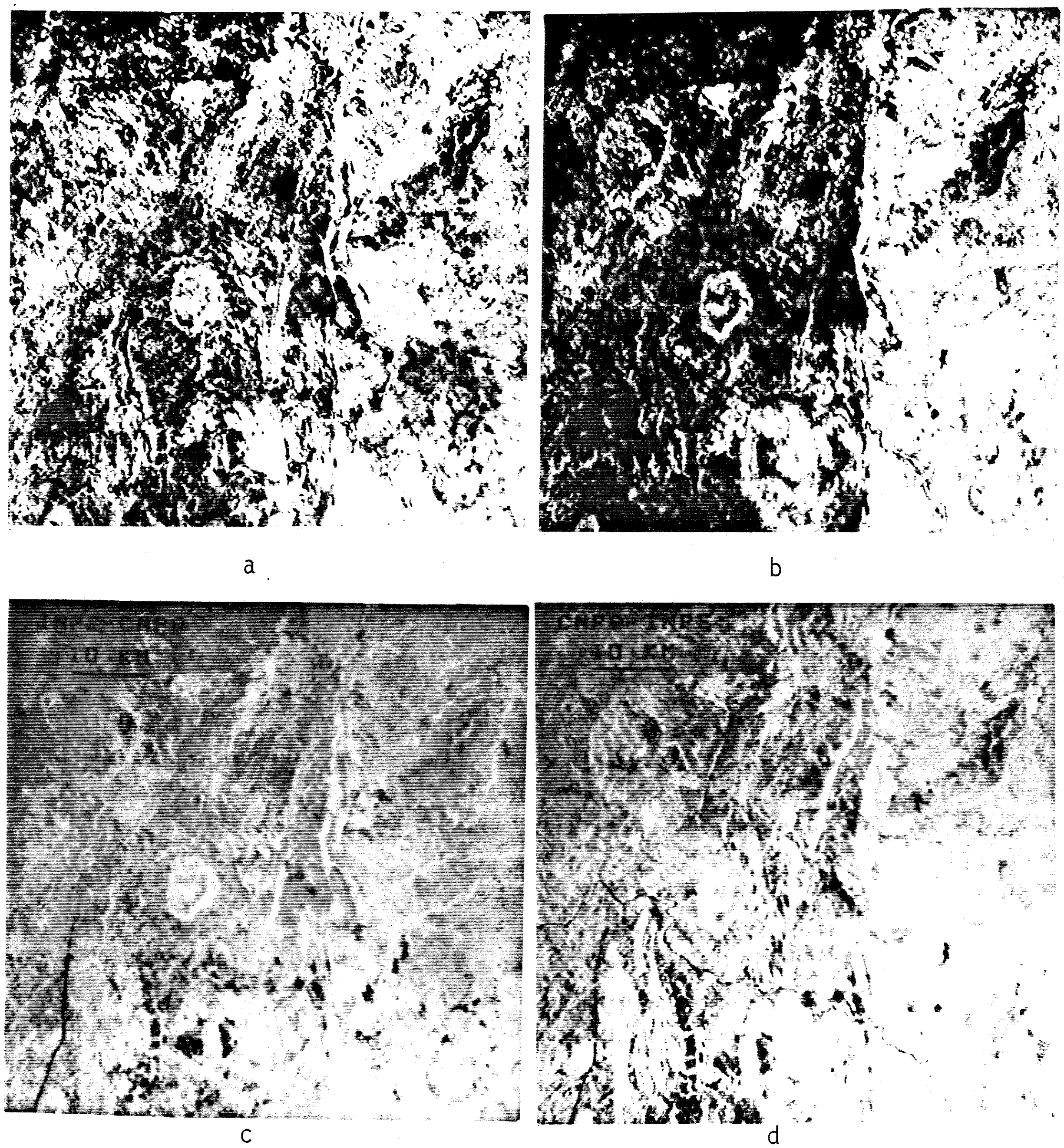


Fig. 7 - Example of Band Ratioing (a and b) and Principal Components (c and d) of the same images as in Figure 5:

a) $R_{7/5}$ of the dry season (June, 77)

b) $R_{7/5}$ of the rainy season (February, 77)

c) Second Component of the dry season (June, 77)

d) Second Component of the rainy season (February, 77).

All these images have been contrast stretched after ratioing, and Principal Component Transformation.

5. FINAL CONSIDERATIONS

The objective of this brief description has been the indication of the importance of geologically related spectral contrast increase associated to multiseasonal imagery, in lithological discrimination.

In view of the effects of the multiseasonal changes in illumination conditions and surface cover behaviour, the use of orbital imagery for applications in structural geology and lithological discrimination sometimes needs contradicting criteria in the selection of the best imagery and enhancement approaches.

When the spatial attributes (texture and landforms) are being analysed, shadow effects produced by favorable illumination conditions should be advantageously explored. As a matter of fact, low solar elevation and appropriate azimuth should always be considered before applying suitable computer techniques commonly used in enhancements of the spatial attributes of an image (Contrast Stretch, Digital Filtering, Principal Component, Color Transformations).

In contrast, the analysis of the spectral attributes, commonly used in lithological discrimination and sometimes in structural geology, requires that shadow effects should be minimized by the choice of appropriate illumination conditions (high solar elevation) and computer assisted techniques (Contrast Stretch, Band Ratioing, Canonical Analysis). Moreover, enhanced multiseasonal images should be analysed for variations in reflectance due to surface cover behaviour related to the underground geology.

In conclusion, differing morpho-climatic surfaces characterized by a particular morphology and surface cover (vegetation, soil, and drainage pattern) need analytical approaches that takes into considerations the solar illumination geometry and seasonal changes.

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