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16.Summary/Notes

This paper describes the Remote Sensing Program of the Institute for Space Research (INPE) and the RADAMBRASIL project which, at this time, constitute the main efforts in the application of remote sensing in Brazil. Remote Sensing Activities in Brazil started in 1968 when a group of persons from several government institutions, under the coordination of INPE, participated in a remote sensing training course offered by NASA/JSC. From this initial training program evolved an INPE group which, today, consists of a research department with more than 60 researchers in the areas of geology, geography, oceanography, agronomy, forestry, hydrology, pollution and image processing. In 1970, the group from the Ministry of Mines and Energy that participated in the NASA/JSC course initiated a project (Project RADAM) to survey the natural resources of a 44,000 km² area in the Amazon region using imagery from a Goodyear GEMS 1000 side looking radar system. This project evolved considerably and currently, with the name RADAMBRASIL, has the task of surveying the natural resources of the whole country.

17.Remarks

OVERVIEW OF BRAZILIAN REMOTE SENSING ACTIVITIES

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The purpose of this paper is to describe the Remote Sensing Program of the Institute for Space Research (INPE) and the RADAMBRASIL project which, at this time, constitute the main efforts in the application of remote sensing in Brazil. Remote Sensing activities in Brazil started in 1968 when a group of persons from several government institutions, under the coordination of INPE, participated in a remote sensing training course offered by NASA/JSC. From this initial training program evolved an INPE group which, today, consists of a research department with more than 60 researchers in the areas of geology, geography, oceanography, agronomy, forestry, hydrology, pollution and image processing. Several research programs, mainly in the area of natural resources surveys, are presently being developed. The principal programs are: Crop Surveys, Land Use and Forest Inventories, Mineral Exploration and Marine Fishing Charts. To support this research, INPE has a Landsat receiving and processing station which is considered the basic source of data to carry out these research programs; an automatic image interpretation system (Image-100) and an aircraft equipped with a Wild RC-10 metric camera, an I^2S multispectral camera and a two channel LN-3 Bendix Scanner. In 1970, the group from the Ministry of Mines and Energy that participated in the NASA/JSC course initiated a project (Project RADAM) to survey the natural resources of a 44,000 km^2 area in the Amazon region using imagery from a Goodyear GEMS 1000 side looking radar system. This project evolved considerably and currently, with the name RADAMBRASIL, has the task of surveying the natural resources of the whole country. The final products are reports and thematic maps at a scale of 1:1,000,000 which illustrate geomorphology, geology, soils, vegetation and potential land use. This project is scheduled to be completed in 1981.

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OVERVIEW OF BRAZILIAN REMOTE SENSING ACTIVITIES

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1. INTRODUCTION

The purpose of this paper is to describe the Remote Sensing Program of the Institute for Space Research (INPE) and the RADAMBRASIL Project which, at this time, constitute the main efforts of the application of remote sensing in Brazil.

The Brazilian territory has a little over 8,500,000 km^2, of which 3,570,000 correspond to the Amazon region. A substantial part of what remains corresponds to the Central-West region, with an area of 1,800,000 km^2, and the Northeast region with 1,540,00 km^2. These regions, which collectively correspond to 82% of the area of the nation, have a low population density and are very little known, mainly in the area of natural resources. In this respect, remote sensing, especially by satellites, which allows surveys of large areas very rapidly and at relatively low costs, is the perfect tool for a large and developing nation like Brazil to augment the knowledge of its natural resources.

The Brazilian remote sensing activities started in 1968 when a group of researchers from several government institutions, under the coordination of INPE, at that time National Commission for Space Activities (CNAE), participated in a remote sensing training course offered by NASA/JSC. From 1969 to 1970 INPE's main concern was to train persons from other institutions, which were potential users of this new technology, as well as to set up its own research group. At this time, a significant step was the acquisition of a 10 passenger twin engine Bandeirante aircraft. It was equipped with several sensors.

In 1970 INPE initiated studies to install a Landsat receiving and processing station. At the same time, the National Department

of Mineral Production (DNPM) of the Ministry of Mines and Energy decided to execute a project to survey the mineral resources of part of the Amazon region. This project was within the government's Plan of National Integration which had a very high priority. This led the DNPM to opt for side-looking radar as its main source of information in the execution of this survey, for which it created its own remote sensing group. At this time the prediction was that INPE's Landsat station would be operational only by the end of 1973. Initially an area of 44,000 km^2 in the Amazon region was to be surveyed with the GEMS 1000 side-looking radar of the Goodyear Corp. This project was named RADAM for RADar in the AMazon. Later the scope of the project was expanded several times until it covered most of the Amazon region. In 1975 it was once more expanded to cover the whole Brazilian territory and was then named RADAMBRASIL Project.

By May of 1973 INPE's Landsat station was already recording data that had to be sent to NASA for processing. At the end of 1974 the processing station started its operation precariously, becoming completely operational only by mid 1975. At this time INPE installed an automatic multispectral image analysis system from GE, an Image-100.

Today, INPE with a group of 68 researchers in the areas of geology, geography, oceanography, agronomy, forestry, hydrology, pollution and image processing, in addition to approximately 70 persons involved with the reception, processing and distribution of Landsat imagery, and the RADAMBRASIL Project with a technical group of more than 300 persons in the areas of geology, agronomy, forestry, geography and cartography constitute the main efforts in the application of remote sensing in Brazil.

INPE's objectives being:

- the development of new methodologies for the application of remote sensing, mainly Landsat imagery, in the survey of natural resources and observation of the environment;
- wide dissemination of Landsat products and their applications;
- transference of the methodologies considered operational to other institutions;

- to divulge remote sensing at various levels ranging from simple short trainings to graduate courses leading to the masters degree.

and Project RADAMBRASIL's:

- to systematically survey the natural resources of the whole national territory in a level of detail compatible with a 1:1,000,000 scale focusing on the geology, geomorphology, soils, agricultural aptitude, ecology and potential land use.

2. INPE's REMOTE SENSING PROGRAM

INPE is one of the institutes of the National Council for Scientific and Technological Development (CNPq) which is under the Secretariat of Planning of the Presidency. The objectives of INPE are research and development in the areas of space science, space technology and applications of the space technology, which is where the Remote Sensing Program is placed. This program is developed by the following departments:

- Department of Image Production; and
- Department of Remote Sensing.

2.1 - Department of Image Production

The main objectives of this department are the reception, processing and distribution of the Landsat products.

INPE's receiving station is in the city of Cuiabá, state of Mato Grosso. This localization allows the coverage of the entire Brazilian territory and most of South America, as shown in figure 1. This coverage corresponds to a nominal antenna elevation angle of 4.5^{o}. Usually reception at lower angles is possible. The electronic and photographic processing stations and the image distribution center are in the city of Cachoeira Paulista, SP, 110 km away from INPE headquarters in São José dos Campos,SP.

The operation of the Landsat satellites for Brazil is deter

Figure 1 - Cuiabá ground station coverage.

mined by a Memorandum of Understanding between NASA and COBAE* signed by the foreign relations agencies of the respective countries. By this memorandum only INPE and the EROS Data Center (for on board recorded images) can distribute Landsat products of the area covered by the Cuiabá station. Also, the prices of INPE's products must be compatible to the EROS Data Center's for equivalent products.

Currently there are a little over 300 registered users (persons or institutions), of which 67 are foreign. Table 1 shows how the number of users has evolved since the beginning of the operations in 1973. The station has more than 1,500 Landsat-1 recorded orbits and over 850 of Landsat-2. Altogether, 700 orbits have been processed giving some 15,000 Landsat scenes. The number of distributed imagery has also grown considerably, as can be seen in table 2.

TABLE 1

NUMBER OF USERS

YEAR	1973	1974	1975	1976	1977
Total number of users	3	27	69	156	301

TABLE 2

NUMBER OF IMAGES DISTRIBUTED PER YEAR TO EXTERNAL (NON INPE) USERS

YEAR	1973	1974	1975	1976	1977
Distributed imagery	323	1,230	2,094	7,564	10,045

The electronic processing, from the reception to the production of the first generation film (70 mm), in an electron beam image

* Brazilian Commission for Space Activities

recorder, is performed in a system developed by Bendix Corp. Table 3 shows the products distributed by the center.

TABLE 3

LANDSAT PRODUCTS

SCALE	FORMAT
1:3,704,000	B/W positive transparency B/W negative transparency
1:1,000,000	color and B/W positive transparency color and B/W paper
1:500,000	color and B/W paper
1:250,000	B/W paper
—	set of two 2400' 800 bpi CCT's

Of these, the production line in the scales 1:3,704,000 and 1:1,000,000 is totally automated.

Recently the station has been adapted to receive and process the thermal band of Landsat-3. Imagery of daytime passages have already been produced.

2.2 - Remote Sensing Department

2.2.1 - Facilities

The department has a twin engine Bandeirante aircraft equipped with:

- a Wild RC-10 camera;
- a I^2S multispectral camera;

- a Bendix LN-3 2 channel scanner with magnetic tape recording and digitizing facilities;
- Barnes PRT-5 radiometer.

Another very important available tool is the multispectral image analysis system, the Image-100 from GE. This system has been expanded considerably since its installation and today has the following additional hardware/software:

- an 88 Mbyte disc;
- 48 K words of main memory;
- a Dicomed D47 photographic recorder;
- RSX-11 M multitasking operating system;
- maximum likelihood classification software;
- software to produce enhanced imagery.

Recently, another automatic image analysis system was acquired, a MDAS from Bendix Corp. Installation is scheduled for October 1978. This system is equipped with maximum likelihood classification hardware, augmenting significantly the computational power to perform crop survey type of work.

2.2.2 - Research Programs

An important objective of INPE in the remote sensing area is the development of new methodologies for the survey of natural resources and observation of the environment. This work is developed by the Remote Sensing Department. The research programs are shown in table 4.

TABLE 4

RESEARCH PROGRAMS

AREA	RESEARCH PROGRAMS
Agronomy and Forestry	Crop Survey Soils Survey Survey of Natural Forests and Reforestation
Geology	Regional Geological Mapping Mineral Exploration
Oceanography	Marine Fishing Charts Hydrography and Physical Oceanography
Geography	Potential and Actual Land Use
Environment	Detection of Pollution in Water Bodies

In the following sections each of these programs will be briefly described together with their latest realizations.

Crop Survey

This is probably the most important of the programs being developed in terms of the economic and social benefits that can be generated for the country. The purpose of the program is to develop a survey system for the major economic crops through the automatic processing of Landsat imagery. Planted area estimations for cultures of sugar cane, soybeans, corn and wheat have been obtained with success for areas no larger than 4 Landsat scenes. Presently a survey of sugar cane is being carried out for the entire State of São Paulo. The area of sugar cane in this state is covered by 14 Landsat scenes and it is responsible for about 60% of the total national production.

The importance of sugar cane is due not only to the sugar industry but also to the alcohol industry which gained relevance with the government's program of substitution of gasoline by alcohol.

All automatic classification work is perfomed by maximum likelihood classification software running in the PDP 11/45 of the Image-100 system. The methodology employed is basically the same described by Bauer et al in BAUER 77 (i.e., the classification program is trained and tested with information obtained by infrared aerial photography).

Soils Survey

The soils survey of the whole national territory by conventional methods would be a very difficult, if not impossible, task to undertake due to the magnitude of the area to be covered and the inaccessibility of certain regions. The alternative offered by remote sensing, mainly Landsat imagery, has been exploited and some promising results with manual interpretation have been obtained (VALER 77), in spite of difficulties inherent to the problem since interpretation parameters are usually indirect (i.e.,soils are classified analyzing the density and format of drainage patterns, vegetation types, relief, land use, etc.).

Survey of Natural Forests and Reforestation

This program aims at the development of methods to survey natural vegetation, mainly forests and reforested areas, by means of manual and/or automatic interpretation of Landsat imagery. Currently, reforestation in the State of São Paulo is being mapped.

Another work being developed in this program is the mapping of natural babaçu in an area of 120,000 km^2 in the states of Maranhão, Piauí and Goiás. Babaçu is a palm tree that produces a coconut of high economic value due to the oil that can be extracted from it (MIC 77).

The Cerrado is another natural vegetation being mapped

using Landsat imagery. This vegetation occurs predominantly in the central part of the nation and occupies an estimated area of 1,500,000 km^2. This mapping will provide valuable information for rational agricultural and cattle raising activities of this region, which is a priority of the present government.

A project to control deforestation in the Amazon region was also in this program (SANTO 77). It has been made operational and transferred to SUDAM which is the government agency responsible for this control.

Regional Geological Mapping

The Brazilian regional geology is generally not well known, even in large scales. In this respect, this program is of high importance since the knowledge of the regional geology is the first step for the systematic exploitation of the mineral resources of a region. To date, this program has already mapped the areas shown in figure 2, at scales equal or greater than 1:1,000,000 (MENES 77).

Mineral Exploration

Several projects have been completed in this program. Some of the more recent ones are:

- Study of the circular structure that forms the alkaline massif of Poços de Caldas, State of Minas Gerais, with Landsat imagery. This study allowed the definition of the main parameters that conditioned its radioactive mineralizations. It has been verified that the presence of radioactive minerals is related to secondary circular structures, internal to the main caldera (i.e. the known deposits are exactly in the perimeter of these internal structures). The mapping of these secondary structures, which were unknown before this work, is being used as a guide for further prospecting work in the area.
- The mapping of the deposits of tin-bearing alkaline granites of

the Xingu River Valley. After publication of this project several mining companies placed requests to do prospecting work in the area.

Figure 2

- The mapping of geo-thermal anomalies in the region of Caldas Novas, State of Goiás, which pinpointed several sources of geo-thermal water.

Marine Fishing Charts

The purpose of this program is the development of a system

to locate zones in the sea that are good fishing grounds. A model is being developed in which the main parameter is the sea surface temperature obtained by means of the thermal imagery of NOAA and SMS satellites. Other parameters like catch statistics, salinity, chlorophyll content etc. are also taken into account. The system is being planned in such a way that the information will go to the fisherman in the shortest possible time.

Oceanography and Hydrography

Among the projects developed in this program, the following that have been concluded recently can be mentioned:

- Study of the thermal discontinuity between the Brazil and Falkland Currents with the THIR imagery of Nimbus V (TSENG 77). The knowledge of the behavior of this discontinuity is important because it has been verified that it is a good Pargo Roseo fishing ground.
- A study of the circulation patterns of the Lagoa dos Patos, State of Rio Grande do Sul, has been concluded (HERZ 77). Landsat imagery and SKYLAB photography were used in this work.

Actual and Potential Land Use Mapping

Recently a project to classify the urban land use of São José dos Campos, based on Landsat imagery, has been concluded (NIERO 78).

Presently a project to map the land use of the Paraíba River Valley, between the cities of Rio de Janeiro and São Paulo, is being developed. This valley is undergoing a very accelerated industrialization which is causing serious distortions in the adequate use of the land (COTTR 78).

Another project being developed is the evaluation of the impact on the land use of a region due to the construction of a secondary road.

Detection of Pollution in Water Bodies

A project to map the circulation patterns of the Guanabara Bay is being developed. The localization of sources of pollution and its behavior is also being done. The problem of pollution in the Guanabara Bay is of extreme importance since it affects considerably the quality of life in the cities of Rio de Janeiro and Niteroi

3. PROJET RADAMBRASIL

The purpose of the RADAMBRASIL Project is to survey natural resources of the entire brazilian territory in a level of detail compatible with a scale of 1:1,000,000. The basic source of information for the execution of this task is the imagery of the GEMS 1000 synthetic aperture side looking-radar from Goodyear Corp. This radar operates at 9.6 GHz (approx. 3 cm wavelength) with a horizontal/horizontal polarization. The resolution of the first generation film product is better than 20 m.

The imaging of the whole nation was concluded in the beginning of 1976. The radar was installed in a Caravelle twin jet, allowing a flying altitude of 11,000m which permitted the coverage of 37 km wide strips for each flight line.

The initial photographic product of the radar is an image at the scale 1:400,000 which is enlarged to 1:250,000 and used for interpretation work. Later, the interpretation is reduced to 1:1,000,000 for publication.

The aircraft also carried two photographic cameras which took color infrared and multispectral exposures where cloud coverage permitted. These photographs and Landsat imagery are also being used in the interpretation work.

The final products of the project are:

- Planimetric maps at 1:250,000 scale;

- Geologic maps at 1:1,000,000 scale with corresponding reports;
- Soils maps at 1:1,000,000 scale and reports;
- Agricultural survey maps at 1:1,000,000 scale and reports;
- Geomorphologic maps at 1:1,000,000 scale and reports;
- Phyto-ecologic maps at 1:1,000,000 scale and reports;
- Potential Land Use maps at 1:1,000,000 scale and reports.

The methodology used for the execution of the above maps and reports is briefly described in the following paragraphs.

Geology

Initially the following information of previous works is placed on the 1:250,000 maps: petrographic analysis, geochemical and chemical analysis, geocronological information, known mineral occurrences and active mines. Additional information of areas that have a lack of data are then collected by field work. All the outcroping that lead to the understanding of the regional geology are described, with samples collected for petrographic and chemical analysis and radiometric dating. The work aims mainly at an objective knowledge of the economic geology, augmenting also the tectonic, structural and stratigraphic knowledge of the region being surveyed.

Geomorphology

The geomorphology map contains the information relative to all the relief forms interpreted on the radar imagery, separated by different colors for: relative elevation, together with relief and areal divisions of uniform structural morphology and morphoclimatology. The legend used qualifies and arranges relief forms conforming to the order of stream size and force of drainage depth. Special emphasis is placed on mapped data with aspects relevant to regional planning.

Pedology

The field work conducted for pedological studies were aimed at soil identification, geographic distribution, cartographic delimitation

as well as studies of the morphometrical, physical and chemical characteristics of different soil consolidation. Various analysis have been carried out with the objective to classify soils according to fertility, water content, susceptibility to erosion and adaptibility to the implementation of agricultural uses. This will make possible a classification of agricultural capability.

Natural Vegetation

Through phytogeographical mapping, floristic areas are defined within various ecological regions. These regions serve as a base for studies in the fundamental disciplines of geomorphology, lithology and climatology. An important objective for understanding is an adequate level for conducting regional plant inventories in areas of economic value. This will also provide information over the occurrence and distribution of species of floristic potential.

Potential Land Use

Those factors taken into account for the determination of potential land use include;

1) relief, hydrologic, floristic and mineral resources, climate and access roads; and
2) a determined "Mean Natural Carrying Capacity" which will indicate those options which best serve the rational occupation and integration of the developing region.

Figure 3 indicates those areas corresponding to already published reports and thematic maps.

By the end of 1978, yet uncompleted work on the greater part of the Amazon region (roughly north of parallel $10^{o}S$ and west of meridian $45^{o}W$) will be published. Field studies over this region have already been realized. This work consisted of field sampling along the few roads existing in the region, along rivers and through the clearing of openings in the dense

selva, for which case, the only viable means of access was the helicopter. In all, field research was conducted at more than 3 thousand points in the Amazon region which represented an average of more than one point per 1200 km^2. Approximately 600 clearings were made in the rainforest by means of crews dropped from helicopters.

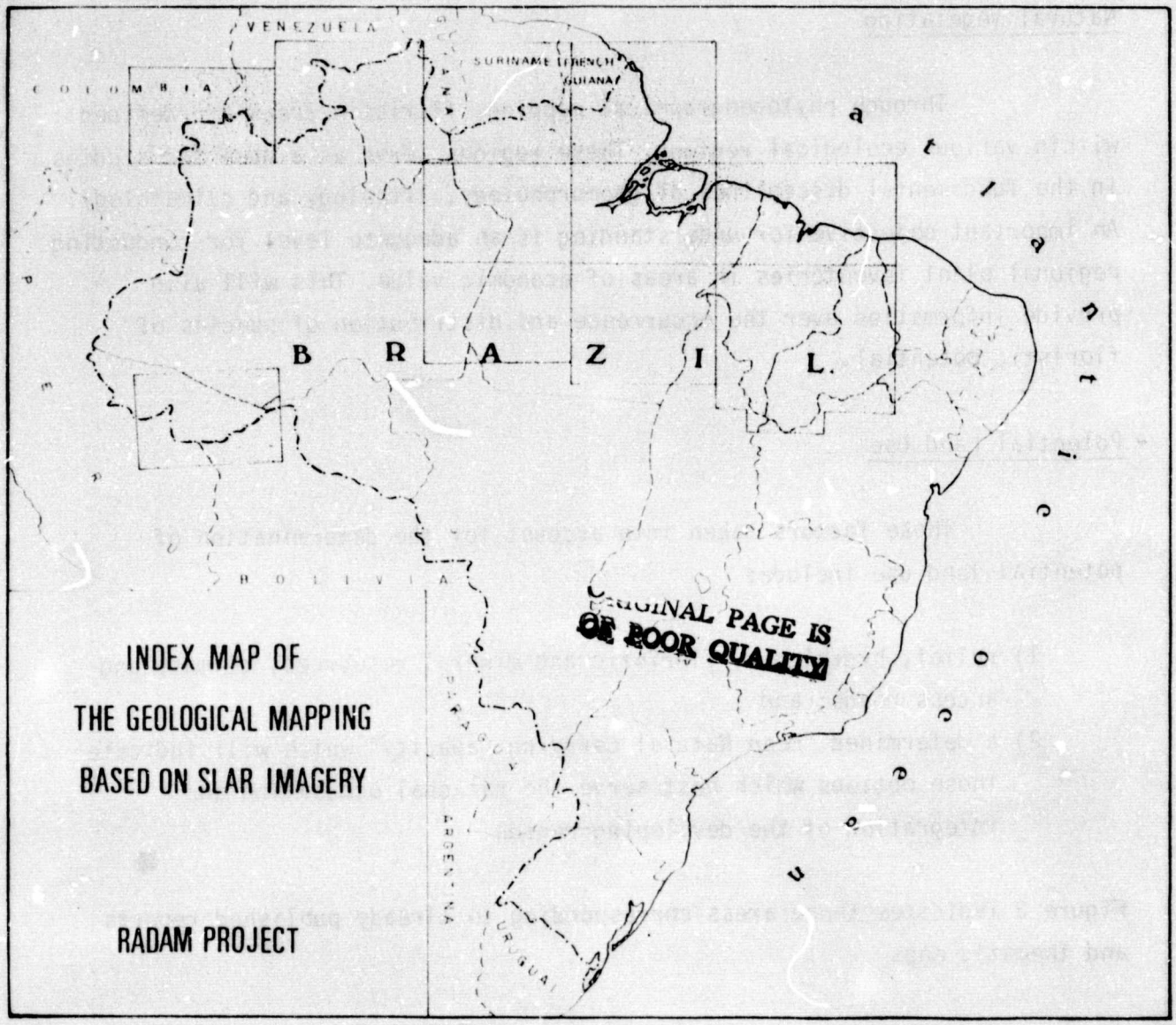

Figure 3

Without doubt, the Amazonian field work was a stage of Project RADAMBRASIL most arduous to fulfill, and, considering the realities of the region, was usually extremely inhospitable. A measure of this adversity is in the number of mortalities by disease and other accidents which totalled more than twenty. With respect to costs, the radarmetric inventory over the entire national territory came to approximately US$ 3.50/ km^2. The total costs per km^2 of areas already inventoried is difficult to calculate, owing to a lack of information of costs associated with field missions which had considerable support from the Brazilian Air Force. Those estimates made are in the area of US$ 15.00/km^2. It must be taken into account that the Amazon field work was extremely expensive which would not be the case for the rest of the country.

Inumerous immediate results were obtained in the Amazon by RADAMBRASIL. Some relevant examples of newly discovered mineral resources include: a manganese deposit in Rondônia estimated to contain 500,000 tons of mineral ore; gold deposits in Tapajós River region and in the Amapá Territory, phospate in the south of Pará State; cassiterite at various locations and various volcanic structures rich in rare minerals. From the point of view of geomorphology, a new map of Amazônia has been completed which reveals that flat land surfaces are a fifth the extent of which they were previously attributed. It was verified that hydroelectric potential in the Amazon is much greater than it was considered to be up to now. With respect to soils, various areas (generally fluvial) bearing extremely fertile soil deposits were discovered.

Project RADAMBRASIL, without question, is a decisive step to augment, by degree, the knowledge of the country's natural resources, and, in principal part, the Amazon region which was largely unknown. What was undertaken, was one of the largest projects ever executed to systematically map natural resources over a considerable terrestrial area of the globe. An important aspect of Project RADAMBRASIL is that it must be considered an inventory at cursory level, aimed primarily as a point of departure from the extropective view to inventories with considerably more details.

4. OTHER APPLICATIONS AND CONCLUSIONS

In addition to the Remote Sensing Program at INPE and of Project RADAMBRASIL, we can distinguish the following entities as large users of remote sensing and briefly outline their applications:

1) Brazilian Institute of Geography and Statistics Foundation (IBGE) uses LANDSAT imagery and radar imagery from RADAMBRASIL to prepare and update maps at scales of 1:1,000,000, 1:500,000 and 1:250,000.

2) Mineral Resources Research Company (CPRM)
Uses information generated by Project RADAMBRASIL as well as LANDSAT imagery for mineral prospecting work.

3) Brazilian Petroleum S.A. (PETROBRÁS)
Uses RADAMBRASIL produced data and LANDSAT imagery for petroleum and mineral exploration.

4) Brazilian Coffee Institute (IBC)
Developed a private system based on an aerially transported television and semi-automatic analysis system for performing coffee inventories (FAGUN 76).

5) Morro Velho Mining Company
Has used LANDSAT imagery conjunct with INPE's IMAGE-100 system for mineral prospecting work. The results of these applications, to our knowledge, have been highly beneficial.

6) Amazon Region Development Agency (SUDAM)
Is using LANDSAT imagery to survey deforestation in the Amazon region.

The number of important users, as the ones listed above, is increasing, which shows that LANDSAT imagery and remote sensing in general are a technology that is still new to several sectors of the government or private business.

For a country of continental dimensions like Brazil, remote sensing is a tool of considerable importance. All trends show that this importance is growing as the applications become more diverse and the number of users larger, especially government users.

To conclude this paper, we would like to mention that INPE has a program in Remote Sensing and Applications leading to a Masters degree. In all, 33 students got their Masters in this program, of which 25 are at INPE.

We wish to thank Dall Arthur Cotrell for helping with the manuscript and Maria do Carmo Silva Soares for typing the paper.

This paper was concluded in June, 1978.

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