Efficient utilization of remote sensing requires the existence of a balance between technological advances and human resources built up. Moreover, the two factors should be matched to the specific needs of the nation. In the case of geology, the greatest contribution of remote sensing, by far, would be to regional geological cartography, due to existing gaps in central, north and northeast regions of Brazil. In this paper, the role of remote sensing is analysed in view of the technological and methodological advances, human and economic resources, and Brazilian needs in the past and the coming years. A greater remote sensing contribution to geology is expected for the future, due to the perspectives of development of new and more elaborated sensors and products characterized by improved spectral, spatial and radiometric resolutions, stereo viewing capability, and recent advances in computer manipulation of data by quantitative approaches.
INTRODUCTION

The problems in the use of remote sensing techniques should be analysed in view of the perspectives of technological and methodological advances, human and economic resources built up, and considerations about the country's needs that can be fulfilled by remote sensing. In fact, 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 (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. Thus, the greatest contribution of remote sensing, by far, under present day knowledge would be to regional geological cartography, due to existing gaps in central, north and northeast regions of Brazil.

TABLE 1

RELATIONSHIP BETWEEN THE % OF BRAZILIAN TERRITORY COVERED BY GEOLOGIC CARTOGRAPHY AT SEVERAL MAPPING SCALE

<table>
<thead>
<tr>
<th>MAP SCALE</th>
<th>% OF BRAZIL WITH GEOLOGICAL MAPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:250,000</td>
<td>32.6</td>
</tr>
<tr>
<td>1:100,000</td>
<td>4.2</td>
</tr>
<tr>
<td>1:50,000</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Since mineral exploration 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, first in the regional scale, and later, in the near future, in larger scale because of the improved capabilities of new sensors.

RETROSPECTIVE

Brazilian application of remote sensing in geology was initiated in the early 60's with the use of airphotos, which are nowadays available over most of Brazil at the 1:60,000 scale (Paradelfla and Vitorello, 1982; Meneses, 1984).

In Brazil, these products have been handled mainly through the use of conventional photointerpretation techniques in regional mapping (Ricci and Petri, 1965; Soares and Fiori, 1976). Only a few aircraft missions flown with photographic equipment over mineralized targets were aimed at defining the potential of remote sensing in mineral exploration (Carraro, 1973).

In the early 70's a large scale program of overflights with side looking radar initially covered the Amazon region but was later extended to the entire country. Since then, radar mosaics have been used by the geological community mainly in the exploration of land forms and texture patterns in regional geology (Meneses et al., 1979). Recent efforts to locate structural petroleum traps in sedimentary basins by the study of geomorphological anomalies defined by drainage patterns has relied on drainage networks obtained mainly from radar and airphotos (Soares et al., 1981; Liu and Meneses, 1982; Miranda, 1984).
However, the availability of successive LANDSAT passages over Brazil since 1972 has opened 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.

The early studies done at INPE with LANDSAT images were directed to surficial geological mapping at several regional scales, exploring mainly the spatial attributes of the images (Liu et al., 1975). Furthermore, research was aimed to access the potentiality of remote sensing products in providing information on lithological and structural controls of known deposits and petroleum traps (Liu and Meneses, 1982; Vitorello and Souza, 1982). For instance, several studies dealing with deposits of bauxites, lead and zinc, tin, marbles, iron and radioactive material, located in different geologic environments of Brazil, were concluded with relative success.

The acquisition of a system for image treatment (General Electric Image 100) in 1975 stimulated efforts in lithological discrimination and structural details by computer processing techniques. Within this context several studies were done with the use of digital enhancements (Paradella and Almeida Filho, 1976) and classifications (Paradella et al., 1979).

Nowadays, 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, as demonstrated by recent detailed studies in the "cerrado" of Central Brazil (Almeida Filho, 1983) and the "caatinga" in the northeast (Paradella, 1983).

However, the use of costly and time-consuming computer 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-geometry (Vitorello and Almeida Filho, 1984). 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 (Vitorello and Paradella, 1984).

To help solve these problems INPE has established, more recently, a research program dealing with the physics of scene radiation and mechanisms of atmospheric interactions. The application activities could not have been realized without INPE's efforts in education and training. Since early 70's, INPE has provided a four year master program that prepares students to use remote sensing in several areas of applications. Moreover, short-term training is offered to management and technical staff from government agencies and private companies that have manifested interest in remote sensing.

The impact of remote sensing in geological activities has been slow, but constant. For example, Remote Sensing discipline has replaced Photointerpretation in regular geology courses in most of the Brazilian universities.
In Brazil, a greater remote sensing contribution to geology both in regional mapping and mineral and petroleum exploration is needed. Such expectation is hoped to be fulfilled in the future, because of improvements in spectral, spatial and radiometric resolution of Thematic Mapper (TM, LANDSAT) and of the improved spatial resolution and the stereo viewing capability of SPOT.

In the case of the TM, INPE will concentrate efforts to evaluate its capability to better discriminate lithological units and hydrothermal alteration products, as well as to provide compositional units about surficial weathered materials. The detection of geobotanical anomalies, however, would be of great value because of the generalized deep weathering and dense vegetation over most of Brazil, and in particular the Amazon Region.

In the case of SPOT products, INPE will analyse subtle spatial attributes that might be enhanced by the proper sun-target-sensor geometry, and the variations of scene radiation due to off-nadir viewing.

Furthermore, a great emphasis will be placed on data treatment by computers as a result of the increased data volume (more bands with improved spatial resolution). In this aspect a significant contribution is expected in the area of mineral exploration with the use of digital terrain models integrated with other data from geophysics, geochemistry, geobotanics, etc.

REFERENCES


