INPE-606-LAFE (Revised)

REMOTE SENSING PROJECT (SERE)

TYPE III FINAL REPORT

COLLECTION OF RELEVANT RESULTS OBTAINED WITH THE ERTS-1 SATELLITE IMAGES BY THE INSTITUTE FOR SPACE RESEARCH - INPE

January 1975

PREPARED FOR NASA

VOL.I

Revised in July 1975 to include corrections suggested by James C. Broderick - NASA/GSFC LANDSAT Technical Monitor - based on a review made by the Scientific Monitor

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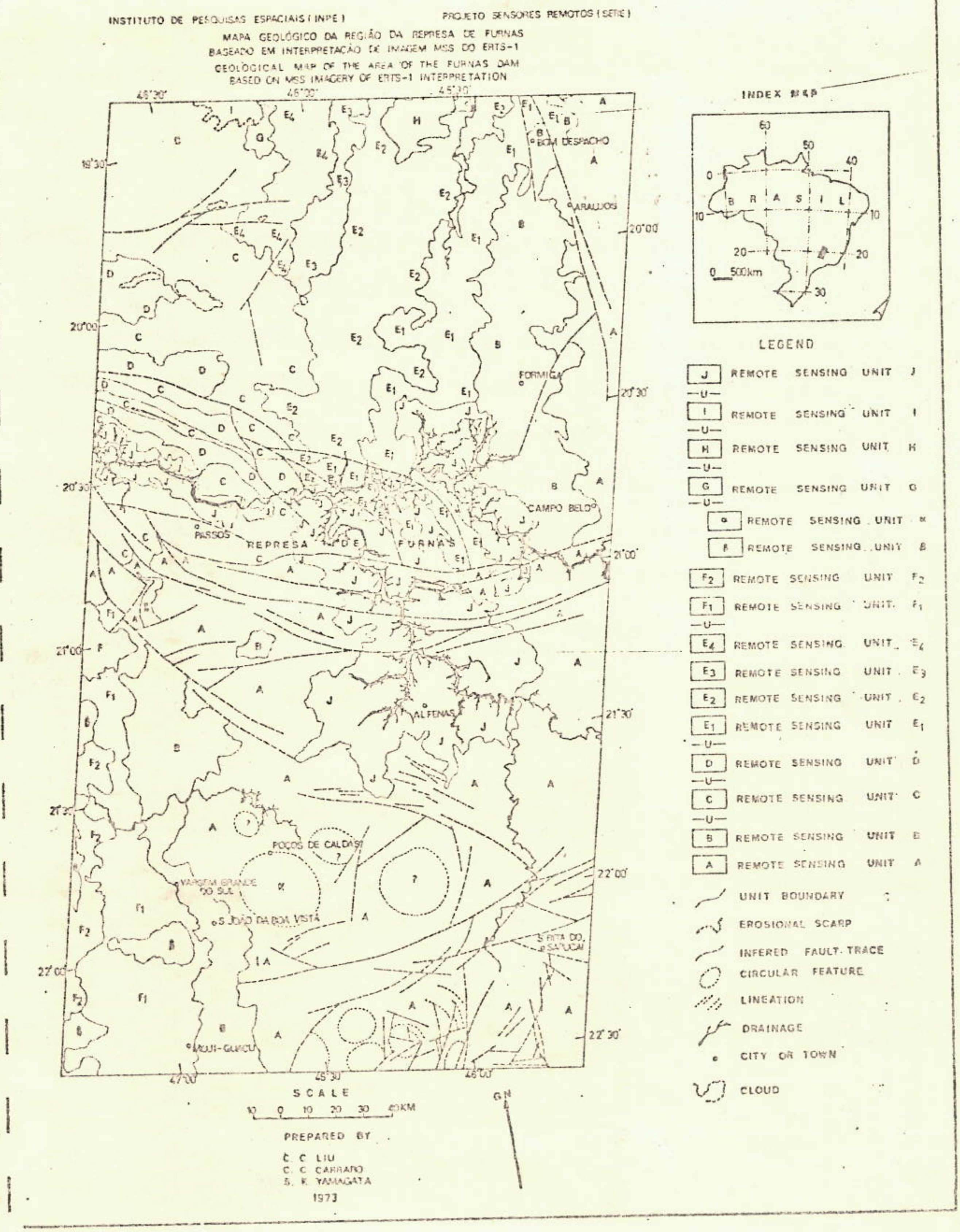
Map 2


INSTITUTO DE PESQUISAS ESPACIAIS (INPE)
PROJETO SENSORES REMOTOS (SERE)
MAPA GEOLÓGICO DA REGIÃO DA REPRESA DE FURNAS
BASEADO EM INTERPRETAÇÃO DE IMAGEM MSS DO ERTS-1
GEOLOGICAL MAP OF THE AREA OF THE FURNAS DAM
BASED ON MSS IMAGERY OF ERTS-1 INTERPRETATION
BOM DESPACHO
ARAUJOS
FORMIGA
CAMPO BELO
PASSOS
REPRESA DE FURNAS
ALFENAS
POÇOS DE CALDAS
VARGEM GRANDE DO SUL
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S. RITA DO SAPUCAI
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C. C. CARRARO
S. K. YAMAGATA
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REMOTE SENSING UNIT E1
REMOTE SENSING UNIT D
REMOTE SENSING UNIT C
REMOTE SENSING UNIT B
REMOTE SENSING UNIT A
UNIT BOUNDARY
EROSIONAL SCARP
INFERED FAULT TRACE
CIRCULAR FEATURE
LINEATION
DRAINAGE
CITY OR TOWN
CLOUD

CHAPTER IX

CONCLUSION

Owing to the low linear resolution capability (70-100 meters), the non-stereoscopic vision, and the small scale (1:1,000,000) the MSS imagery may only give a general geologic feature. Identification of stratigraphic units, which is the basis of a geological map seems difficult; grouping several similar looking stratigraphic units "remote sensing" as single units is possible. These "remote sensing" units have some practical utility in outlining tectonic provinces and showing the large structural relationships present in a region.

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SERVIÇO PÚBLICO FEDERAL
CONSELHO NACIONAL DE PESQUISAS
INSTITUTO DE PESQUISAS ESPACIAIS
São José dos Campos - Estado de S. Paulo - Brasil

COLLECTION OF RELEVANT RESULTS OBTAINED WITH THE ERTS-1 SATELLITE IMAGES BY THE INSTITUTE FOR SPACE RESEARCH (INPE)

The material contained in this report on the images of the Earth Resources Technology Satellite (ERTS-1) was authorized by the undersigned. The analysis presented here are done by specialists, from different groups of INPE, in order to show the potentiality of the uses of the ERTS-1 images for Brazil.

Fernando de Mendonça

General Director

COLLECTION OF RELEVANT RESULTS OBTAINED WITH THE ERTS-1 SATELLITE IMAGES BY THE INSTITUTE FOR SPACE RESEARCH - INPE

Principal Investigators:

- Dr. Fernando de Mendonça (Soil Resources)
- Dr. Gilberto Amaral (Mineral Resources)
- CF Emmanuel Gama de Almeida (Sea Resources)

TYPE III FINAL REPORT

Jan. 1975

INSTITUTO DE PESQUISAS ESPACIAIS (INPE)

(Brazilian Institute for Space Research)

This report has been prepared by:

Sea Resources:

. Renato Herz - INPE/University of São Paulo-IOUSP

. Sydnêa Maluf

Mineral Resources:

. Gilberto Amaral - INPE/University of São Paulo

. Aderbal Caetano Corrêa

. Paulo Veneziani

Soil Resources:

. Getúlio Teixeira Batista

Geography:

. Celina Foresti

. Evlyn Marcia Leão de Moraes

Coordination of:

. Maria do Carmo Silva Soares

Revised by:

. Fernando de Mendonça

. Renê Antonio Novaes

The following persons also contribute to the execution of this report as Co-Investigators:

Sea Resources:

. Affonso da Silveira Mascarenhas Jr. - INPE/Univ. São Paulo
. Claudio Cicero Sarti
. Hector Manuel Inostroza Villagra
. Keiko Tanaka
. Luiz Toshio Takaki
. Tseng Yun Chi

Mineral Resources:

. Aderbal Caetano Corrêa
. Anita Kacenelenbogen
. Athos Ribeiro dos Santos
. Celio Eustáquio dos Anjos
. Clovis Carlos Carraro - Federal University of R.G. do Sul
. Edison Crepani
. Flavio Soares do Nascimento
. Juércio Tavares de Mattos
. Liu Chang Chiang
. Paulo Roberto Martini
. Paulo Roberto Menezes
. Raimundo Almeida Filho

- Roberto Pereira da Cunha
- Sergio Kunio Yamagata
- Ubiratan Porto dos Santos
- Waldir Renato Paradella

Soil Resources:

- Antonio Tebaldi Tardin
- Armando Pacheco dos Santos
- Carlos Vicente Barbieri Palestino
- David Chung Liang Lee
- Mario Valério Filho
- Mostafa Kamel Nosseir
- Natalio Felipe Koffler
- Nilton Tocicazu Higa
- Pedro Hernandez Filho
- Sherry Chou Chen
- Vitor Celso de Carvalho
- Yosio Edemir Shimabukuro

Geography:

- Madalena Niero
- Maria Amélia Guimarães Leite

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14. Supplementary Notes: Our Proposal (April,1971) to NASA for participating in the ERTS-1 program presented three (3) disciplines namely: Soil, Mineral and Sea Resources. In this report we show final results of these three mentioned disciplines and Geography as an additional research.

15. Abstract:

(See pages vii and viii for abstracts of the five chapters.)

PREFACE

This final report describes the significant contribution obtained by the Brazilian Institute for Space Research (Instituto de Pesquisas Espaciais - INPE) in the areas of Sea Resources, Mineral Resources, Soil Resources and Geography, performed with the MSS/ERTS-1 Satellite images.

It is divided into five Chapters as follows:

Chapter I - Introduction - It is a brief description of the Brazilian Remote Sensing main activities.

Chapter II - Sea Resources - It describes the usage of the MSS/ERTS-1 images for bathymetric studies; coastal sedimentation (distribution, transport and deposits);carthographic correction and control of the coastal lines to nautical charts atualization; information of the coastal circulation processes based on sediments distribution; identification of polluter centers.

Chapter III - Mineral Resources - It indicates the value of ERTS imageries for the several geological purposes as mineral prospection, hydrogeology and geological engineering.

Chapter IV - Soil Resources - It shows how the MSS/ERTS-1 images could be used for soil resources purposes specially vegetal coverage aspects and soil properties under the pedologic point of view.

Chapter V - Geography - It presents how the MSS/ERTS-1 images could be useful for several geographic purposes specially geomorphological and hydrographic mappings and studies of demographic inference.

This report has 2 volumes (I and II). Chapters I, II and III belong to the First and IV,V to the Second Volume.

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CHAPTER I

GENERAL CONSIDERATIONS

I.1 - THE BRAZILIAN SPACE ACTIVITIES

The first definitions of a Brazilian space program started in 1961. By that time the Brazilian Government named a special commission to study and suggest the space research program of the country, proposing steps to its implementation. This is the begining of the Organization Group for the National Commission for Space Activities, known as CNAE. The new entity, closely related to the National Research Council, CNPq, had as its principal objective to study the space activities, not only through the scientific viewpoint but to furnish important contributions to the national technology.

The presidential decree numbered 68.532 - April 22, 1971 - transformed the group into a permanent institution: INSTITUTO DE PESQUISAS ESPACIAIS - INPE (Institute for Space Research). According to that document INPE is the principal civilian agency for space including fundamental and applied researches.

Today INPE has about 1000 persons working full time at the installations of São José dos Campos. It has also installations at Cachoeira Paulista, Natal, Fortaleza as well the ERTS tracking and recording station at Cuiabá in western Brazil.

From these 1000 people working at INPE more than a third is college graduates, MS and PhD holders. One of the main efforts at the Institute is in the field of remote sensing surveys and studies (SERE Project) in areas of hydrology, geology, mineralogy, agriculture,forestry, oceanography, geography, geodesy, urbanism, public health, etc.

I.1.1 - The SERE Project

Practically speaking Brazil must rely on remote sensing techniques to obtain the necessary information in a useful time frame. Conventional methods have proven too lengthy,costly and insufficient. The lesserdeveloped a country is the more it needs to use efficient technologies, and Brazil is no exception.

About six years ago we started to form an interdisciplinary group at INPE and work on the application of remote sensors in the different disciplines related to natural resources survey: The SERE Project is based upon an organizational structure similar to the general structure of INPE. The SERE Project is formed by nearly a hundred qualified specialists in natural and cultural earth resources working in close relationship with internal groups (instrumentation, flight operations, data processing data bank, the ERTS system groups) and outside agencies (government and private sectors).

The main objective of the SERE Project is to develop surveys and studies of the Brazilian territory, aiming at the research and control of our natural resources using the most modern remote sensing techniques. Besides the use of ERTS and SKYLAB imagery we use an aircraft modified to carry passive sensor equipments. Since 1971 this aircraft is used for flight missions over chosen Brazilian test sites. For the oceanographic research two vessels are used to support INPE: They are the oceanographic vessels NOc Prof. Besnard from the Oceanographic Institute of the São Paulo University and the NOc Almirante Saldanha from the Brazilian Navy. We also use the data obtained by the Ministry of Mines and Energy from Project RADAM (SLAR).

Through a matrix organization chart, at the end of this Chapter (Fig. I.1), we show the different disciplines which form our SERE Project under the management of a Coordinator who reports directly to the General Director of INPE.

Since its creation, our agency has maintained a close cooperation with NASA. This cooperation has proved to be highly beneficial.

Among the many cooperational programs between NASA and INPE, the one related to remote sensing activities, was initiated in 1968 through a Memorandum of Understanding, which was extended in 1971 to cover the period up to December 31,1972. An additional extension was performed in 1973 to enable a new agreement concerning the inclusion of the ERTS Satellites Experiment.

This mutual cooperation involves mainly personel trainings, transference of soft technologies and the use of satellites. From this support received from NASA we are prepared to continue to pursue the objectives stated at the begining of the collaboration as well as to enlarge it.

I.1.2 - The ERTS System

The last Memorandum of Understanding permitted INPE to establish a tracking and acquisition data station at Cuiabá, in western Brazil for the ERTS program as well as the data processing facilities located at Cachoeira Paulista in the State of São Paulo.

Indeed, one of the reasons given for the importance of installing such a system was to enable Brazil to receive real time data directly and uninterrupted even after the five hundred hours of operation forecasted for the wide-band or board tape recorder was over.

The ground station at Cuiabá (State of Mato Grosso) has been operational since April 1973. The Data Processing Facilities at Cachoeira Paulista became operational on September 1974. Previously the tracking and receiving stations recorded images only for one orbit of ERTS, since 15 July 1973, however 2 or 3 orbits are being recorded daily over Brazil. Approximately 43 scenes/orbit are recorded or 86 scenes/day. Since all four channels of MSS are being received, this means that approximately 344 images are recorded each day. (Fig. 1.2).

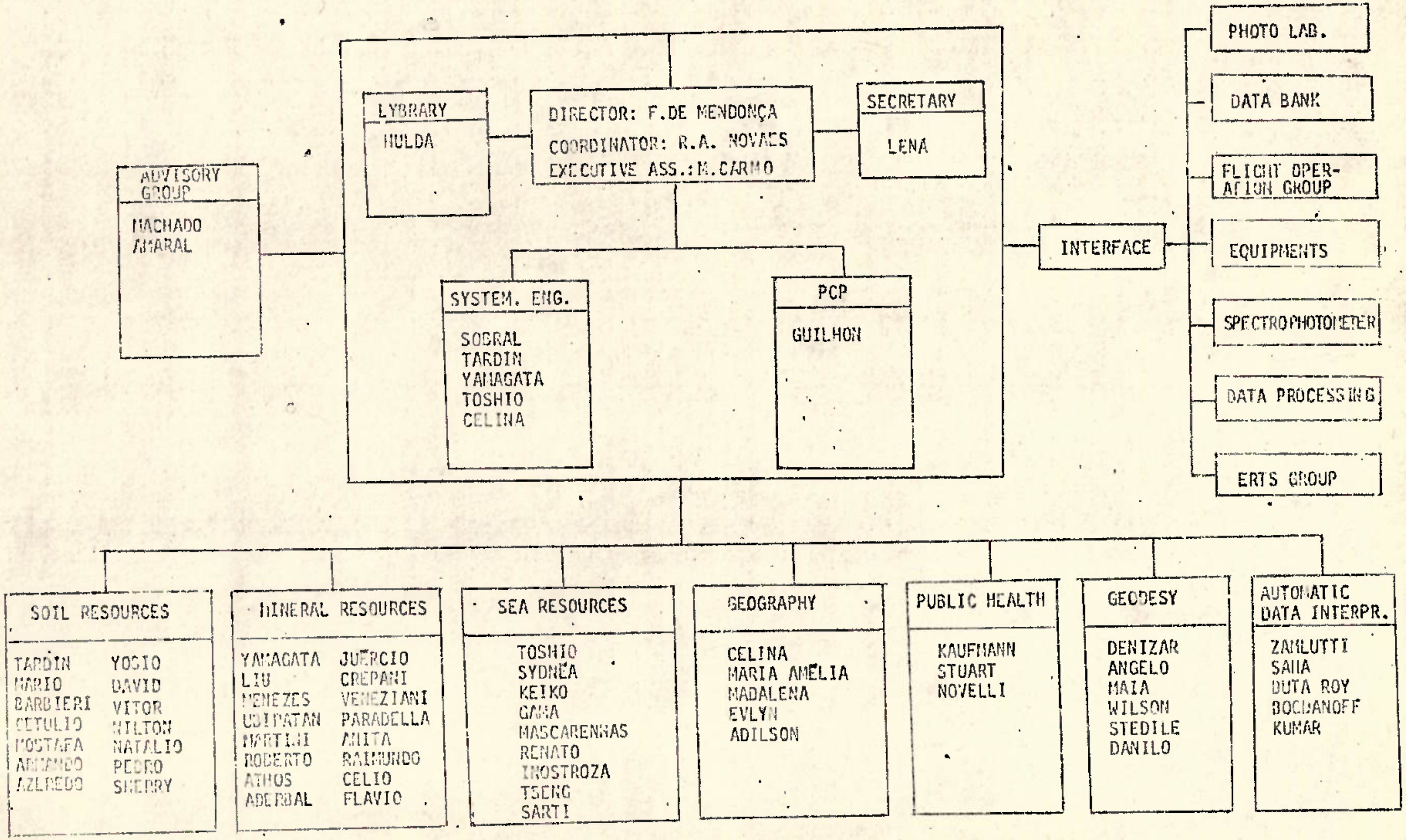
Efforts are being made to increase the number of users (the policy of placing the ERTS-1 data on a basis of being available to all who desire to pay the small reproduction costs is in accord with U.S. policy) and to develop methods to automatically interpret aircraft and ERTS images. Research in this line has been conducted at INPE seriously since January 1973. INPE has recently ordered a GE-Image 100 system. The process of developing software to program computers for automatic interpretation of the ERTS images, is long and difficult. There is a lot of research to be done in this area before one reaches an operational status. Visual interpretation is important but it is felt that ultimately the answer for the future can only lie in automatic interpretation, and Brazil is trying to prepare for this advanced stage.

As an additional response to the potential problem of data INPE has installed a Quick-Look Monitor at Cuiabá. Canadian and Brazilian experience have shown that the Quick-Look process provides good spectral resolution. Its lack of geometrical precision is more than compensated by the fact that end users can receive data when it is at the most a few days old.

The particular problems and need of Brazil are quite adaptable to solution through the use of remote sensing. Vast, remote and sparsely populated areas are now mapable, coffee and sugar cane inventories can be conducted on a more timely and less expensive basis; new mineral deposits can be located, etc. Brazil is not only meeting its responsibilities to its fellow developing countries in South America, but is becoming a leader in this field and sharing its experience with other developing countries.

In conclusion, Brazil has one of the most rapidly developing economies in the world today. Remote sensing is seen as a technology which must be fully utilized in helping our development.

After this brief introduction, which was made with the purpose of showing the progress attained due to the ERTS program, we will go into the report proper.



PCP = Planing and Control Project

Fig. I.1 - Matrix Organization Chart - Remote Sensing Project

Fig. 1.2 - Map of Brazil with location of ERTS images received up to June 1974.

CHAPTER II

SEA RESOURCES

Principal Investigator:

Gama, Emmanuel de Almeida - INPE/Brazilian Naval Hydrographic Office-DHN

GSFC ID-F0453 MMC 326-03

CHAPTER II

SEA RESOURCES

II.1 - THE USE OF ERTS-1 SATELLITE IMAGERY IN OCEANOGRAPHY

When analyzing multispectral images, it is necessary to consider the propagation of light in space and its physical properties in each environment.

Propagation of light in a liquid is different from that in the atmosphere.

Different water types such as coastal waters, oceanic waters, river and lagoon waters, behave differently from the point of view of transparency in relation to suspended mineral particles or organic particles as detritus or living organisms.

Each basin retaining or flowing a special kind of water type indirectly furnish different conditions to its transport capability putting in evidence its morphology and water volume resulting in its proper capability.

The quality and quantity per cubic unit of sediments and its transport are fundamental factors, that cause different conditions for the penetration of sun light in the water (Fig. II.1).

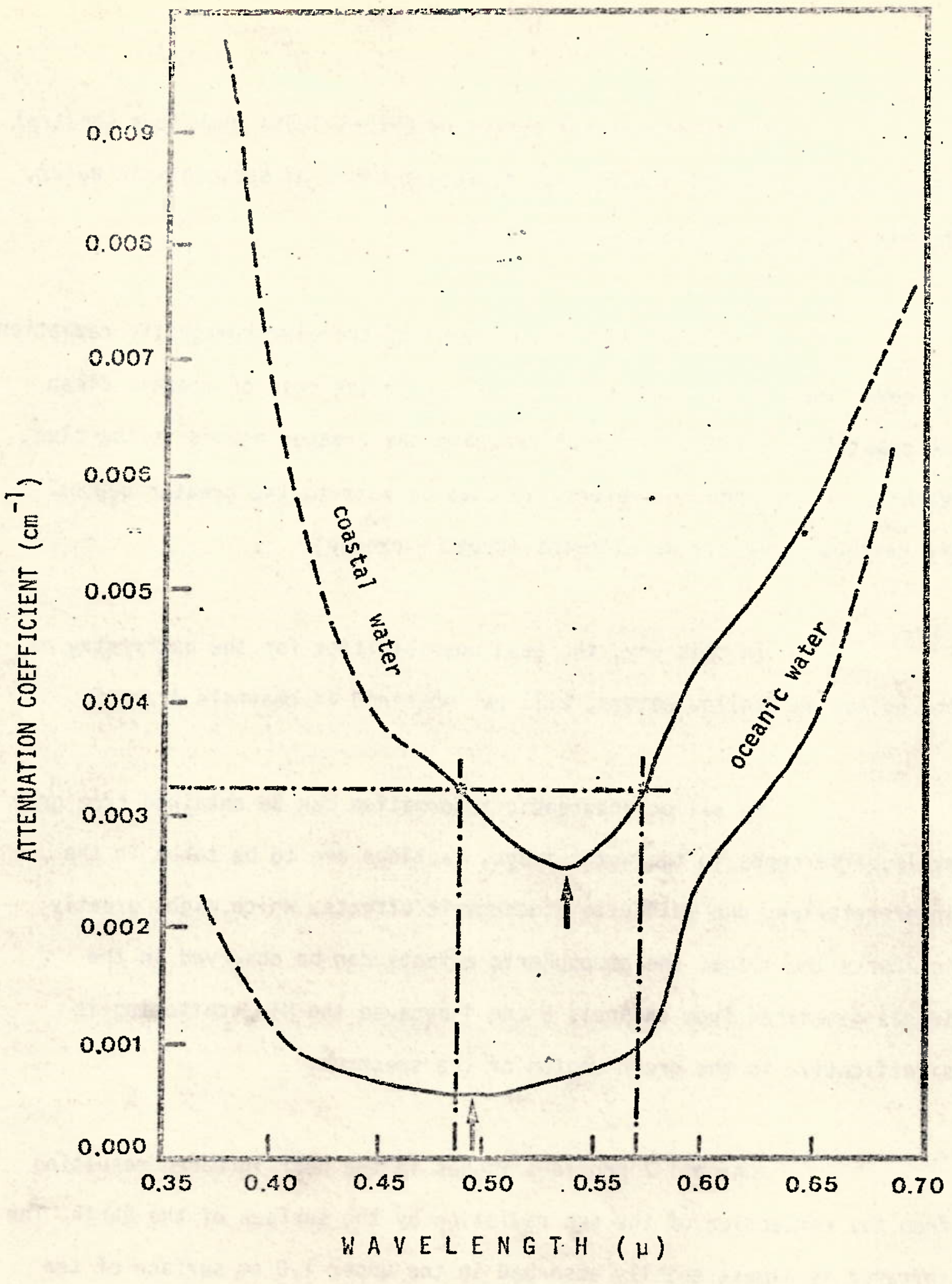


Fig. II.1 - Shows the attenuation of light by sea water, as a function of the materials in suspension. (Polcyn and Rolin, 1969).

The multispectral system of ERTS-1 (MSS) with four spectral bands, can register in its images, different kinds of sediments in water, flowing the spectral responses of these.

In figure II.2 the behavior of the electromagnetic radiation is shown, when it is absorbed by sea water in the case of oceanic clean and coastal water. The radiation reaching the greater depths is the blue, reaching several tens of meters. In coastal waters, the greater depths are reached by longer wavelengths (green - orange).

In this way, the best possibilities for the bathymetry of the bottom in shallow waters, will be obtained in channels 4 and 5.

As all oceanographic information can be obtained from gray scale differences in the water image, cautions are to be taken in the interpretation, due mainly to atmospheric effects, which might greatly influence the image. The atmospheric effects can be observed in the images generated from channels 5 and 4 because the Mie scattering is significative in the green region of the spectrum.

Channel 7 provides images in the near infrared resulting from tne reflection of the sun radiation by the surface of the Earth. The infrared is almost totally absorbed in the upper 1.0 cm surface of sea water, and that is why the surface of the sea appears very dark, representing black zones in the images of MSS-7. This channel is very good for the

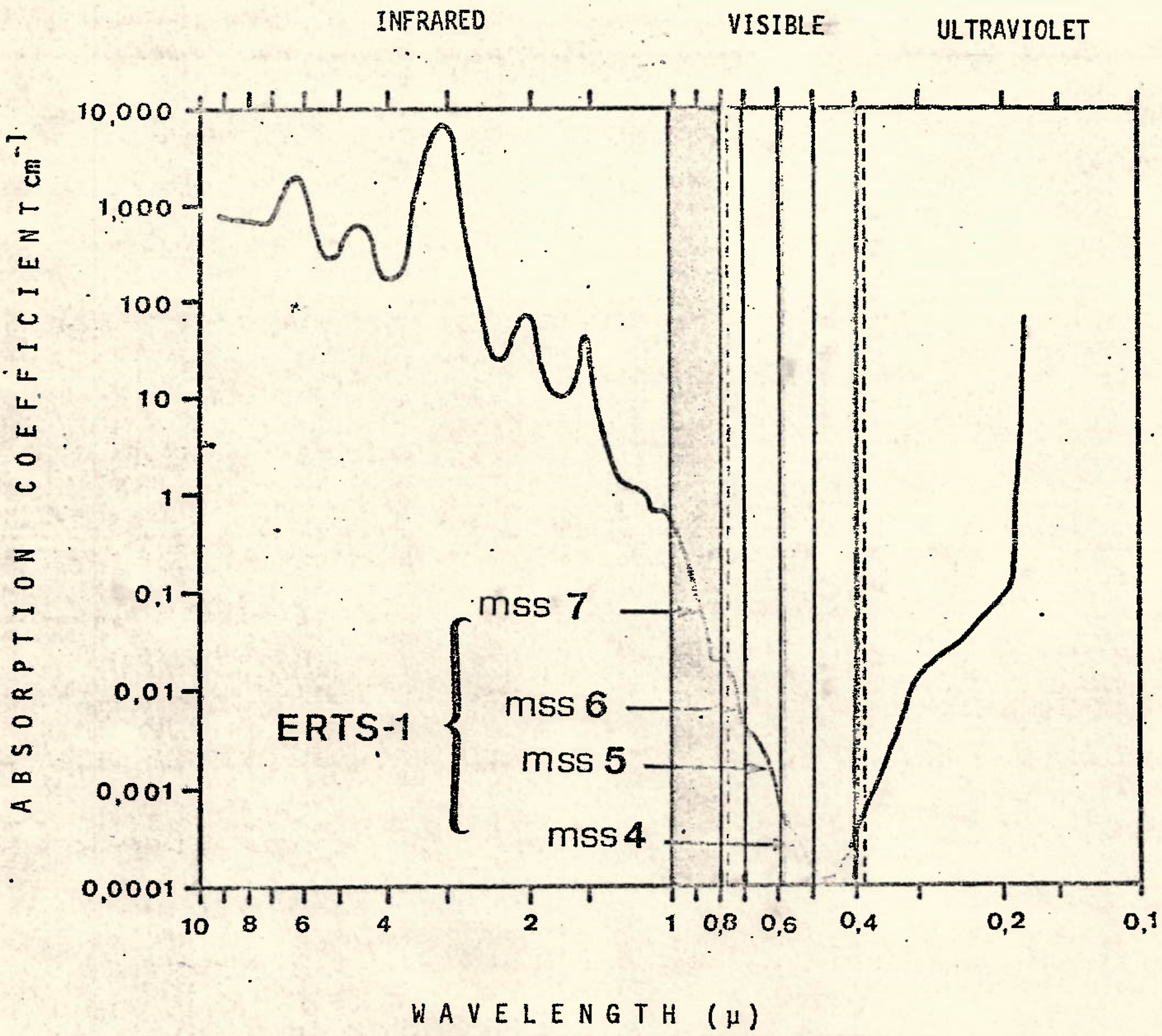


Fig. II.2 - Shows the absorption of sea water on the ERTS-1 MSS channels.

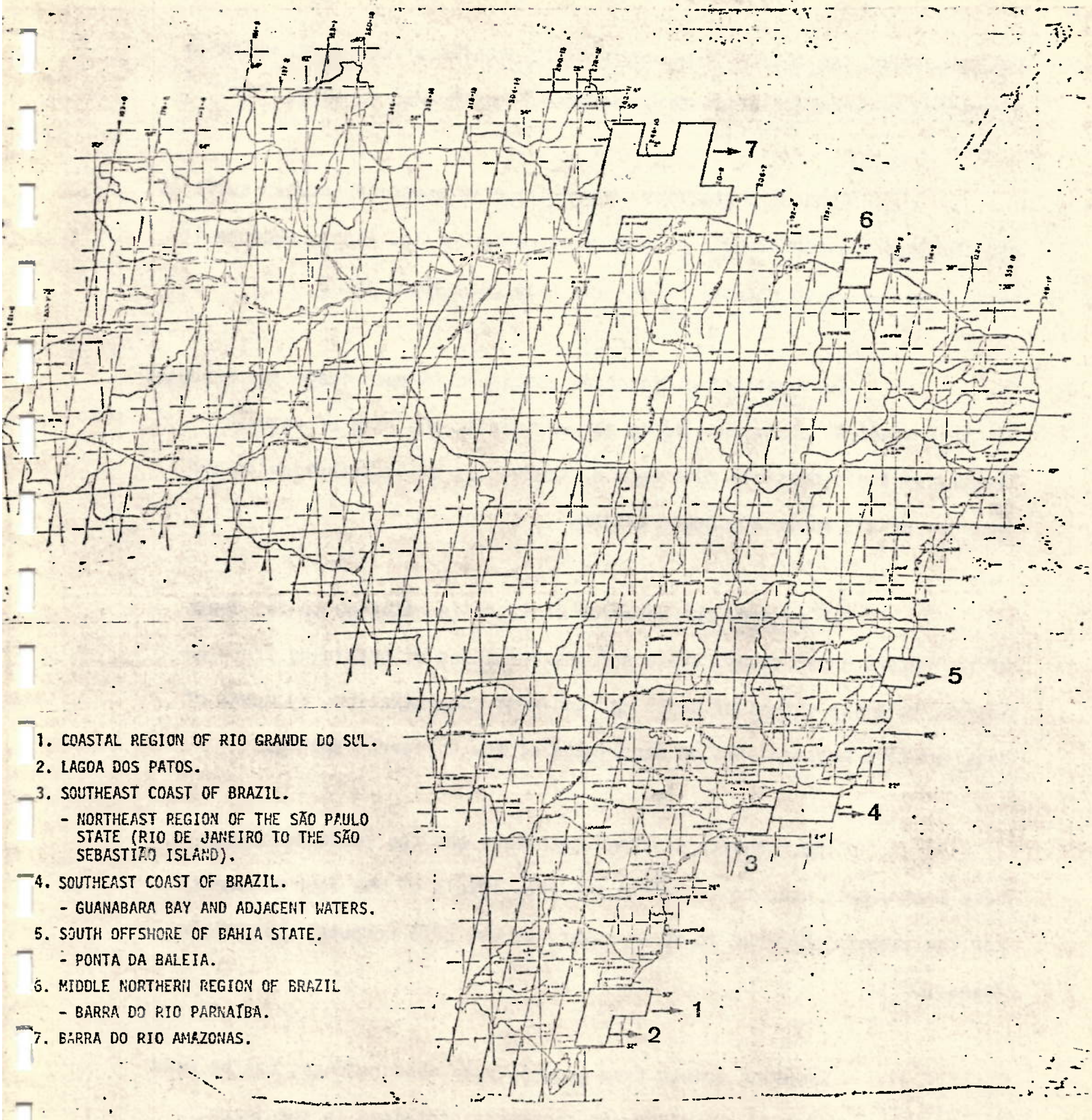


Fig. II.a - Test site areas of the Sea Resources Group.

delineation of the coastal line registering details of 60-100 m, which is a somewhat better resolution than expected from the MSS of ERTS.

Channel 6 provides intermediate information between surfaces and the layers which exhibit greater penetration of the light, because it penetrates more than channel 7 and less than channels 4 and 5.

The contrast differences contained in each image and produced by their spectral behavior give to the sediments, the role of natural tracers of their possible movements or tendencies of distribution in the interior of the river and ocean basins.

If we know the behavior of light in relation to the depth of the waters under study, there are possibilities of obtaining from the images, relative values of depth and sediment concentration, by means of densitometric measurements on each image of the different channels.

The "density slicing" technique and the ratio technique have been widely used to correlate the gray levels of the four channels. For the latter technique it is necessary to use ERTS Computer Compatible Tapes (CCT).

Sampling points from ground truth measurements, can be used as elements to qualify the different contrasts contained in the image, because they are taken simultaneously with the satellite passage and can be extrapolated for the rest of the image, by means of automatic processing.

A description will be made of the analysis of the ERTS-1 images done over relevant areas by the Sea Resources Group of the SERE Project.

In the first part we will include the description of the selected test sites presented in the Proposal submitted to NASA in 1971 (Research and Development Proposal for Investigation using Data from Earth Resources Satellite, April 1971 - Report INPE-LAFE-150 -and Addenda to Report INPE-LAFE-150, August, 1971).

The selected test sites were:

Test Site Area 827: Rio da Prata Estuary and South Coast of Brazil, contained in the Rio Grande do Sul Project.

Test Site Area 826: Rio de Janeiro and Espírito Santo States Coast and Offshore contained in the Southeast Coast of Brazil Project.

Test Site Area 828: Amazon river delta and offshore, contained in the Barra do Rio Amazonas Project.

At the first test site area, two regions were analyzed:

the coastal region of Rio Grande do Sul and the Lagoa dos Patos Region, with additional information obtained by NIMBUS IV, APOLLO 8 and SKYLAB satellites images interpretations.

At the second test site area, it was included two important regions situated on the Brazilian Southeast: part of the São Paulo State region and the Guanabara Bay region and its adjacent waters, one of the most polluted places along the Brazilian coast.

Thirdly a mosaic was analyzed. This mosaic included the Barra Norte - Amazon River, formed by 10 ERTS images on channel 4.

Afterwards, this report also describes the analysis of ERTS images made over two areas not included on the 1971 Proposal and considered here as additional areas.

These are:

Ponta da Baleia - situated at an approximate latitude of $15^{o}S$ at the South coast of the Bahia State

Barra do Rio Parnaíba - in the Brazilian Northeastern region (Maranhão, Piauí and Ceará States).

The first of them is included in the Abrolhos Project, now in development by the Sea Resources Group which will be briefly described in Chapter II of this report.

II.2 - RIO GRANDE DO SUL PROJECT

Test Area 827 - Rio da Prata Estuary and South coast of Brazil

II.2.1 - Description of the Test Area

This area is in the Southeast coast of South America. The theoretical limits of the phenomena to be studied are in the region between 30^{o} to 50^{o}S and 040^{o} to 060^{o}W. Within these general limits, some smaller areas are considered "key" areas where the occurrence of some phenomena are characteristic. The coastal zone adjacent to the Rio de La Plata Estuary (Estuãrio do Rio da Prata) and the coastal province of Rio Grande do Sul constitute two important zones for this project.

The coastal province of Rio Grande do Sul is considered in two steps: lagoon and coastal areas. The development of the research will provide connecting elements to the understanding of the hydro/oceanographic system of the area.

The lagoon system with 168000 km^2 includes materials of different lithological origin, and is separated from the coastal province which is composed of materials of the quaternary period. This space together with the coastal province will be studied as a sub-area on its hydrological aspects.

The continental shelf adjacent to Rio Grande do Sul has features associated with ocean currents and materials provided by the Rio de la Plata Estuary and by the lagoon complex of Lagoa dos Patos. The coastal and oceanic process over the shelf are greatly influenced by the currents and local winds which determine the coastal and oceanic circulation in the region.

II.2.2 - Justification of the Area Selection

The coast of Rio Grande do Sul has important characteristics for the development of studies on Remote Sensing in the fields of Hydrology and Oceanography.

Lagoa dos Patos offers good elements for a study of the surface circulation and the transport of suspended materials. The connecting canal between the Patos basin and the sea presents differential conditions in the distribution of saline water in the interior of the bay. This fact is important to the understanding of the interaction phenomena and also to the primary production, which comes at the end to be important for the fishing economy of the region and also for the deposition rates.

The coastal and oceanic zone have the necessary elements for experiments on remote sensing aimed at evaluating marine resources where coastal currents and sediment transport could be detected on MSS of ERTS.

Other elements related with the physics of the waters over the shelf, can be measured with the use of images of NIMBUS satellites and of the INPE aircraft.

The shelf and oceanic areas are on the boundary between the Brazil and Falkland Currents where favorable conditions for commercial fisheries exist. It is possible, for instance, to chart seasonally the sub-tropical convergence associated with the boundary.

The Brazil Currents moves towards the South reaching the Rio de la Plata Estuary at about 35^{o}S, where the Falkland Current moves to the North in form of a cold wedge on the shelf to meet the warm current coming from the north. This boundary produces different water structures in the different seasons of the year.

Reports of oceanographic cruises done in the area describe fishing zones on the borders of the boundary between the Brazil and Falkland Currents where two waters masses occur.

These occurrences should be studied together with the drift of the sub-tropical Convergence, where a mixing zone exists which produces gradients adequate for a favorable environment for different species of fishes or marine animals to stay there.

The fluctuations of the boundary zone of the Convergence between the Brazil and Falkland Currents have fundamental importance and interest for the area, because the Continental shelf of Rio Grande do Sul is subjected to those changes. In the Rio de la Plata Estuary currents and coastal features can be detected in the images of ERTS and NIMBUS satellites series.

This spacial information can be correlated with the existing oceanographic data and which will be increased by means of a thermal sensor on board of the aircraft in simultaneous surveys with oceanographic vessels in perpendicular lines to the coast.

The synoptic interpretation of the distribution of properties of the sea surface waters, obtained in charts, show a seasonal behavior and the use of images from satellites will greatly improve these charts,either in geographic coverage or repetitivity of observation, not possible to be obtained with conventional oceanographic techniques

II.2.3 - Objectives of the Project

The objectives of this project, in terms of ERTS images, are:

1. Define a seasonal behavior of the surface circulation in the interior of Lagoa dos Patos.
2. Correlate the present processes of erosion transport and deposition in Lagoa dos Patos with the circulation. The

purpose of this is to help the drainage works being done, to keep the conditions for navigation adequate.

3. Correlate conventional oceanographic data with Remote Sensing data, to locate fishing areas, and exploit them on a rational basis.

Preliminary interpretations of ERTS-1 imagery (1973) have shown that the region is interesting and adequate for application of remote sensing in the evaluation of hydrologic and oceanographic resources.

ERTS-1 and SKYLAB images allowed us to evaluate synoptically the dynamical behavior of the coastal and oceanic waters in the surface. In order to justify the models and patterns is necessary to correlate the satellite images, with series of data obtained simultaneously.

The definition of the seasonal behavior of the surface circulation, permits one to obtain a better understanding of the patterns of the transports and distributions of sediments and the tendencies of their deposits.

The interaction between sea and lagoon waters has characteristics associated with the winds, hydrological regime and local tides, which is important to know from an economical point of view, because of the primary production of the basin.

The coastal and oceanic regions are being studied with satellites, aircraft and oceanographic vessels, in order to get a synoptical view of the seasonal fluctuations of the sea water properties.

The synoptic study of the distribution of the Brazil and Falkland Currents is of fundamental importance for this area considered the most productive fishing area of the country.

The information obtained by conventional oceanographic methods will be used as a basis for the interpretation of the images to be analyzed in the different levels with Remote Sensors.

With the results of research in other areas, zones of the greatest primary production, either on the surface or on the vertical, will be done. Also the knowledge of plancton on the surface and on the vertical will correspondingly be done.

A special methodology for the determination of primary production of this area, shall be created with the help of remote sensing.

With colaboration of specialized institutions (IOUSP - Oceanographic Institute of São Paulo University; IPqM - Marine Research Institute; SUDEPE - Superintendency for Fishing Development; DHN - Brazilian Navy Hydrographic Office, and others) surveys, should be done (seasonal basis) in the most important fishing areas, with emphasis on commercial fisheries. With data from conventional oceanography and remote sensing, a methodology shall be established to locate areas adequate for fishing (seasonal and/or real time).

The next chapter shows the interpretations of images of the coastal region of Rio Grande do Sul and of the Lagoa dos Patos, presented as part of the development of this project.

II.2.4 - Coastal Region of Rio Grande do Sul and Rio da Prata Basin

II.2.4.1 - Introduction

The analysis of ERTS-1 images (E-1103-12.415) of the coastal region of Rio Grande do Sul points out partial details of the hydrologic complex that involves this area (Fig. II.3). However, the intention of a dynamic interpretation analysis would be completed if a number of images of consecutive orbits were available covering all the space considered as participant of the eco-system (9 orbits, 9 positions in each of the four channels).

The study of the coverage mosaic of this area would contain approximately 70 images in each channel at scale 1:1,000,000, covering hydrological elements of the whole Prata River basin and its influence in the characterization of coastal water masses, taking into consideration their distribution by the Falkland Currents, and some local coastal

Fig. II.3 - Image E-1103-12.415, 3 NOV. 1972, channel MSS-4, Scale 1:1,000,000.

processes, following the manifestation of seasonal climatic regimen.

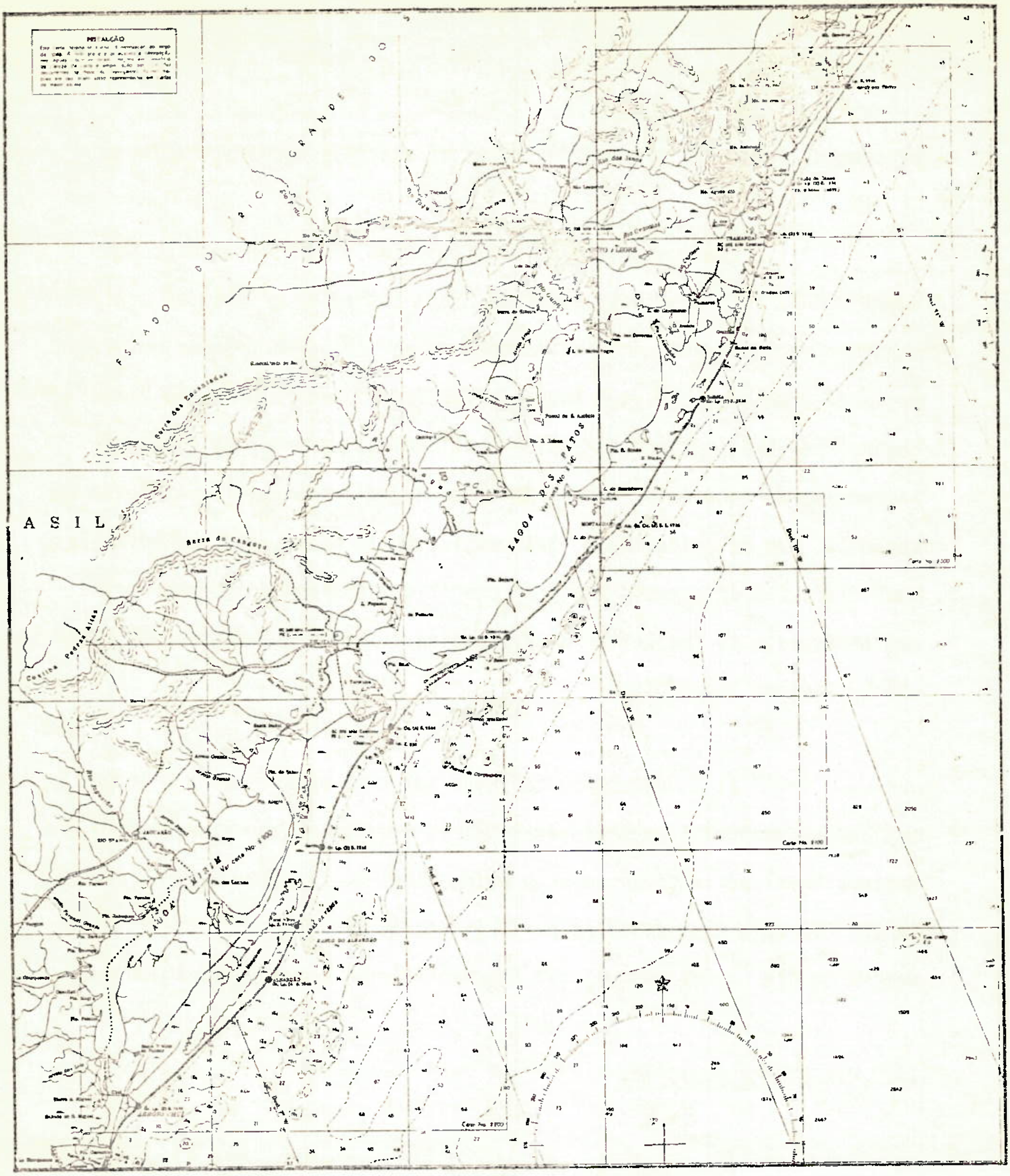
The oceanographic conditions of the Rio Grande do Sul coast can be very precisely observed, from the point of view of distribution considering its importance and factors which influence greater or lesser regional fish productivity. The contribution of waters from the Prata basin, from the lowland lagoons or from coastal sedimentary plain as either sub-surface water contribution or normal contribution by means of channels, can be observed in their evolution in space, and periodically qualified. Thematic cartography of conditions presented in each period can contribute to the better understanding of hydro/oceanographical behavior which involves the region.

It is necessary to point out that establishing a larger or smaller geographical or ecological space, depends on the dimension of the factors involved in the ecosystem being studied. This can be well defined in the elements considered as participants of the nature of the coastal waters in Rio Grande do Sul, and its spatial and temporal distribution.

II.2.4.2 - Interpretation

The images E-1103-12.415 (NASA-ERTS) correspond to the region represented in figure II.4, which is a partial detail and a reproduction of the nautical chart DHN nº 90, of scale 1:990,526 in the latitude of $31^{o}25'$S.

COSTA SUL-BRASIL



DETALHE DA CARTA DHN Nº90 RH 28474

Fig.: II.4 - Partial reproduction of the nautical chart of DHN (Diretoria de Hidrografia e Navegação - Brazilian Naval Hydrographic Office) nº 90, scale 1:990,526 (1965), lat. 031º25'S.

The cloud coverage on that date was approximately 30% over the area covered by the image, which appreciably reduced the interpretation of the NE coast of the Lagoa dos Patos (Fig. II.3).

The coverage of the image is approximately 1/3 of the land and 2/3 of water on a total of 100 x 100 nautical miles.

- <u>Oceanography/Hydrography</u>

The pair of channel 4 and 5 images present together the coast, from Lagoa do Sumidouro to Lagoa dos Patos, with discolorations of coastal waters according to the different contrast densities represented. This represents the existence of a large quantity of sediments moved by coastal currents with complex dynamics principally due to the wind distribution. As this phenomenon does not occur in channels 6 and 7, it is concluded that this is connected with sub-superficial movement of great intensity principally near the Banco da Berta where the turbulence in waters is greater in view of the presence of the sand bank (Fig. II.5). In executing an overlay of C4 and C5 it was verified that the general form of the distribution of suspended sediment coincides in the periphery with the alignment of the isobath at 50 m over the two channels 4 and 5. The maximum plume width of this suspended sediment layer is approximately 20 miles (indications B, C and D in the overlay C4 and C5).

The discontinuation of contrast in the images is due to the

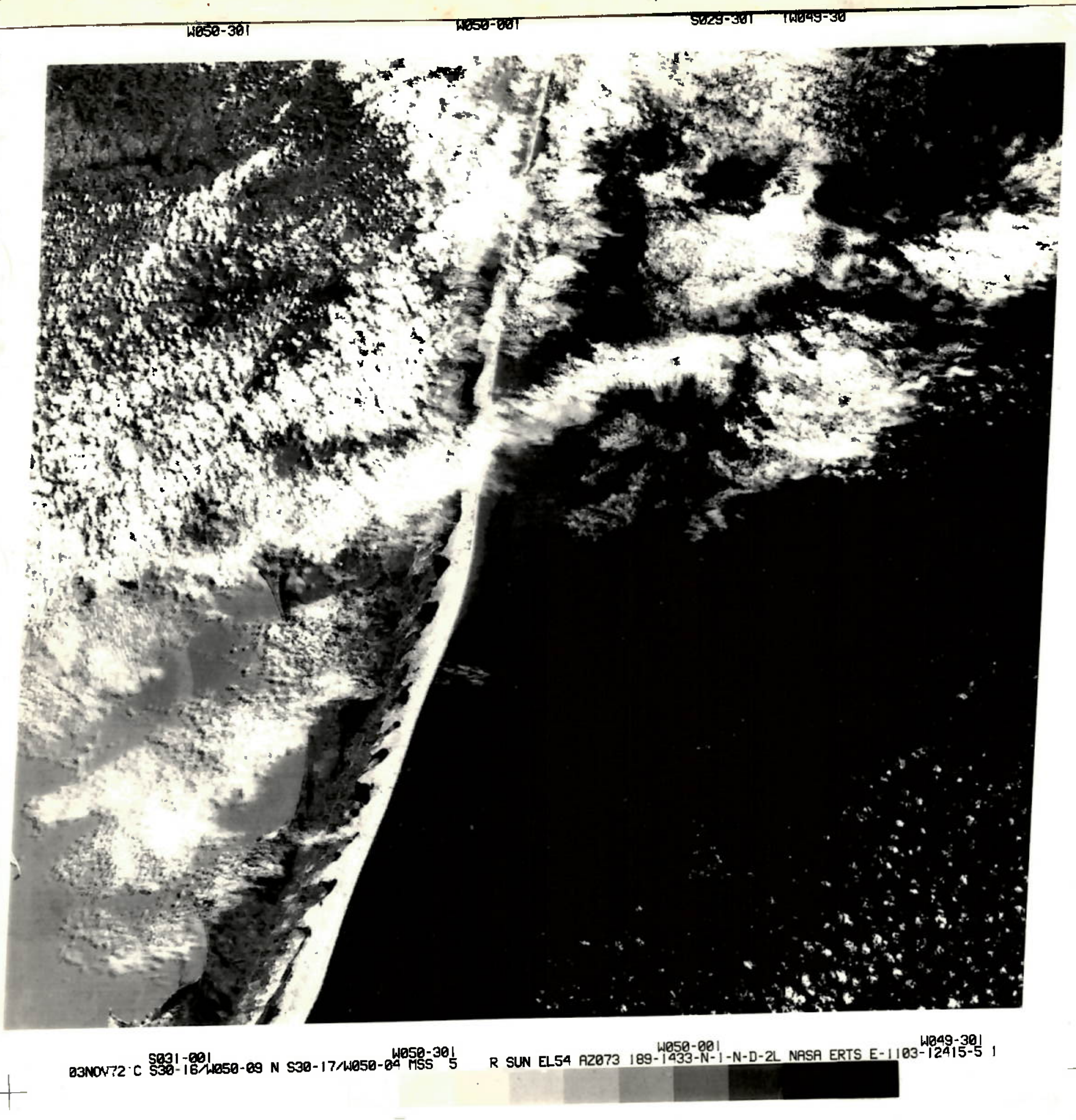
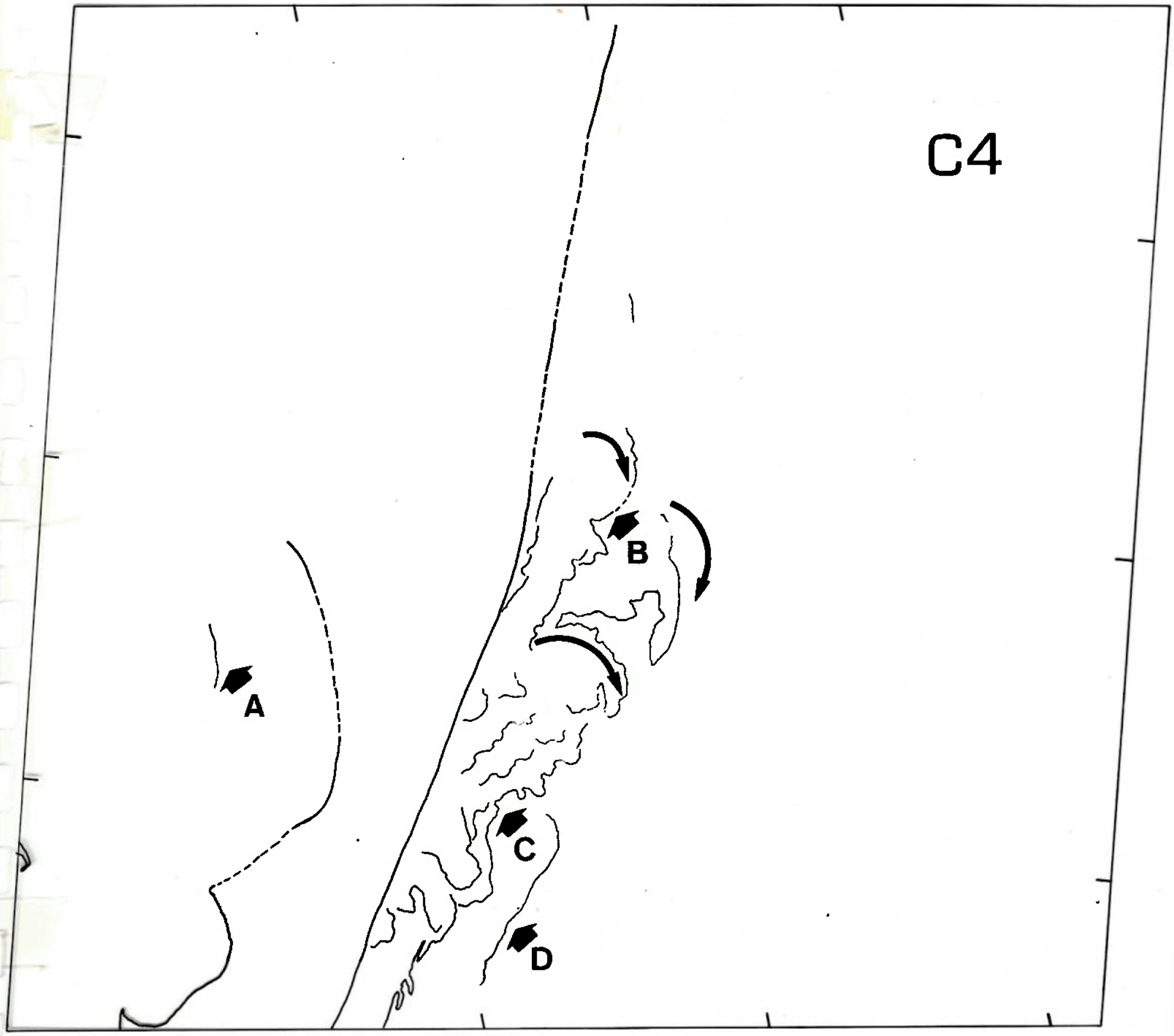
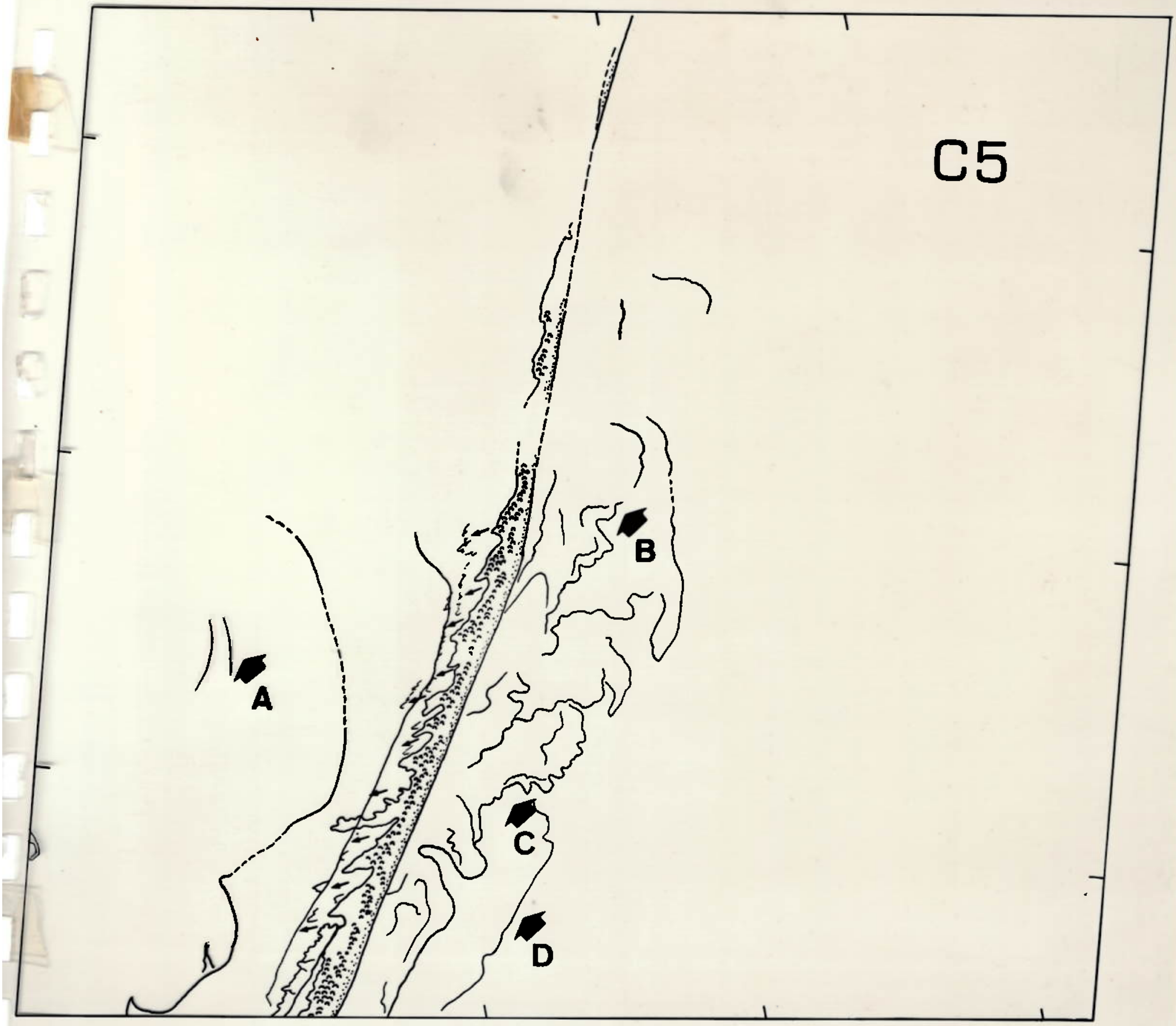


Fig. II.5 - Image E-1103-12.415/5 scale 1:1,000,000, overlay C4, C5 and detail of nautical chart of DHN, nº 90.


C4
A
B
C
D


C5
A
B
C
D

different concentrations of the material maintained in suspension, as well as its depth or vertical distribution which is found in the coast.

The decreasing intensity of the patches denoting the mixing processes near the bathymetric lines of 50 m, probably indicates that the process of transport from this limit to deeper zones is reduced.

The horizontal morphology of this distribution establishes elements that possibly indicate that the dynamics of the sub-superficial waters, and probably superficial, are moving along the coast to the N, detouring to the NE, continuing the cyclonic rotation until reaching the SE direction in the bathymetric zone of 50 m, when occurred a change in wind direction from SW to NE.

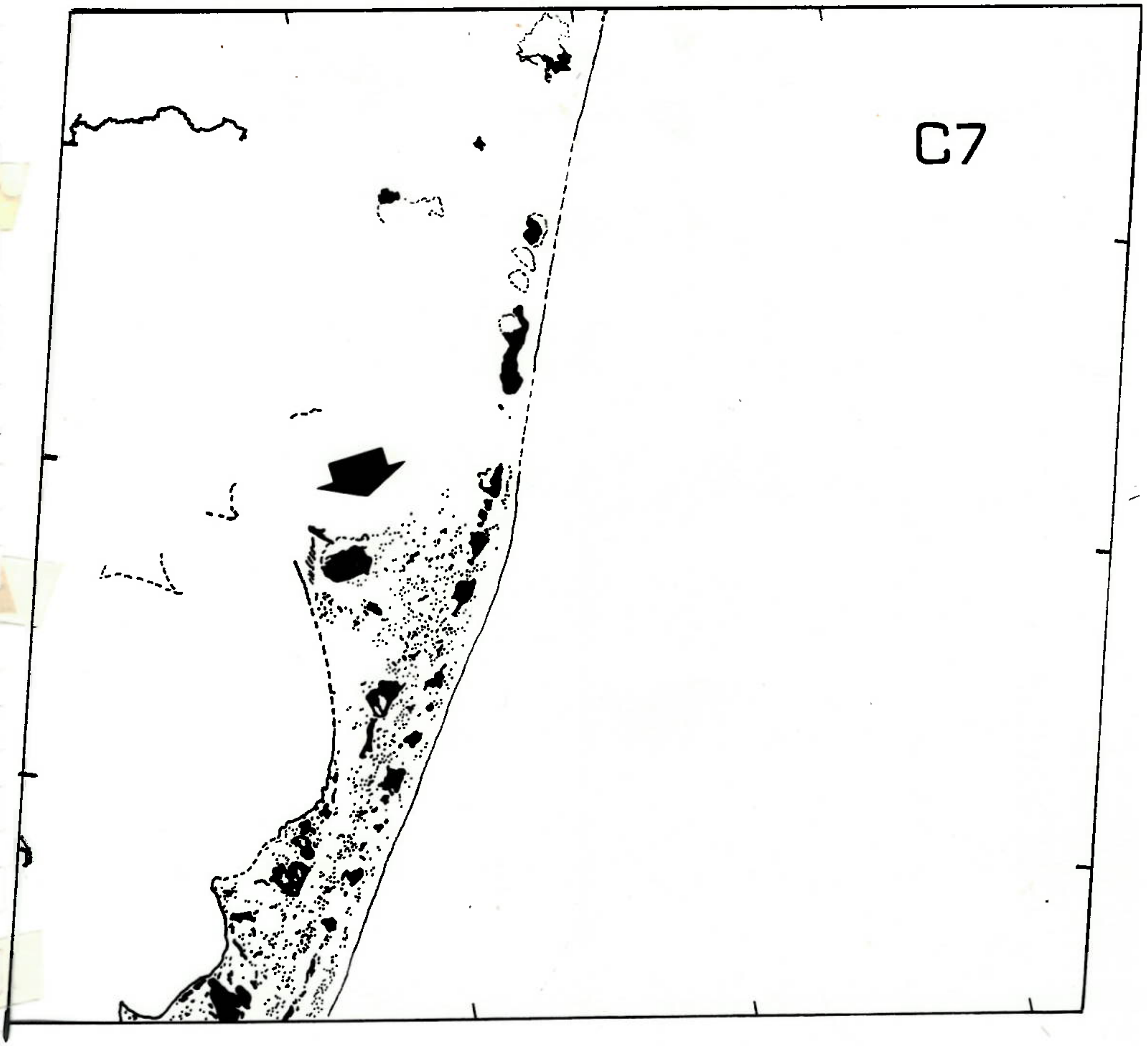
The indications of B,C and D in the overlay are elements of the same nature which result in the same type of spectral response for the image of the coastal sediments in suspension in the coastal waters. Indication A represents discoloration of the interior of the Lagoa dos Patos near the Ilha do Barba Negra and Ponta de Itapuã; the nature of this interior water is different from that of the coastal one considering the sediment transported, which appears also in channel 6 as well as channels 4 and 5. The first (A) is a sediment fluvio-lacustrine with a high content of clay, while the second (B,C,D) is exclusively coastal with little or no content of clay, therefore, free of coloidal suspension. The channel 6 image registers better in the indication A, which is the sediment originating from the Rio Guaíba basin: channel 7 gives practically no definition in this respect, as the existing sediment in this location reflects little energy in this band of the spectrum (Fig. II.6). In channel 4 there is no visible contrast in lagoon waters since the energy reflected by the sediment is the same as that reflected by the lake waters, through scattering.

It can be observed that zone B in channel 6 marked in the overlay C4 and C5 remains in C6; comparing this with the nautical chart the fact becomes clear, since the bathymetry indicates a sand bank (Banco da Berta) at the depth of 10 m where there is an intense sub-superficial turbulence (C6-B).

All this leads one to believe that the transport of sediment is more extensive because the sand bank constitutes natural barrier which deviates a part of the water to the N, when the regional winds blows from the south.

- Coastal Geomorphology

The quaternary coast to the extreme south of Brazil from Cabo de Santa Marta Grande is comprised of vast formations of sand with a low topography and rectilineal type, constituting an accumulated coastal plain.


C7

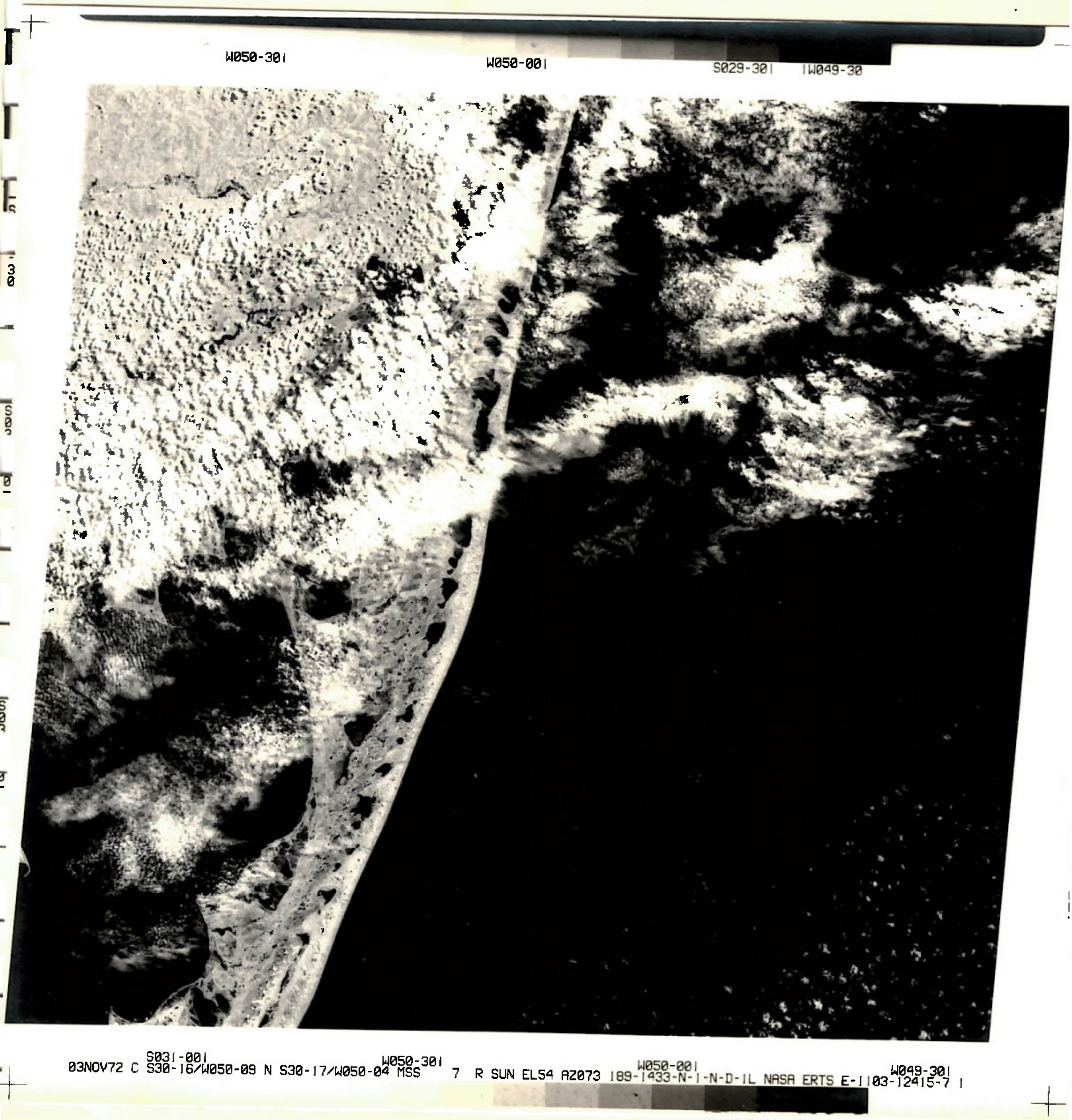


Fig. II.6 - Image E-1103-12.415/7 scale 1:1,000,000; overlay C7. Note that in this channel the lakes are very well defined.

In the analysis of the section from Banco da Berta to the Lagoa do Sumidouro, it is observed that the channel 4, 5 and 6 images clearly separate the older sand formations from the more recent ones (C5). The coastal line is constituted of holocenic sands accumulated by local marine processes (currents, waves, tides, etc.) and later moved by eolian processes which transport these sediments to the interior (channel 5).

The further to the interior plain is of pleistocenic origin and is constituted of compact sand and covered by gramineous vegetation and shrub species. This part actually receives sediments by eolian transport from the coastal zone, following NE orientation and without creating dunes.

The coastal sediments probably come from the south, from the contribution of the Bacia do Rio da Prata, where sedimentary debris is taken in the direction N by the currents. All of the coastal sediments are intermittently moved, going a long distance in their course.

The statistical distribution of the winds in the area (according to studies made by the DHN) indicates that the predominant wind is from the NE (Fig. II.7) which is responsible (Bigarella - 1972) for the distribution of the sediments, as can be observed in the images by means of morphological interpretation.

Before finishing this interpretation section it is important to discuss a little more about the regional hydro/oceanographic problems.

Fig. II.7 - Partial detail of aerial navigation chart USAF-ONEQ-28, scale 1:1,000,000 and predominant direction of displaced coastal dunes in the South of Brazil.

The NIMBUS and APOLLO 8 images (Fig. II.8) offer elements indicative to hydrological distribution of various water masses in lagoons, rivers and coastal zones. The material examined from NIMBUS III presented a series of facts related to temperature differences in fluvial and oceanic waters. As an example of thermal contrast we can add, by means of observation of repetitive images of the same satellite, the evolution of behavior of the hydric balance of the flooded plain of the Paranã and Paraguai Rivers (10 July, 29 July, 11 October, 26 October and 14 November 1969). The simple observation of this fact permitted the seasonal evaluation of fluvial water volume increase in the Prata River basin from June to November (Fig. II.9).

It is concluded that as this water of continental origin is drained through the Prata River basin, there is an increase in fluvial contribution of fluvial oceanic water. Since this is not clearly perceptible in the ERTS-1 images, we conclude that the difference in coloration between the two types of water could be also perfectly detected in the visible region of the ERTS-1 spectrum (channel 5). Naturally, the ERTS potentiality in channels 6 and 7 provide sufficient elements for identification of continental hydrological cycles in evolution due to the capacity to clearly detect continental water reserves on the surface.

The NIMBUS IV images (29 April, 9 July, 25 September, 14 October, 4 November, 19 December 1970, 5 January and 9 January 1971) provide elements for interpretation of fluctuations of thermal contrast

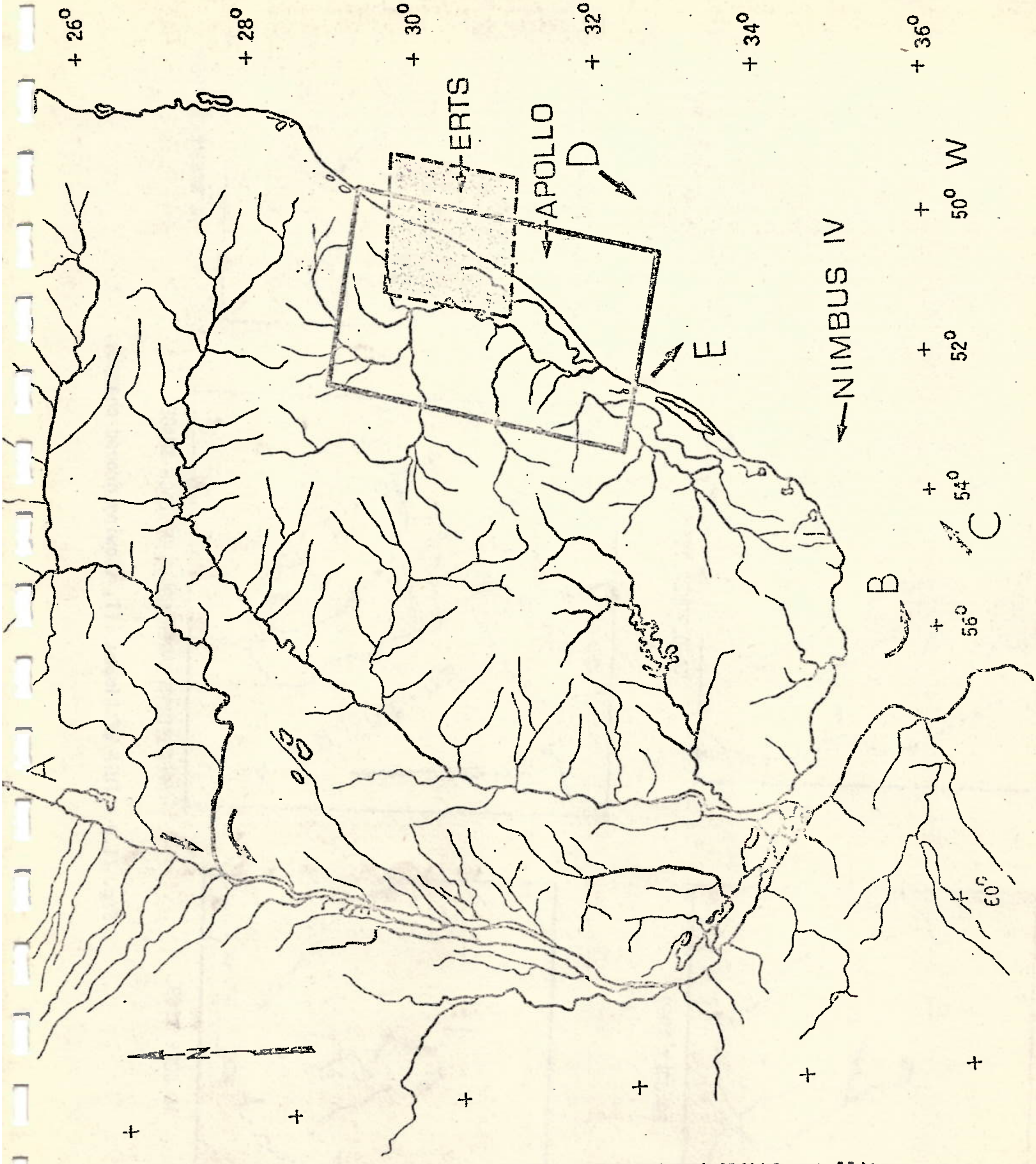


Fig. II.8 - Areas covered by ERTS, NIMBUS IV and APOLLO satellites, corresponding to the coastal region of Rio Grande do Sul.

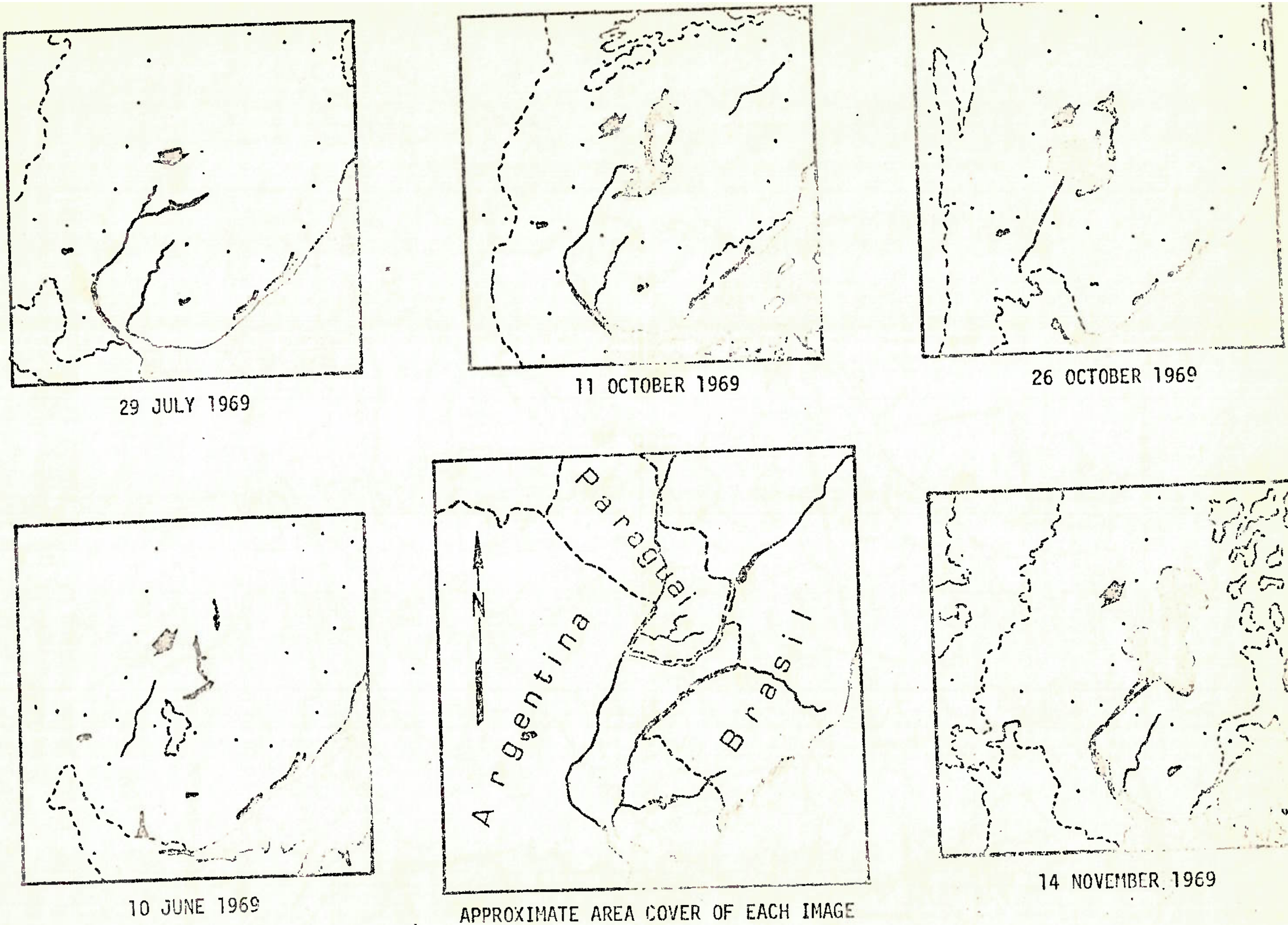
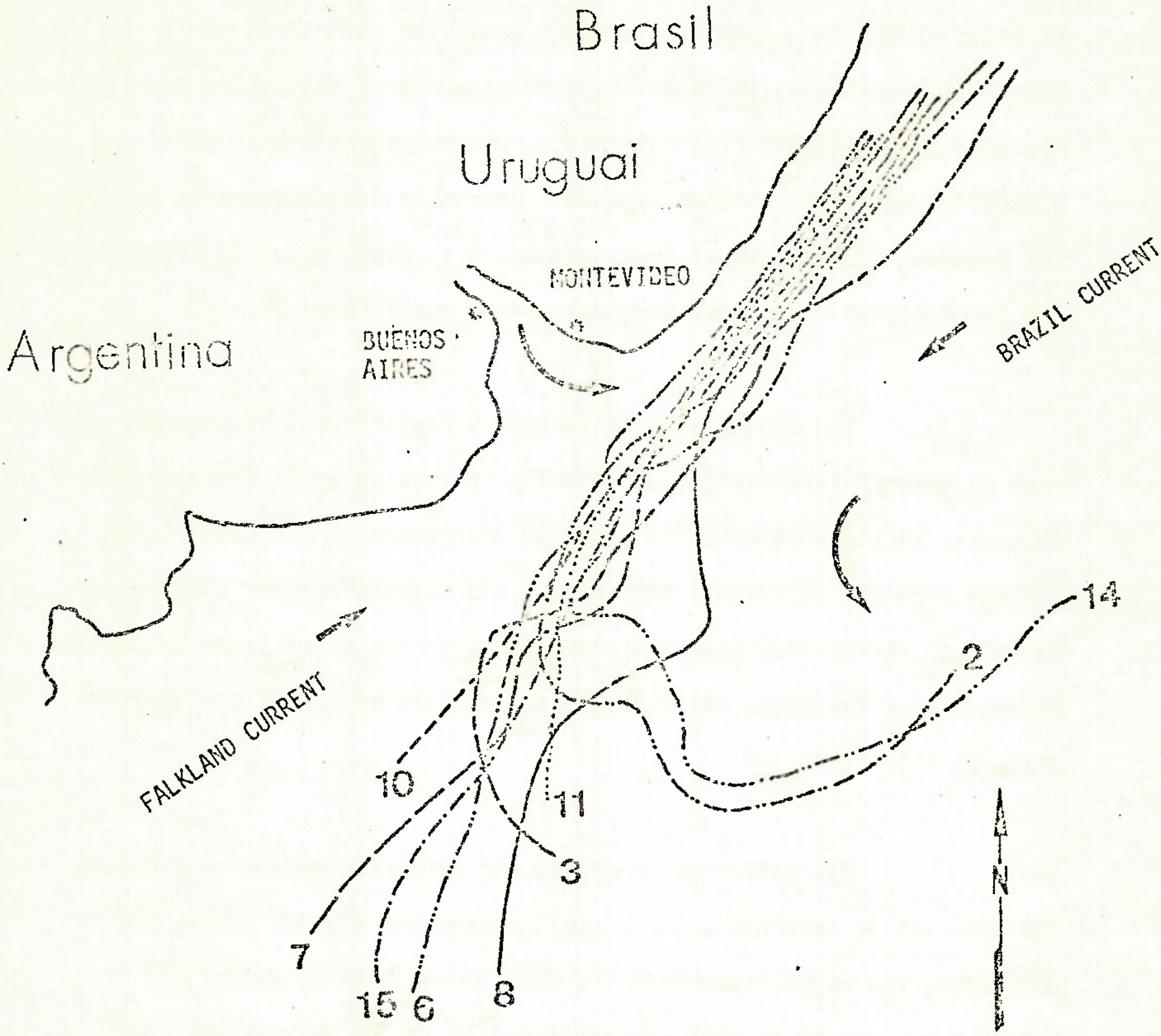


Fig. II.9 - THIR of Nimbus III, showing ground changes.

of water at the Prata Outfall and coastal zone. The channels 4 and 5 eventually could contribute in the knowledgement of this phenomena since the waters are of different coloration, as the waters are of polar and equatorial origin in contact with well characterized material in suspension. The seasonal fluctuation of these phenomena is fundamental in reference to the distribution study over the continental shelf (Fig. II.10).

The photographs collected by the APOLLO 8 Mission are very rich in general information, principally in showing ample coverage of elements. What can be noted is of great importance in the conclusions derived from the more ample coverage of the mosaic from the ERTS images, as well as the various elements represented in the colorations of coastal waters and of the Lagoa dos Patos in the visible region of the spectrum (Fig. II.11).

The different contrasts and different colors of sediment and material in suspension in coastal, lagoon and fluvial waters are sufficient for us to state that the ERTS images totally detect the referred to phenomenon with extraordinary selective definition. The detection of these contrasts in color and tone by repetitive ERTS-MSS images gives the investigator the opportunity to observe the dynamics of the water and sediment in suspension, using the concentrations like natural tracers.



NIMBUS IV THIR

2: APRIL 29, 1970
3: JULY 9, 1970
6: SEPT. 25, 1970
7: OCT. 14, 1970
8: OCT. 24, 1970
10: NOV. 4, 1970
11: JAN. 5, 1971
14: DEC. 19, 1970
15: JAN. 9, 1971

Fig.II.10 - Systematic Analysis including images of NIMBUS IV THIR (11.5μ) showing approximate limits of Brazilian current according Tseng Yun Chi (1974).

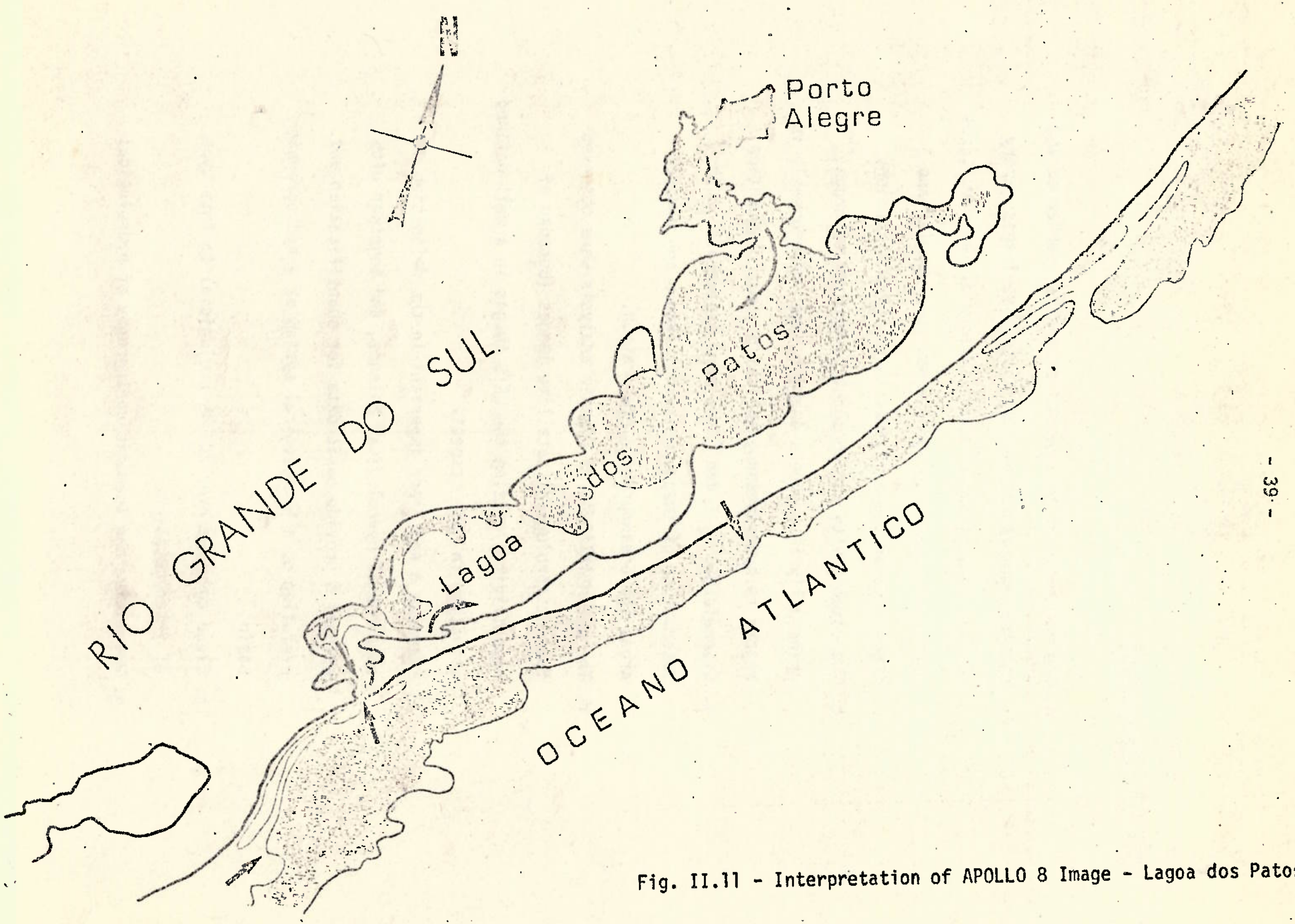


Fig. II.11 - Interpretation of APOLLO 8 Image - Lagoa dos Patos.

II.2.4.3 - Conclusions

a. The geography of the coastal sediments, submerged and emerged, can be followed by successive images (every 18 days). The seasonal modifications of the structures which were identified could show an evolution and importance of the phenomena in the area of ecology.

b. The repetitivity and consecutive orbital coverage, principally in channels 4 and 5, are indispensable in regard to hydro/oceanographical dynamic observation.

c. Channels MSS 4, 5 and 6 are more applicable in the observation of images regarding lagoon and coastal areas for oceanographic elaboration.

d. The potentialities of dynamic analysis were observed from meteorological satellite images (because of repetitivity) putting the ERTS images in a well defined situation in this respect.

e. Channels 6 and 7 are important in the definition of continental hydrological balance, and together with channel 5 provide basic data for quantification and evolution of a hydrological system of a hydrographic basin.

f. Cloud coverage over 30% is prejudicial to this type of interpretation.

g. Repetitive and thematic cartography of hydrological and oceanographical factors is fundamental in dynamic interpretation of interaction of ecosystem components.

h. The images analyzed clearly show that it is possible to accompany coastal, lagoon and fluvial geo-dynamic evolution.

i. Elements identified in the Lagoa dos Patos show the potentiality of images in the study of pollution in critical areas (Guaíba River).

j. The field work for prospection of key elements is of fundamental importance for the establishment of interpretation and analysis criteria aimed at greater depth of study.

II.2.5 - Lagoa dos Patos

II.2.5.1 - Introduction

The received ERTS-1 images for the area under study, were the first ones acquired by the Brazilian Recording and Reception Station, located at Cuiabá (Mato Grosso State), Brazil. From these images it was selected three consecutive images in four multispectral channels.

As could be noted, they are images of excellent quality, thus permitting a detailed study about the coastal plain of Rio Grande do Sul.

From the analysis to be presented in the following step, a first visual notion will appear of the interaction processes between lagoon and coastal waters, through the narrow bar of Rio Grande . The repetitivity of the ERTS-1 Satellite will permit the continuation of this kind of analysis, creating this way a new concept of the behavior of the lagoon water surface.

The inside and coastal waters distribution, the sediments transport distribution and the trends in the present deposits evolution will be associated to this observation.

The slope drainage covering 168.000 km^2 contributes to the identification of a differential behavior in rivers regime and of the proper lagoon adjacent to the sea, whose debit is always suffering the wind and tide different conditions, and rain precipitation whose reflection are identifiable in the multispectral images of ERTS-1.

II.2.5.2 - Interpretation

Initially, a non-controlled photo-mosaic of three consecutive MSS-7 images was composed (Fig. II.12). This mounting permits at a time the observation of a large portion of Rio Grande do Sul coast. Due to the definition of the contours (MSS-7) and detailed resolution it is of great utility for hydrographic works because of the large coverage in each unit.

Fig. II.12 - Reduced Photomosaic, channel MSS-7 - Lagoa dos Patos, in June 1973.

The morphology of the edge and the details of the sedimentary structures of fluvial-lacustrine origin are well defined in this band of the spectrum.

The correlation of the quaternary structures shown on MSS-7 with the information obtained from the MSS-5 and MSS-6 may establish criteria for the behavior of the ascents of erosion and deposition in function of the present processes.

Generally, the coastal sandy plain which separates the lagoon from the ocean is considered as a large emersed sandy barrier subject to the action of marine processes on the one side and lacustrine ones on the other. In addition to that the winds contribute to the rehandling of the sedimentary material deposited giving rise subsequently to dunes through eolic processes, pre and post pliocenic.

In order to understand the true environmental system conditions it is necessary to conclude that the landscape dominating the coast of the State of Rio Grande do Sul resulted from the interaction of marine, lacustrine and eolic agents during the recent geological periods.

The Patos lagoon is connected with the ocean through Rio Grande Canal, and its present geographical conformation is defined by an estuarine system which receives more than the half of all the debt of the whole hydrographic net of the State.

The bathymetry of this lagoon presents depths which vary up to a maximum of 8 meters. The shallower portions are between 0.50 to 1.00 m and the deeper ones from 7.00 to 8.00 m; though near Rio Grande Canal depths up to 15.00m are encountered (Fig. II.13).

The basin circunscribed by the Patos lagoon covers about 11000 km^2. Its major axis is distributed over an extension of 250 km, from NNE to SSE,. presenting a maximum width of 60 km (Fig. II.14).

The oceanic tides which influences the lagoon regime are of the diurnal kind and reach values of up to 0.47m in near Rio Grande bar.

In addition to the regimes of tides, the seasonal variation of the regime of the fluvial basins which unload its water and which are subjected to different pluviometric regime should be considered. The debt of the rivers provokes the developing of streams in the interior of the lagoon modifying the circulation caused by the action of the winds on the surface of the water.

The regional winds contribute quite a lot for the dynamic manifestation of the waters in the interior of the lagoon in function of its banks as well as of its bathymetry.

The frequency and intensity of the winds acting on the

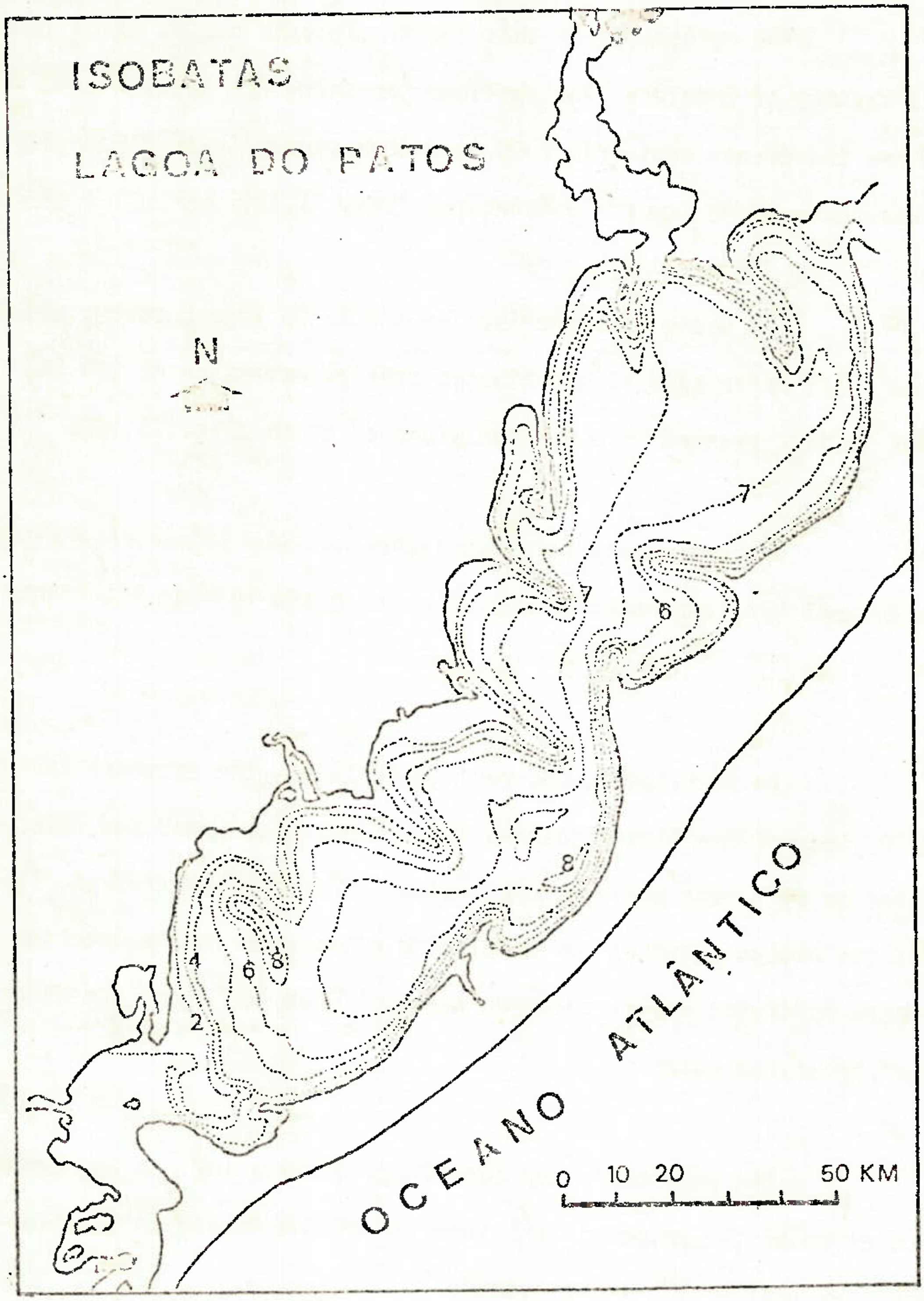
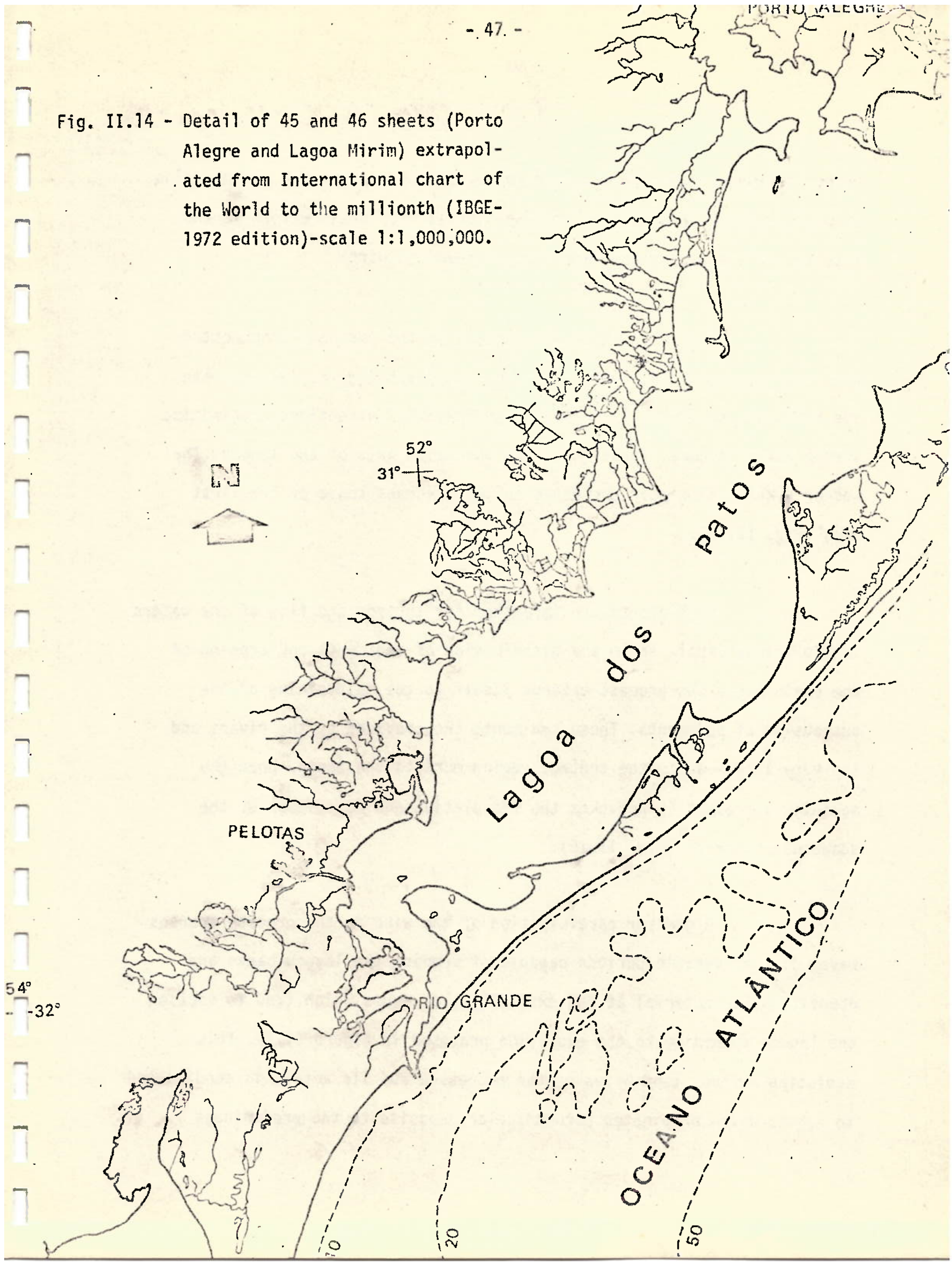


Fig. II.13 - Isobath - Lagoa dos Patos.

Fig. II.14 - Detail of 45 and 46 sheets (Porto Alegre and Lagoa Mirim) extrapolated from International chart of the World to the millionth (IBGE-1972 edition)-scale 1:1,000,000.



waters influence not only the propagation of the streams but provoke also an unequilibrium of the normal surface levels from those waters in the interior of the basin; they are truly "tides" of wind.

The very origin of sandbank in the lagoons is connected with the regimen of the regional winds. Its morphology is related with the fact that the winds blow towards preferential directions originating strong axial streams. These determine the major axis of the lagoons.The weaker streams flow near the banks in the reversed sense of the first ones (Fig. II.15).

Such events are important for the ebb and flow of the waters in Rio Grande Canal. As to the distribution of sediments and erosion of the basin banks the process extends itself to the maintaining of the suspension of sediments. These sediments are provided by the rivers and the very lagoon up to the contact region more to the South. When the salinity increases it provokes the floculation and deposition of the suspended material (Fig. II.16).

A greater participation of the wind in the process courses waves of considerable periods capable of eroding the lagoon banks and depositing the material at the extremities of spurs which tend to section the lagoon according to the evolution proposed in figure II.15. This evolution defines tendencies of the processes and its action is conditioned to agents which originates perpendicular deposits to the predominant

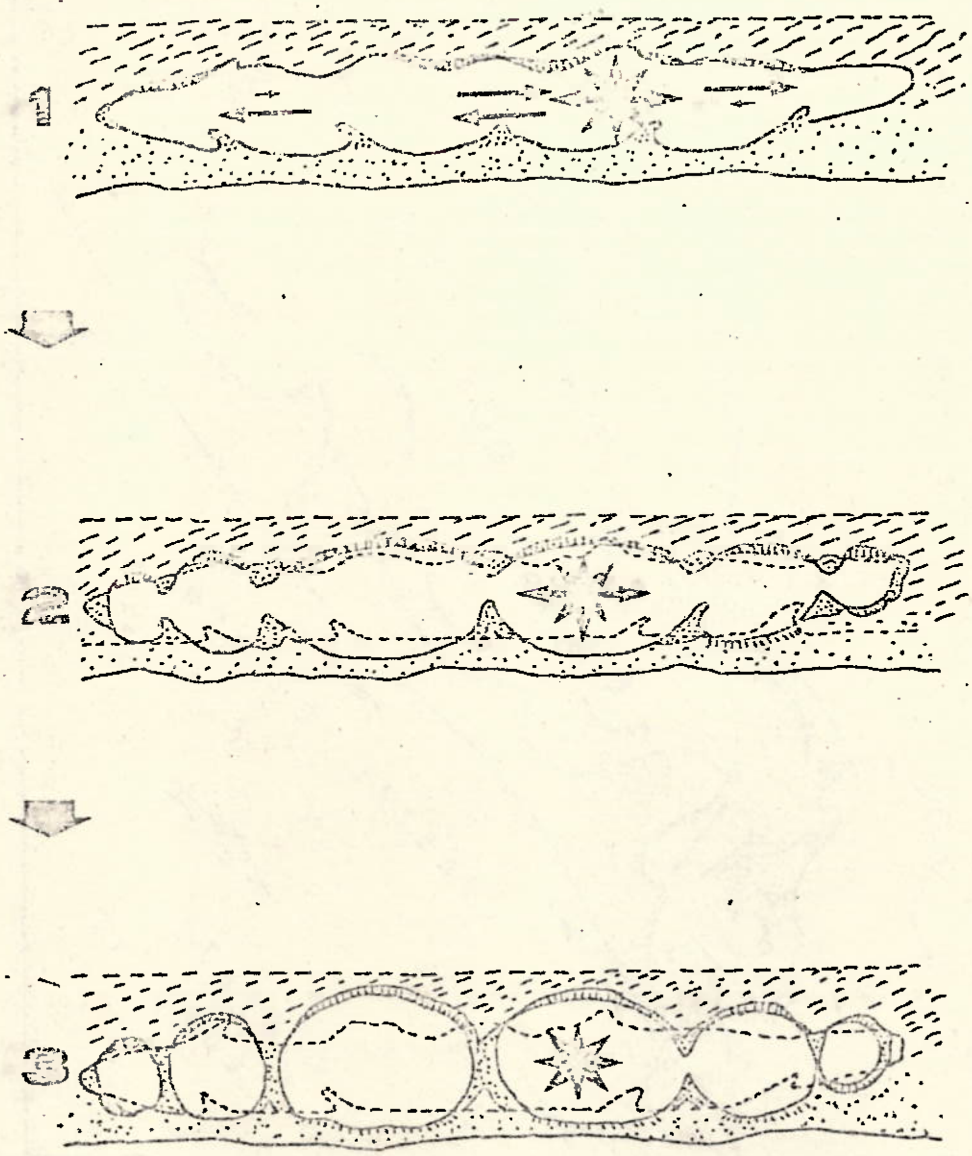


Fig. II.15 - Scheme of coastal lagoons morphologic evolution, associated to the sandbanks formation, according Zenkovitch (1967).

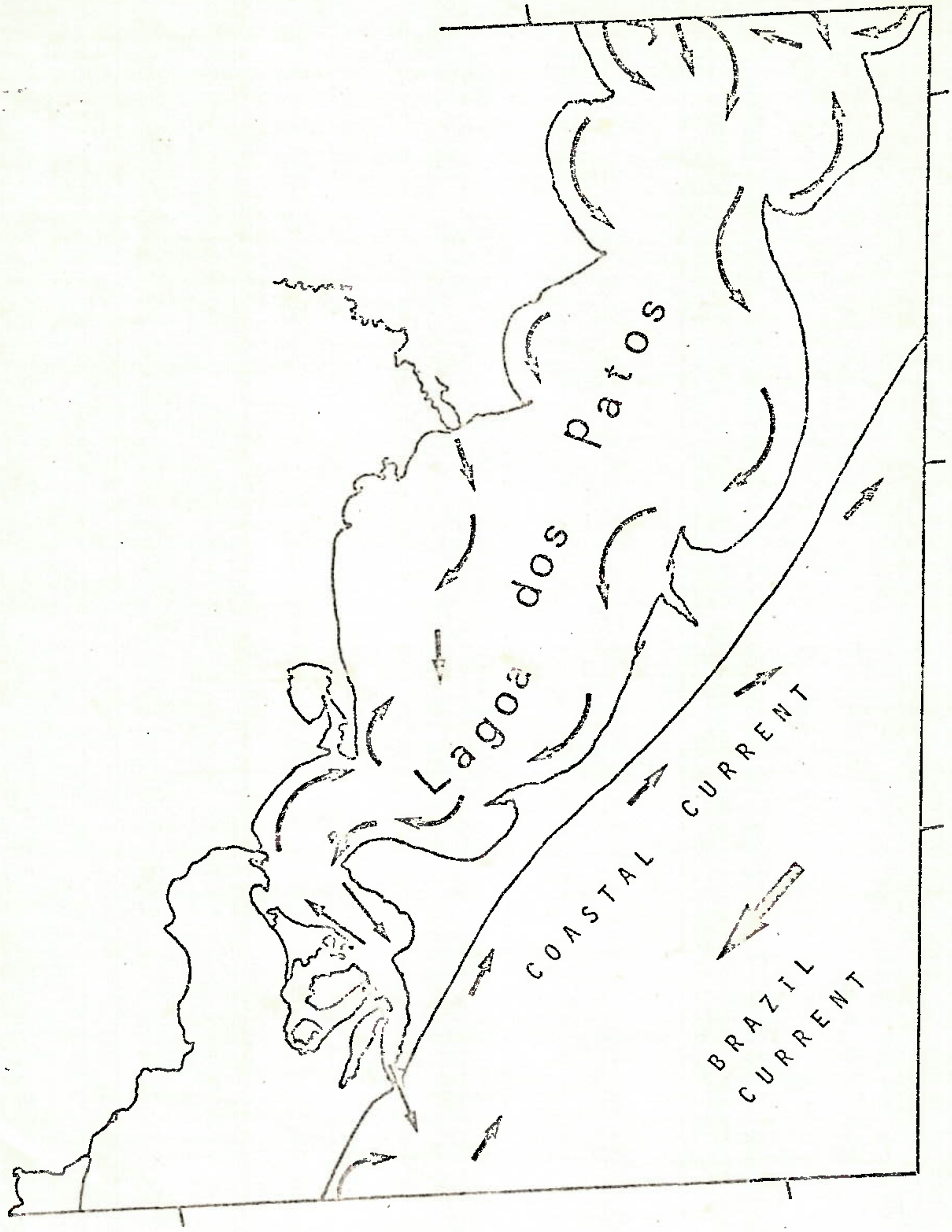


Fig. II.16 - Surface currents distribution in Lagoa dos Patos. After Delaney, 1965.

orientation of the wind over the lagoon.

The definition of the present morphology of the coast is due to the fact that the waves performing a very important role between the erosion and deposition are ruled by the local winds. These winds originate coastal streams which move generally towards NNE.

The above is confirmed by observing the images MSS-5 and MSS-6.

The nautical chart of the Diretoria de Hidrografia e Navegação (Brazilian Naval Hydrographical Office - DHN) number 2140 (Fig.II.17) comprises all the lagoon with bathymetric details in a scale of 1:271.600. From this base it was done a hypsometric chart which divides into nine hypsometrical classes with the following zones:

from	0	to	1	meter
"	1	"	2	meters
"	3	"	4	"
"	4	"	5	"
"	5	"	6	"
"	6	"	7	"
"	7	"	8	"

above 8 meters.

A spatial distribution chart from these intervals is shown in figure II.13. Besides this it was organized a series of vertical profiles about the same chart obtaining in this way a new document of great utility to the inter-

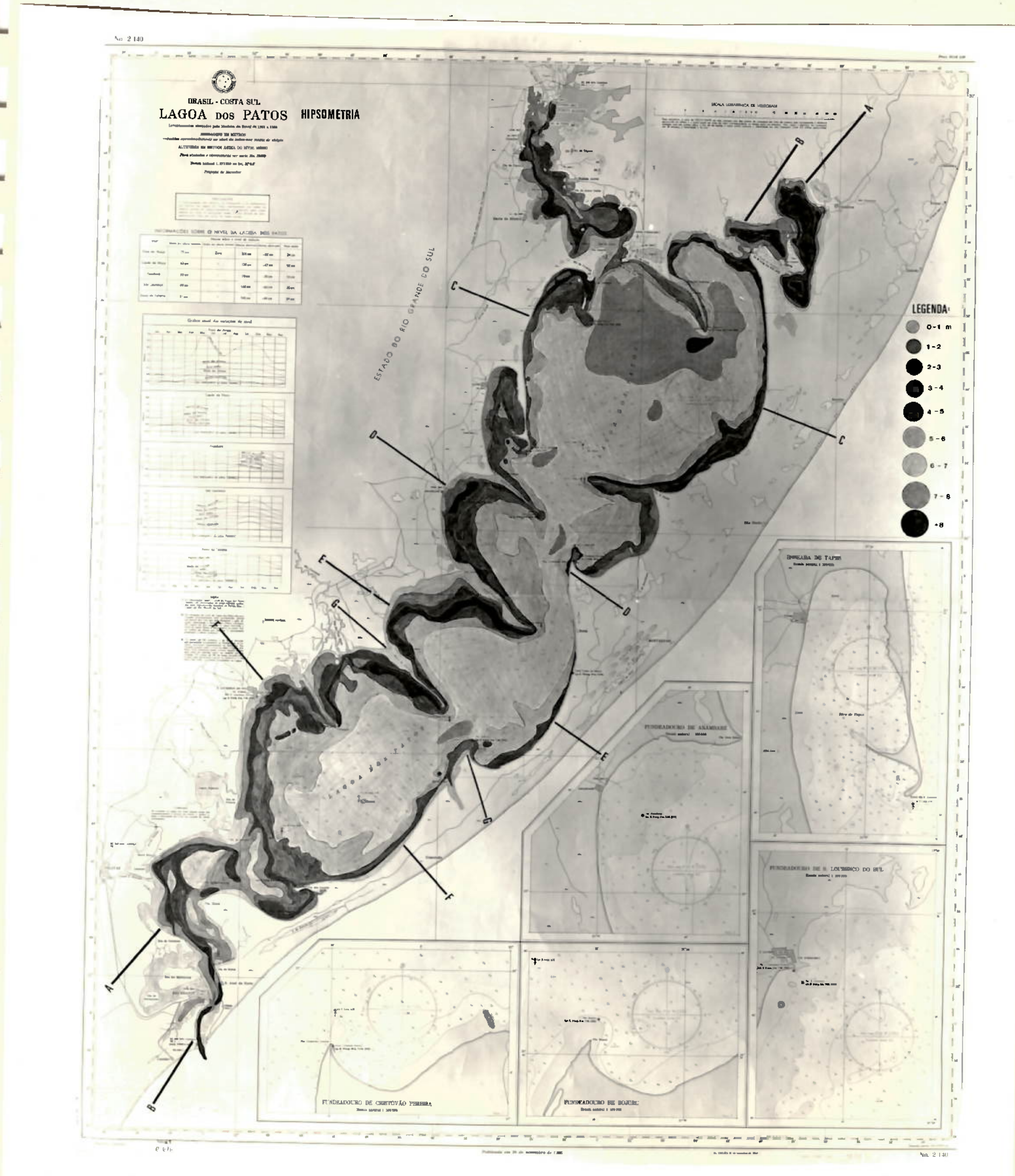


Fig. II.17 - Bathy-hipsometric map of Lagoa dos Patos, indicating the vertical profile orientation (DHN Nº 2140).

pretation of circulation trends proposed in function of images observation.

The different gray tone levels of the contrast registered by the ERTS images over the lagoon surface waters, permit us to schematically interpret the surface circulation distribution in several lagoon points (Fig. II.18).

Also it should be said that, besides the wind and tides, the basin form is specially responsible for the spatial distribution of that surface circulation.

Thus the ellaborated longitudinal profiles (AA, BB) (Fig. II.17) permit us to say that the five sedimentary spurs, immersed on the ocidental lagoon margin, and just one on into open cells, where the dynamics of the waters are maintained according to the deep basin morphollogical trend (Fig. II.19).

Four vertical profiles (CC, DD, EE, FF), figure II.17, show that some of these nucleous are linked by narrow subterranean passage, as observed in the GE profile. Another fact that should be observed is that the spatial distribution of the deeper zones is more frequent on the oriental margin where the waters flow from one cell to the other. The spatial distribution of the shallower zones is more frequent on the ocidental margin, where the resultant circulation maintain a clock-wise vortex direction.

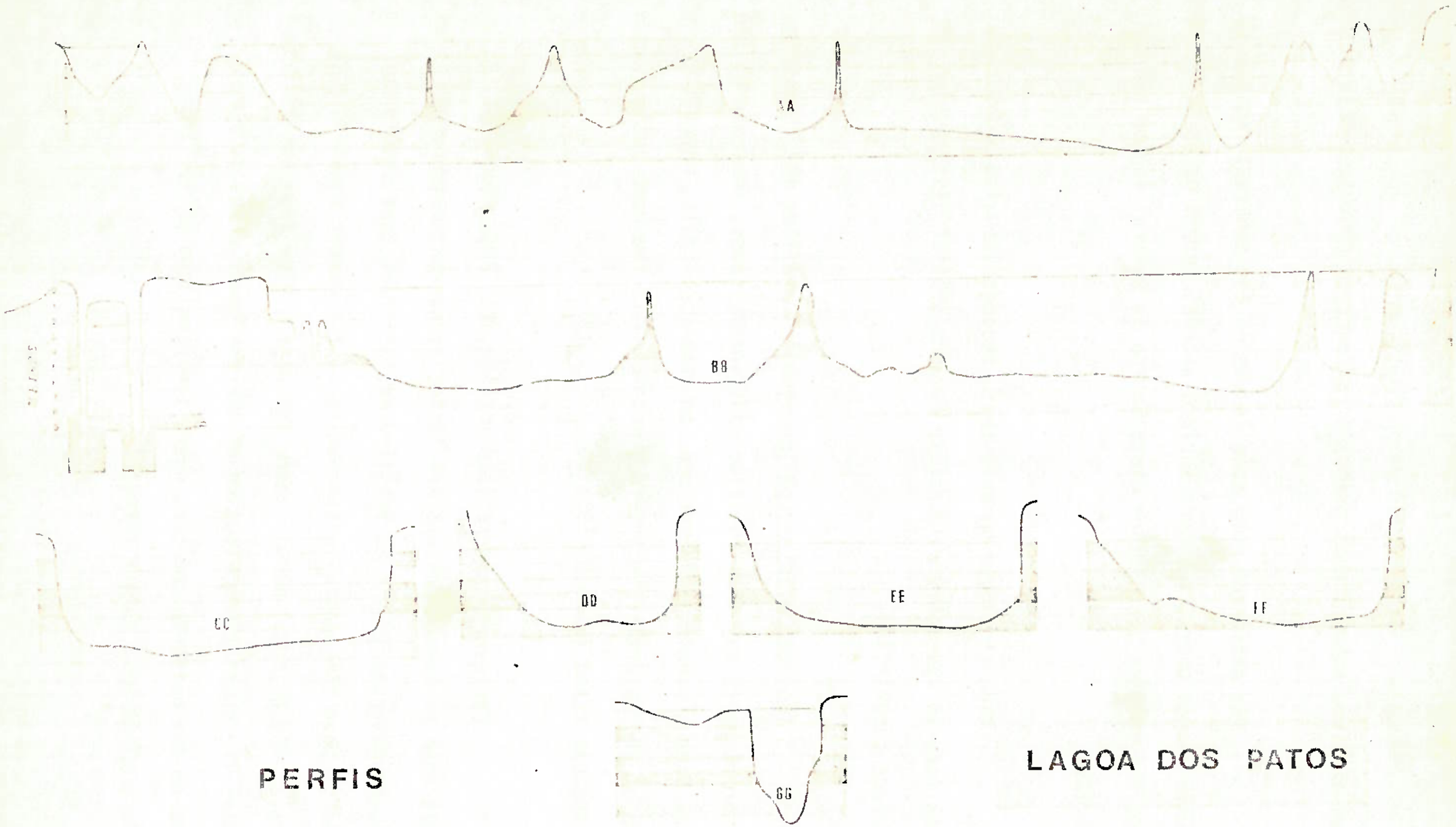


Fig. II.18 - Diagram of vertical profile ellaborated over the DHN chart nº 2140.

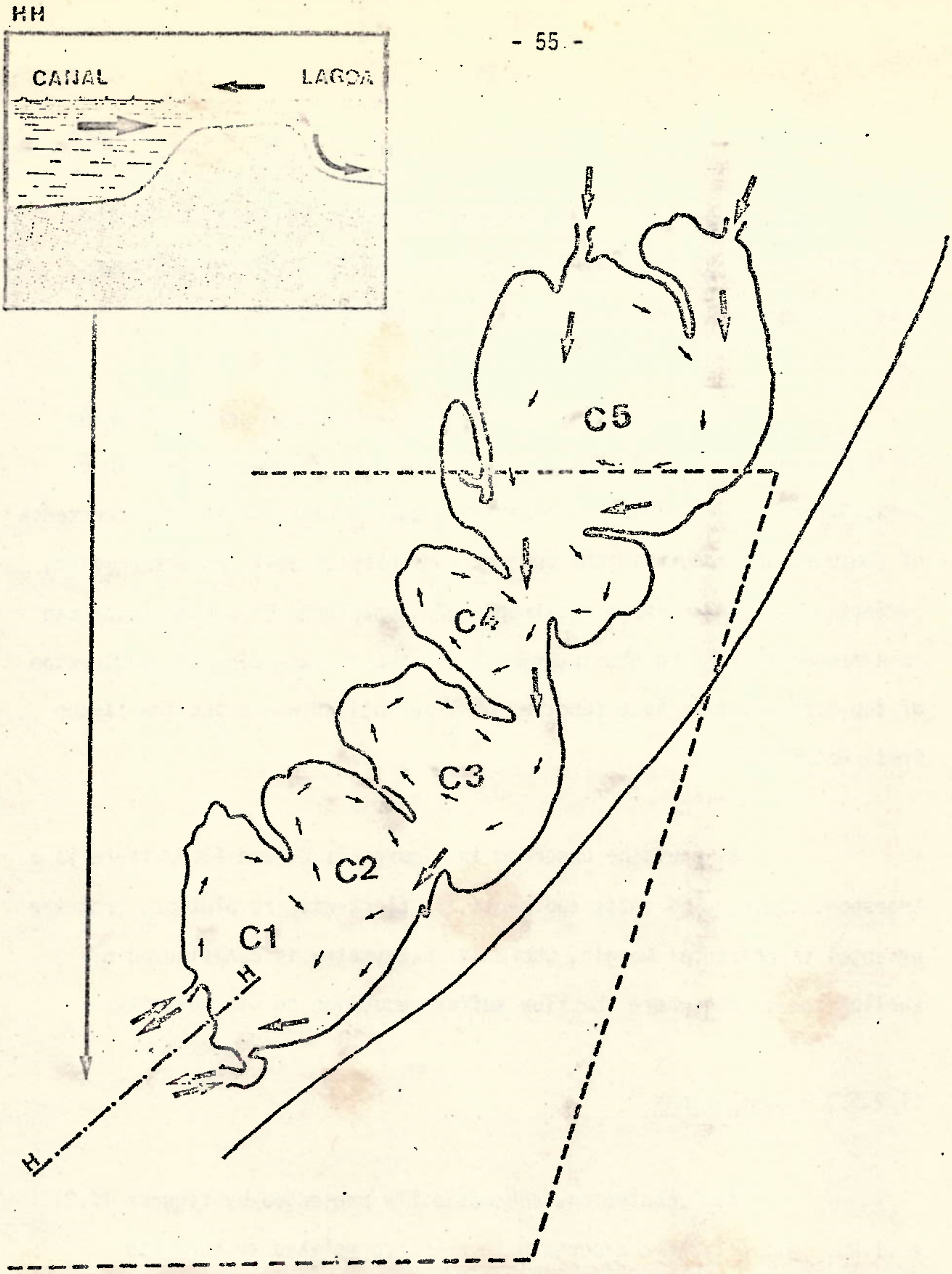


Fig. II.19 - Schematic outline of the internal circulation cells in Lagoa dos Patos Basin.

The continental dedritus furnished by the river of the ocidental margin possibly are also responsible for dedritus increase, which are deposited there, giving to it a smooth aspect.

The entering of the Rio Grande bar canal attains depths of 15 m. In the lagoon interior (Ponta Rasa), it is observed shallower zones, where clay sediments deposition should appear due to the occurrence of floculation process in the contact zone between salt and fresh water, perfectly visible on image obtained in 26 June 1973. This phenomenon can be extended further to the interior of the basin depending on penetration of the marine waters as a function of tides height winds and the lagoon fresh water content.

As could be observed in figures II.21 and II.23 there is a transport tendency of these sediments, in clock-wise revolution, from the oriental to ocidental margin, where the bathymetry is constituted of shallow zones, and where the flux suffer reduction on its velocity.

II.2.5.3 - Conclusions

The conclusions schematically presented by figures II.21 e II.23, initially have a certain incoherence related to currents distribution in the interior of the lagoon. See the image for June 26/73. It is necessary to consider that there are two distinct interpretations and the one of channel 6 is related to the surface. Channel 5 furnishes

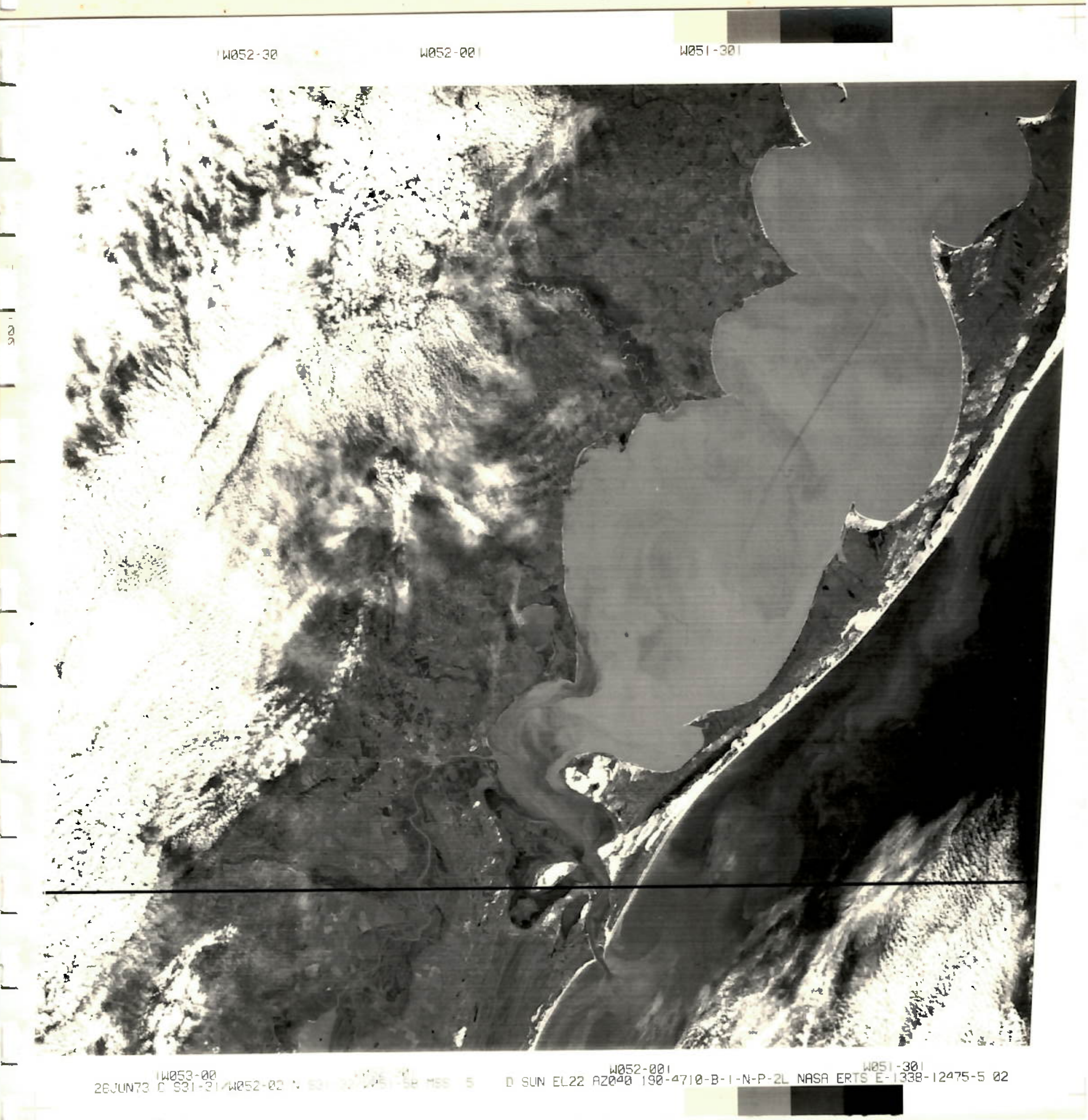


Fig. II.20 - Image E-1338-12.475 - channel MSS-5, 26 June 1973, received by Brazilian Recording and Reception Station located in Cuiabá (Mato Grosso), scale 1:1,000,000.

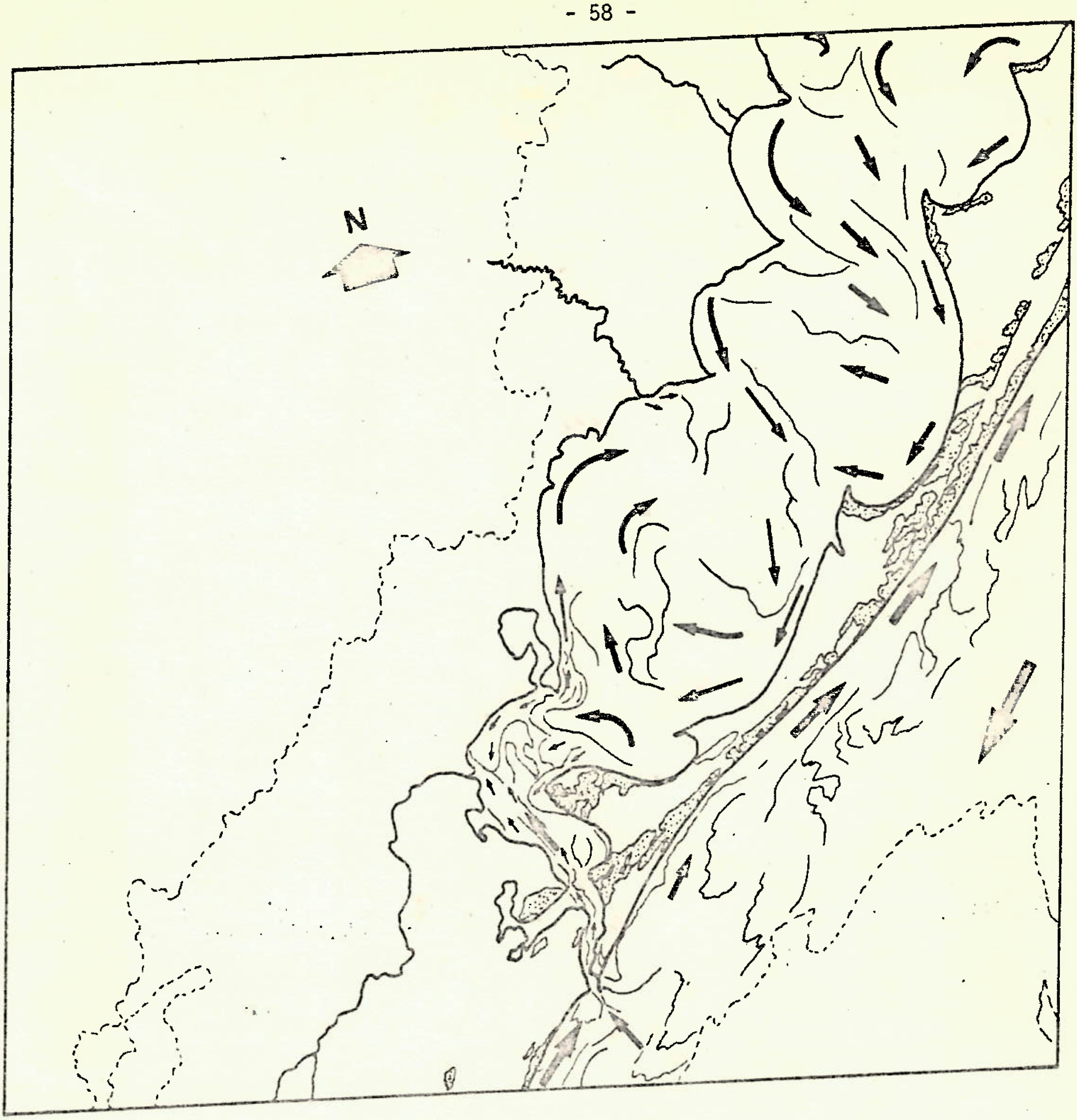
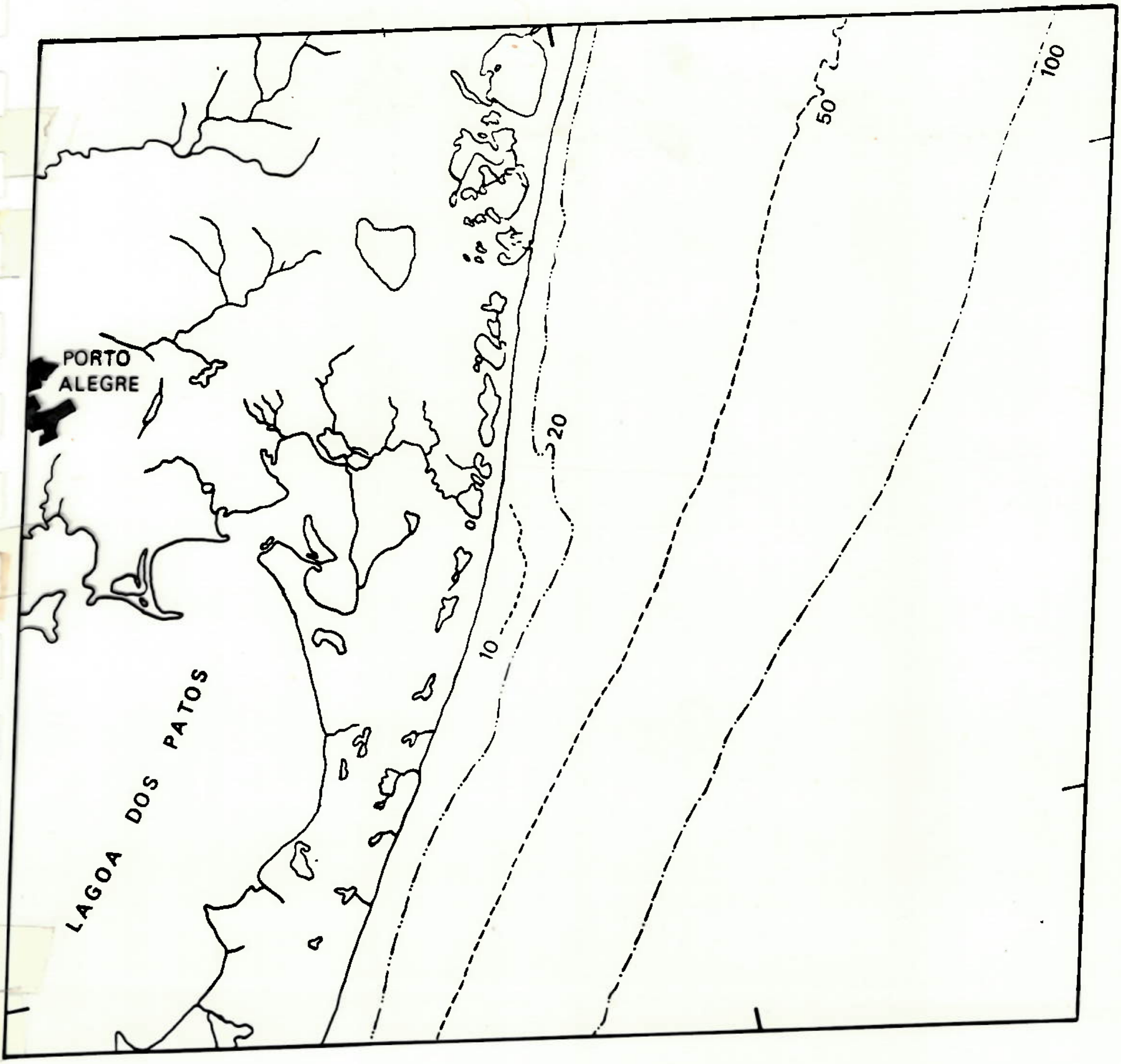


Fig. II.21 - Surface waters distribution and circulation in Lagoa dos Patos, proposed by interpretation of E-1338-12.475 image, channel MSS-5, in 26 June 1973.



PORTO ALEGRE
LAGOA DOS PATOS
10
20
50
100

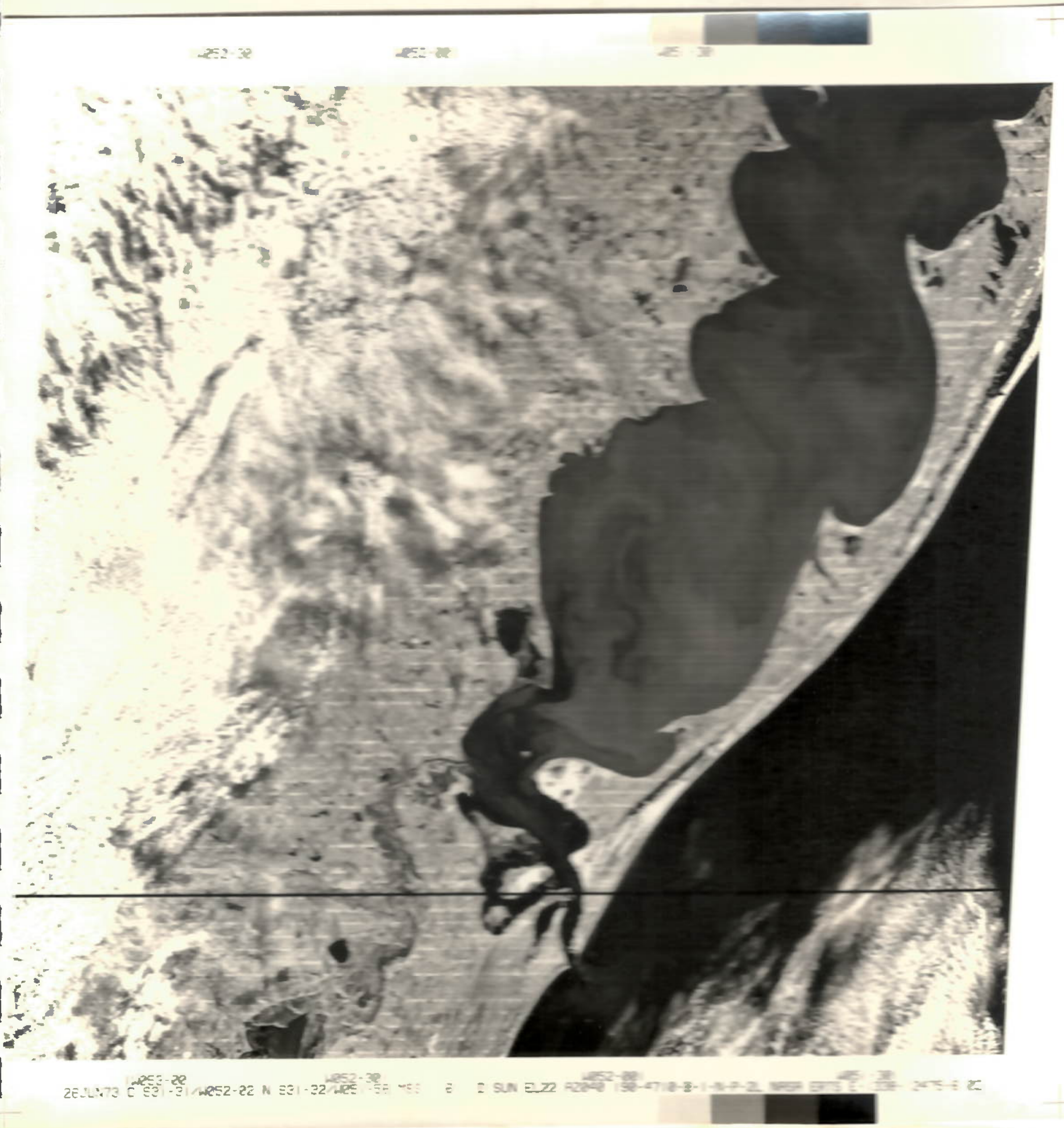


Fig. II.22 - Image E-1338-12475, channel MSS-6, 26 June 1973, received by the Station located in Cuiabá (Mato Grosso) - scale: 1:1,000,000.

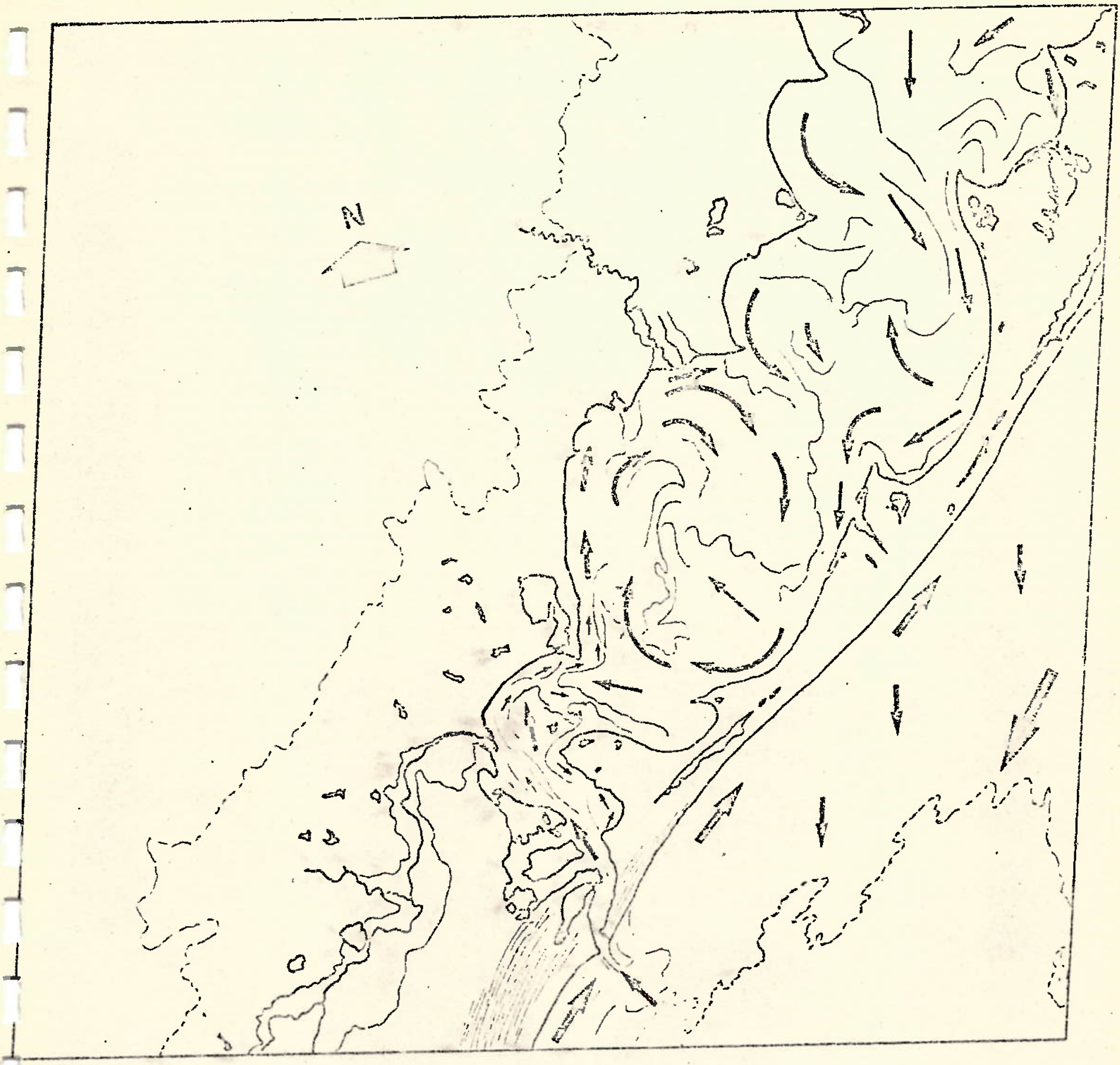


Fig. II.23 - Surface waters distribution and circulation in Lagoa dos Patos, proposed by interpretation of E-1338-12.475 image channel MSS-6, in 26 June 1973.

other details according to water transparencies in each point. To precisely determine the distribution level, according to forms or tendencies presented in the images, it would be necessary the simultaneous acquisition of groundtruth, collecting transparency data, light penetration and solid content.

Comparing figures II.21 and II.23 with figure II.13 it is possible to observe that the mentioned currents distribution mapping could not be generalized. It must be referred to each moment with the maximum available environmental information. This will permit, from the interpretation of a large number of data, the ellaboration of seasonal maps of general tendencies, or anomalous specific conditions.

With the margin gray tones analysis it is perfectly possible to say that the mixing zones could happen at the surface, as well as in depth. This permit the marine water subsidence, denser in the lagoon gate, to emerge again later on, due to consjdered cells of ciclonal circulation moviment. The tendency is to silt up the basin .

II.3 - SOUTHEAST COAST OF BRAZIL PROJECT

Test Site Area 826 - Rio de Janeiro and Espírito Santo States and Offshore

II.3.1 - Description of the Test Area

From Cabo Frio up to the Guanabara Bay, covering an extension of about 63 miles, the coast goes in the East-West direction. The currents, with a SE wind, flow towards the coast. However when the NE winds are predominant, there is a westerly current along the coast. Immediately at the South of Cabo Frio a counter-current is formed reaching the coast and which is perceived up to 10 miles West of Cabo Frio. The great number of maritime accidents occurred in this place, attributable to the counter-current, seems to indicate that it becomes stronger in September and December, principally in the latter month.

The Guanabara Bay is one of the most protected Bays in the world. It expands to the North about 16 miles. In the bar it has about one mile and the width goes increasing to the bottom where 15 miles is found in the WSW-ENE direction. This bay is covered all over by several islands and small islands and walled by high mountains which go down in smooth declivity to the sea. Its margins are outlined by several beaches separated one from the other by less prominent points covered by vegetation. Many rivers drain in this Bay interior. In its West margin appears the Rio de Janeiro city and to the East the Niteroi city.

II.3.2 - Area Selection Justification

The Guanabara Bay is presently one of the most polluted places of the Brazilian coast. This pollution is originated from many sources as: industrial, organic, sewage and that resulting from dock activities.Related to its importance this Bay requires a detailed study utilizing orbital images and radiometric measurements done in this place.

In the East coast the predominant wind is the Northeast, virtually parallel to the coast, the dominion is almost total (from Northeast to East) in Cabo Frio region. This way, the water contiguous to the coast are thrown to the ocean center in an equal thickness (in meters) of 4,3 times the wind velocity (in knots). (For example, for a 15 knots wind, 65 meters). The waters distant of the ocean center are substituted by profound waters which emerge to the platform by the slope, phenomenon called upwelling. The study of this phenomenon in Cabo Frio will permit to extrapolate it for other areas of the Brazilian coast where it occurs.

II.3.3 - Objectives of the Project

1. Obtain meteorological data in order to correct the radiometric measurements.
2. Study of the surface oceanographic conditions by means of thermal contrasts. The surface temperature structure will provide oceanographic information to the fisheries biologist, giving him time variation of the marine environment and also the areas where fishes can be detected.

3. Localization of the Brazil Current limits. This knowledge of the current with a seasonal basis of its strength, will provide to the commercial vessels, the most economical ways for their activities.
4. Reconnaissance of areas of upwelling discernible by color changes of offshore water.
5. Studies of coastal sedimentary environments including two major deltas (Rio Paraība and Rio Doce).

II.3.4 - Northeast Region of São Paulo State

II.3.4.1 - General Considerations

This part contains the analysis of four MSS images of the Northeast Region of São Paulo State, of 8 September 1972, 1227 hrs GMT, and received from NASA/GSFC by INPE.

From a preliminary analysis of the four images, the following details discussed bellow could be identified.

Comparing the image of channel 5 (Fig. II.25) with the nautical chart 1600 prepared by the Brazilian Navy Hydrographic Office (DHN) (Fig.II.24) it was observed that the beaches and their sedimentary deposits are visible in the foreground together with some bathymetric features, when the water transparency is adequate.

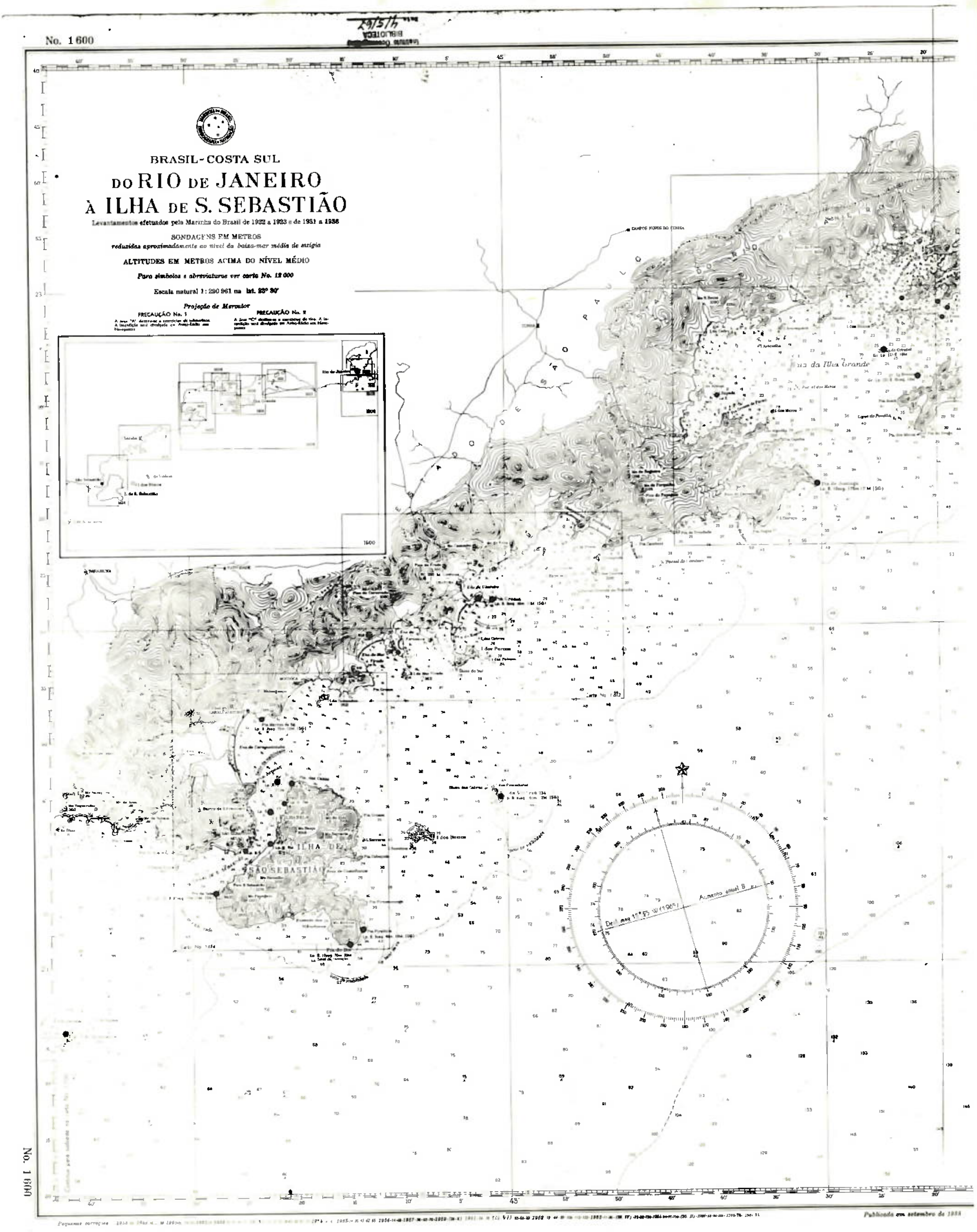


Fig. II.24 - Detail of Nautical Chart nº 1600, ellaborated by DHN (Brazilian Naval Hydrographic Office).

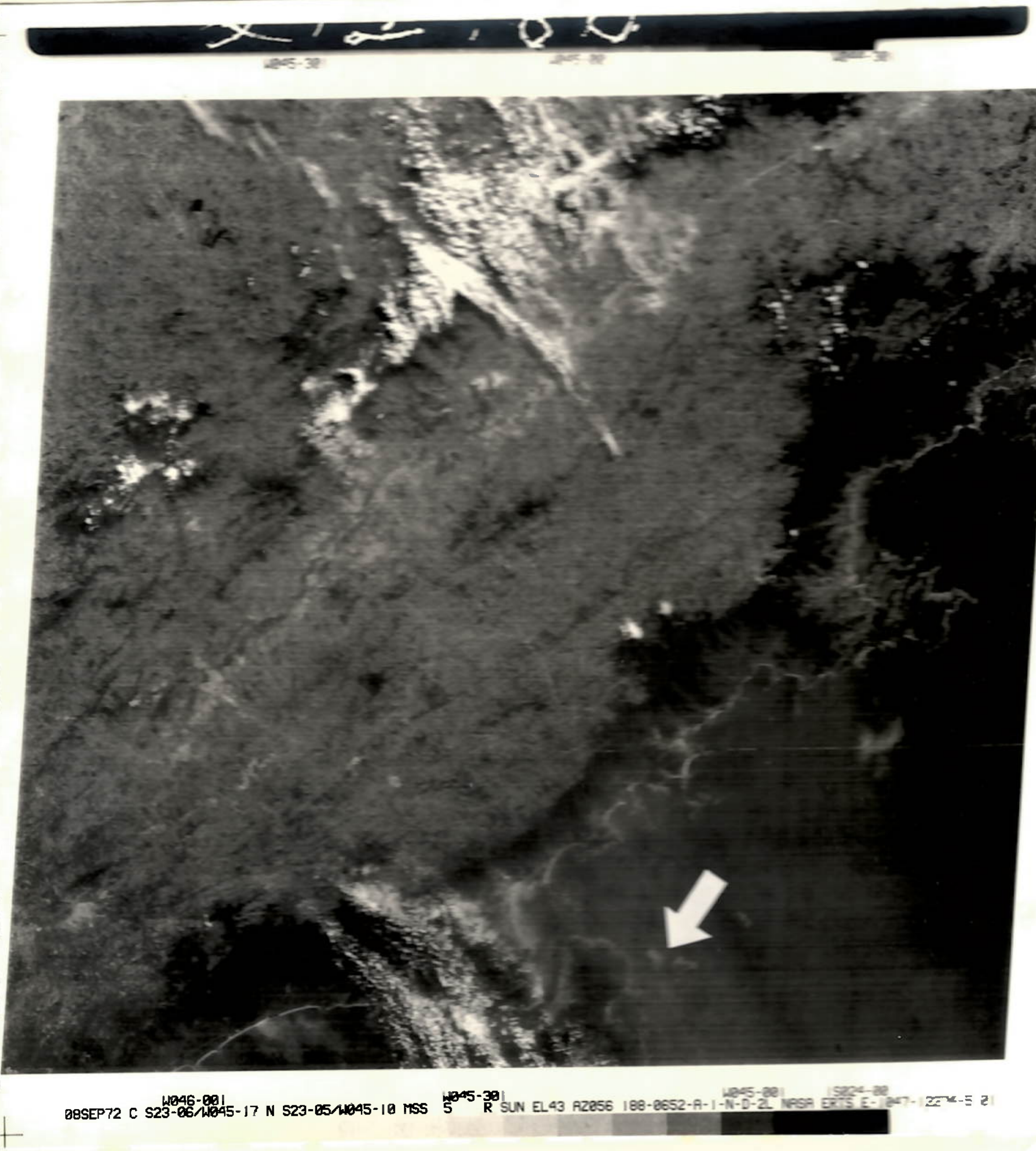


Fig. II.25 - Image E-1047-12274, channel MSS-5, obtained by ERTS-1 in 8 Sept., 1972.

The 10 m isobath to the NE of the São Sebastião Channel (Fig. II.25) is well characterized in front of the port, near Arpoar point. Further to the North, this isobath looses its distinctiveness with the suspended sediments coming from the bay of Caraguatatuba.

The images of channels 4 and 5 in the bay of Caraguatatuba have discolouration near the beach, which could induce to wrong interpretation with respect to bottom configuration. Channels 6 and 7 also have these discolourations.

It is possible to conclude that the variations in the gray shades of the images are associated with the distribution of suspended sediments because channel 7 gives information contained in the 1.0 cm surface layer only.

One should note here with this example, one of the advantages of MSS images, with one channel completing the information of the others.

With the nautical chart 1600, the existence of various rivers transporting water to the bay is demonstrated. Among these, the greatest is the Juquiariquerê river, bringing sediments (sand, silt and clay) which stay in suspension in the coastal water. The transport of these relatively small rivers are not enough to change normal conditons. But, in 1967 a regional outbalance of hydrological equilibrium was produced with entraining and slippery of the surface formations of the water sources of Serra do Mar, producing a great quantity of sediments and detritus taken to the bay. This phenomenon was probably of clay which appears in the images analyzed.

Similar facts are observed in smaller proportions in other bays such as that of Parati, in Ilha Grande Bay. The presence of a "slick" (see the arrow in Fig.II.25) to the East of Ilha São Sebastião, was also observed.

The "slick" mentioned above was found where the average depth is 40 m, which eliminates the possibility of a bottom irregularity or sediments. The image was registered with different intensities in the four channels and could be confused with a cloud or oil in the surface of the sea. The possibility of oil in the surface should be abandoned, because this has less specific gravity and therefore would stay in the surface and correspondingly it could not be detected in channels 4 and 5.

The possibility that the "slick" could be a cloud should not be taken into account, because of the geometric form and the experimental proof with the VIEWER I^2S, which is an image combiner giving the chromatic recomposition.

The false color image of the "slick" was also observed, which showed a pronounced red shade, corresponding to the green in its natural color. Besides, recent research done by the Oceanographic Institute of the University of São Paulo in agreement with INPE, demonstrated that the area under discussion is one of the most used by sardines for their "spawning" in the southern coast of Brazil.

The reproduction of this species (sardine) occurs in the period from September to April and when the temperature of water is 18^{0} to 24^{0}C and the salinity is 35.1‰ to 35.9‰ . The reproduction is accomplished between the surface and the thermocline and the dimensions of a sardine school in the period before reproduction is compatible with a school of adult sardines (approximately 3.5 km).

But with all the evidences it can not be said that the "slick" is a school of sardines (or other fish), although everything appears to show that . More repetitive images would be required to see the displacements of the slick in combination with groundtruth and also the spectral features of a fish school.

The possibility that the school was a "red tide" should also be kept in mind, but ground truth measurements would be necessary to prove this.

The discolouration appearing on the ocean to the NE of Ilha de São Sebastião are related to phenomena of atmospheric origin (fog in dissipation). Such an occurrence could entangle or make false, possible correlations with the productivity of the waters and their color, especially in a preliminary visual interpretation.

The continuation of the studies will provide better interpretations, especially when ground truth measurements are correspondingly done.

II.3.4.2 - Conclusions

With the analysis of the images in the NE of the São Paulo State (Brazil) it is possible to conclude that bathymetric charts can be improved with help of ERTS images in clear shallow waters, which will help very much in hydrographic measurements in coastal areas.

The sediments distribution obtained with ERTS is also visualized. It shows the evolution of the coastal line, with zones of sedimentation, erosion, coastal currents transport of sediments and also some ideas of sub-surface circulation can be obtained which could be used to detect and evaluate pollution.

Channel 7 shows that Cartography could be done, which would greatly help the coastal hydrography. Besides the Cartography could be associated also with Geodesy in such a way as to obtain detailed cartographic products, in points of difficult access to hydrographic measurements, as the coastal areas. Charts on a scale of 1:250,000 should be produced, which would show the advantages of this method over the conventional one in the handling of the data. Even a simple visual comparison of the images and the hydrographic charts, show the potentiality of the method of ERTS image interpretation. The repetitive coverage of ERTS updates the charts information and help us to control regions where constant and costly hydrographic surveys are to be performed. Besides a short range evaluation of the morphological evolution of the litoral zones can be obtained.

The coast of Rio de Janeiro State to Santa Catarina is the main fishing zone for sardine in Brazil, producing 61,000 tons yearly, which is almost the total production of sardines of the country. The ERTS images showed that it might be possible to determine school localization, with repetitive coverage, which could give information of the school migrations, following the biological conditioning factors and the variables of the environment.

II.3.5 - Use of ERTS-1 Images in Coastal Studies in Guanabara Bay and Adjacent Waters

II.3.5.1 - Introduction

Guanabara Bay, with an approximate area of 400 km^2, containing about 2.10^9 m^3 of water, is presently one of the most polluted places of the Brazilian coast (Fig. II.26). The main sources of pollution are: industrial, organic, sewage and that resulting from dock activities.

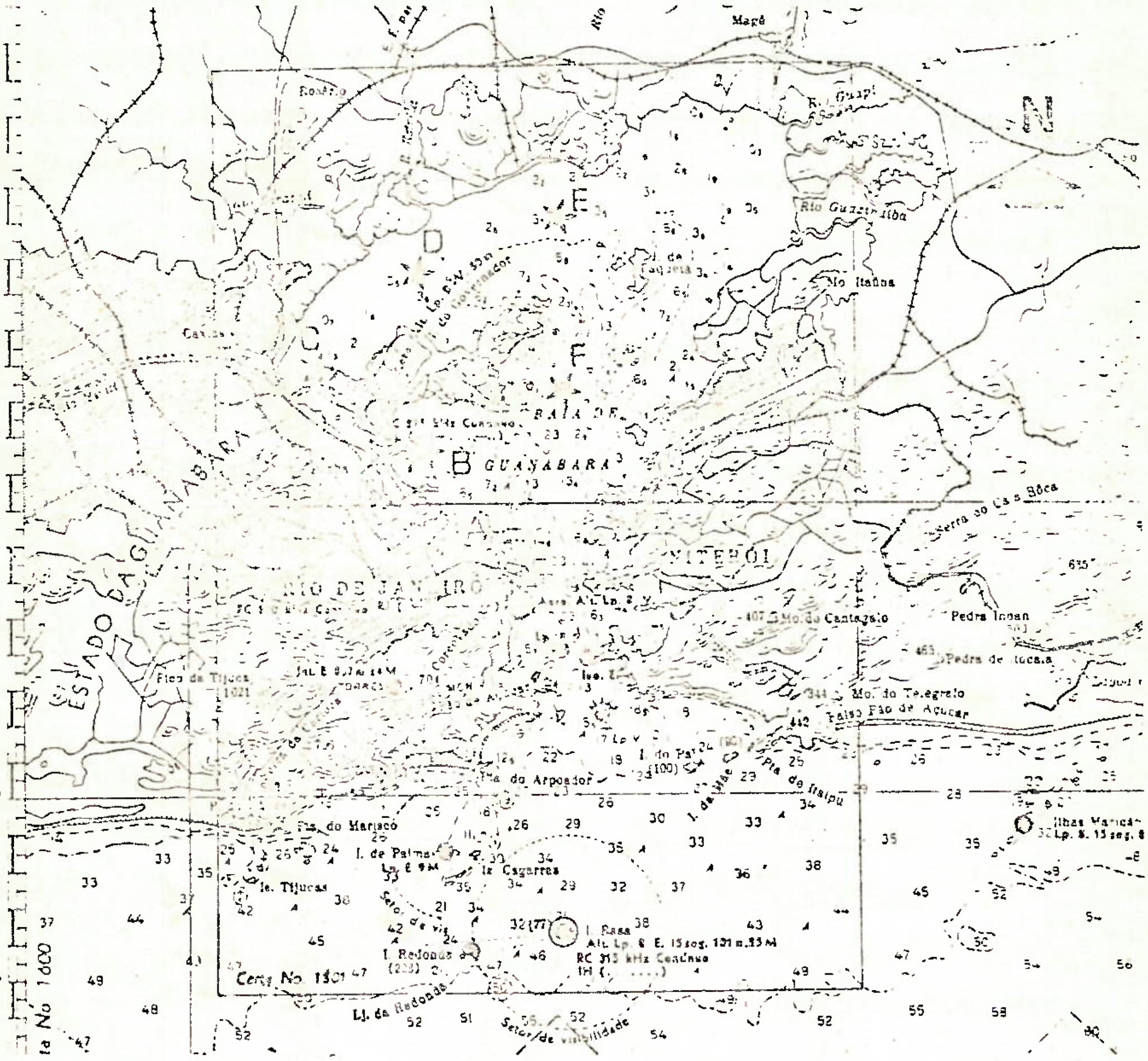


Fig. II.26 - Guanabara Bay (Nautical Chart nº 1501, from Brazilian Navy Hydrographic Office). ✩ Sampling locations.

The industrial pollution is being discharged into the bay mainly in the West and Northwest of it, from industries located in urban areas. Oil and oil products from the refinaries of Manguinhos and Duque de Caxias are outstanding examples of industrial pollution.

The organic pollution is derived mainly from suspended matter from the river effluents such as Guapi and Guaxindiba in the Northeast, Sarapui and Estrela in the Northwest and the Miriti river in the West of the bay. Concering the pollution due to sewage this comes from the Paquetã and Governador Islands as well as along the port side, Pão de Açucar, Jurujuba inlet and Vidigal outlet which is outside the bay.

Studies about solutions to the sewage disposal problem in Guanabara Bay. The figure II.27 shows the Guanabara Bay and the sources of pollution described above.

Classification of coastal waters from ERTS are based on the variation or returned spectral radiances. The major parameter affecting this variations of the returned energy process is related to the concentrations of suspended particles. Techniques for coastal waters classification have been carried out by Clark et al. (1964). Greater detail in suspended matter is revealed by MSS band 4 and 5, although some images of band 4 are affected by light scattering.

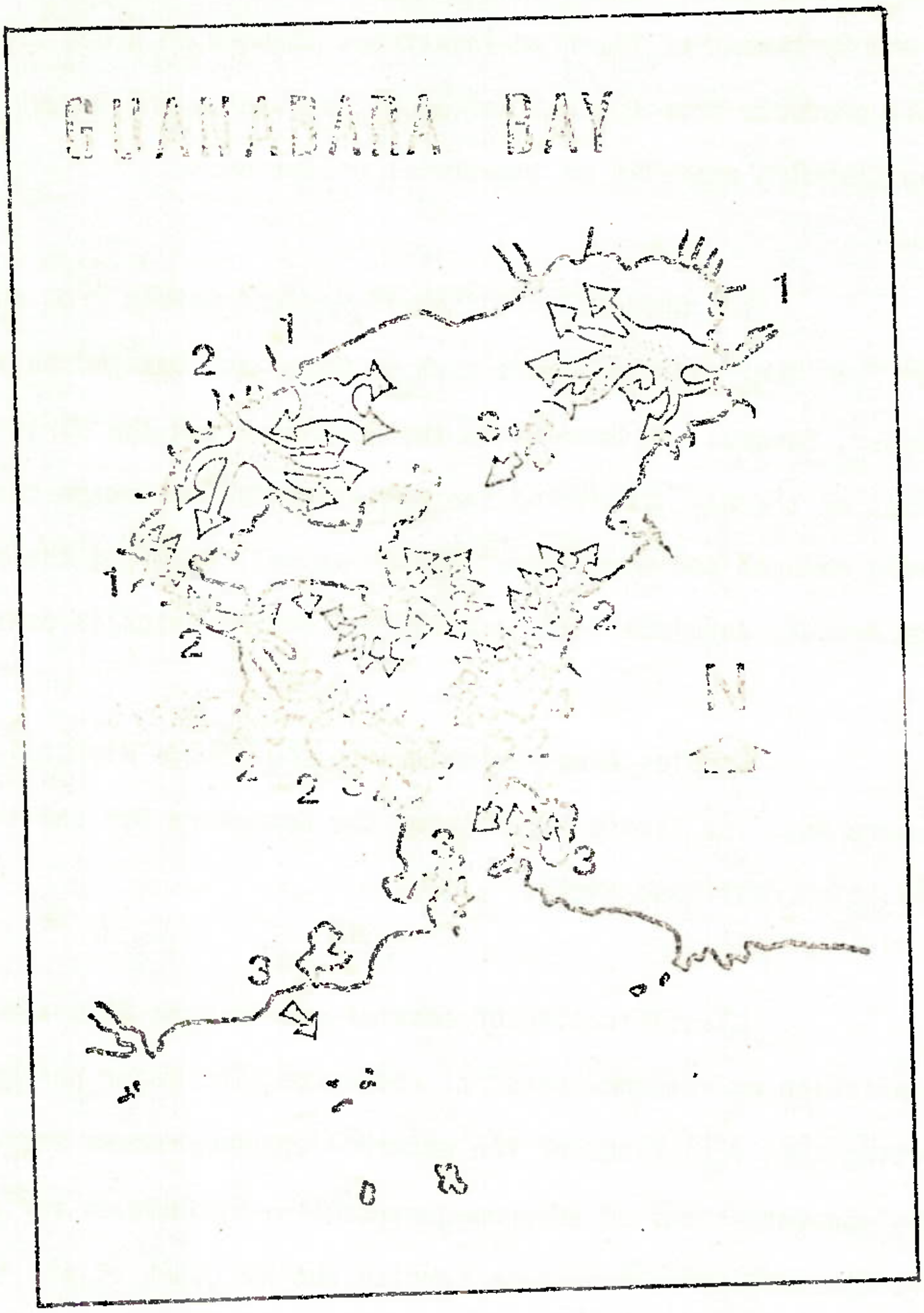


Fig. II.27 - Sources of pollution in Guanabara Bay.

1 - Organic 2 - Industrial 3 - Sewage 4 - Docking Activities

II.3.5.2 - Techniques used in the Analysis

Imagery from six ERTS-1 passes over Guanabara Bay have been studied to determine the feasibility of water mass classification for pollution evaluation. The passes took place on February 16, July 27, August 14, September 19, 1973, January 5 and 6, 1974, with cloud cover ranging from zero to twenty percent. Visual interpretation and density slicing analysis of the images was performed. Meteorological parameters were taken from records of the Brazilian Navy meteorological station at Fiscal Island inside the bay and Rasa Island outside of it, as well as records of four tide gauges inside the bay.

In order to know something of the spectral characteristics of the returned irradiances of the surface waters in the bay, some measurements of spectral distributions of irradiance were performed with an ISCO Spectroradiometer Model SR, which works between 380 nm and 750 nm for both the incoming or incident spectral radiation E_0 and the returned spectral radiation E_r from the sea surface. These measurements were performed with the help of an Hydrographic vessel of the Brazilian Navy Hydrographic Office. The ISCO was calibrated against a calibrated lamp. The location of the sampling stations can be seen in Fig. II.26.

The image were enlarged for comparison with the nautical chart of the region with a scale of approximately of 1:300,000 and the boundaries were drawn over the transparencies. The pass over Guanabara

Bay on February 16, 1973, was used for color enhancement in a Datacolor System Model 704, which analyzes the gray scale of photographic transparencies and displays the density values by means of color television in 8 color levels.

II.3.5.3 - Results and Discussion

The river discharges can be seen very well and their boundaries into the bay were determined in the images of MSS 4 and 5. The best plumes can be mapped in band 5. The organic pollution can be mapped also in the same way. (Fig. II.27a).

Another interesting feature which can be seen better in band 4 is the plume due to the sewage disposal of Vidigal outlet as well as the water with the same characteristics, inside the bay. A good contrast was found in both areas.

Figure II.28 shows a curve of spectral reflectance of the sea water at station B (see also Fig. II.26), obtained from field measurements using the spectroradiometer. The solar radiation was at the moment perpendicular to the surface of the sea (at the highest point of the sky - between 11:00 and 14:00 hrs.). A maximum of the reflectance was obtained at about 500 nm, corresponding to the green yellow band of the electromagnetic spectrum and which also corresponds to MSS-4 of ERTS-1. The same curve of Fig. II.28 also shows a minimum at about 480 nm, which corresponds to the blue band. The minimum is due to the presence of industrial

Fig. II.27a - Image E-1208-12225, 16 Feb. 1973, channel 5 - Guanabara Bay rivers discharges.

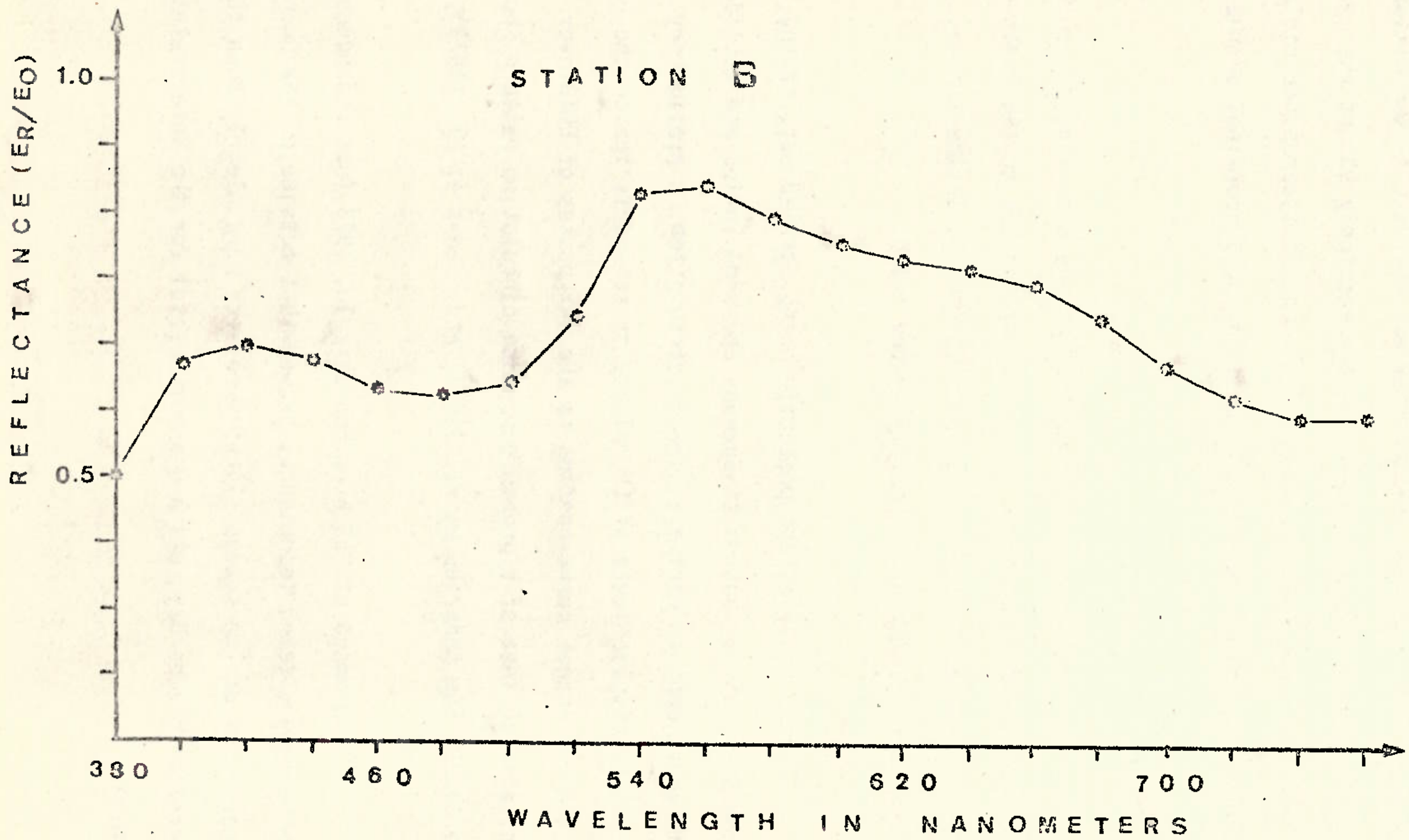


Fig. II.28 - Spectral Reflectance in Station B.

and sewage pollution which had a predominant green-yellow color producing a reflectance of 85% at 560 nm. The minimum was due also to the mixture of the polluted waters which produce a reflectance of only 50% at the wavelength of 480 nm. There was also a secondary maximum towards the violet with a reflectance of 60% indicating the different proportions of the pollutants.

Current measurements outside the bay show that the currents follow the wind and that no tidal effect is discernible to the South of the entrance to the bay. See Moreira da Silva (1964). Inside the bay, the regime of currents is determined mainly by the tides.

Some analysis are presently being carried out, taking into account the tidal cicle, bottom topography and wind inside and outside the bay in an attempt to derive a surface circulation. A preliminary analysis of the displacements of the plumes of sediments inside the bay, shown by the six images corresponding to the six passes of ERTS over Guanabara, gave an idea of a probable surface circulation pattern shown in Figure II.29. See Anderson et al. (1973) and Klemas et al. (1973).

The image of MSS 5 on February 16, 1973 (not reproduced) using the density slicing techniques, showed that outside of the Guanabara Bay the contrasts of the sewage slicks were seen more clearly than those in the interior of the bay, which was very useful for the interpretation of the image.

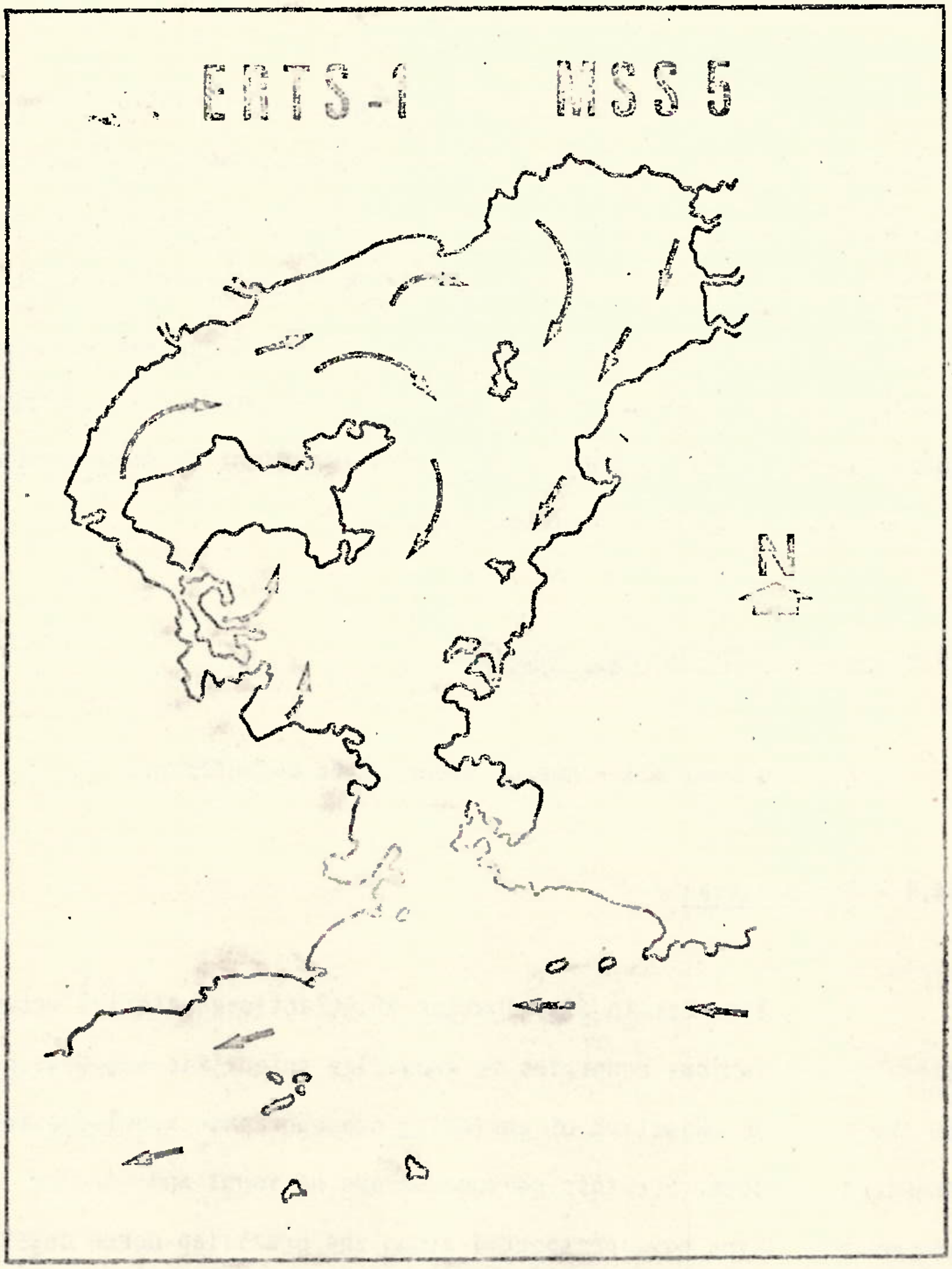


Fig. II.29 - ERTS-1, MSS5, Probable surface circulation patterns.

II.3.5.4 - Conclusions

The usefulness of ERTS-1 images in information on coastal circulation processes is clearly evident. The distribution of sediments and pollution plumes are visible on MSS bands 4 and 5. The images have shown the possibility to monitor pollution processes inside and outside the bay. Two consecutive passes (January 5 and 6, 1974) gave the possibility of studying ocean processes in time periods of about 24 hours. Presently studies leading to the calculation of the coefficient of eddy diffusivity are under development for Guanabara Bay.

II.4 - BARRA DO RIO AMAZONAS PROJECT

Test Site Area 828 - Amazon River delta and offshore

II.4.1 - Introduction

Interest in distribution of Atlantic-equatorial water masses has led various countries to subsidize scientific expeditions with the specific objective of enriching oceanographic knowledge for economical purposes. For this reason various national and foreign oceanographic ships have prospected along the Brazilian north coast since 1925. In 1963, oceanographic activities were intensified through ICITA where various countries worked in collaboration to complete Project EQUALANT.

Some data and interpretation results from work already published elaborate a series of problems. They suggest the existence of coastal currents which are in contrast with currents of the Guianas.These currents have different physical and biological characteristics condition. The Amazonas and Parã Rivers provide large quantities of material in suspension which contribute to the increase of productivity in the coastal waters. This productivity declines toward the open sea in the NE direction where the equatorial oceanic waters predominate.

Mainly in waters with low salinity and contained within a depth of 0 to 10 m from the surface the presence of continental waters with a more dense distribution of phytoplancton are observed (Teixeira and Tundisi, 1967). The oceanographic survey performed by the oceanographic ship "Tōko Maru" along the Brazilian coast in 1958 classifies the Brazilian coast in three large fishing areas. The Southern, Northeasten and Northern coasts constitute these areas of economic importance for fishing.

The Amazonas river waters affect a large part of the Northern coast, this influence being the most pronounced in surface waters over the continental shelf. Using the isohaline of 35 ‰ surface salinity as an indication of the continental slope, the South boundary is supposed to be at 01^{o}S .

The planctonic distribution accompanies the coastal water distribution in a belt parallel to the coast and with a 100 miles width.

The Northern limit is not known. The coastal waters of low transparency are abundant in plancton in the surface zones to the NE the transparency increases and the productivity diminishes due to the equatorial ocean waters.

The currents, predominantly to NW direction, contribute to the formation of the clay bottom, orange color, extending almost 200 miles with a width of approximately 100 miles where the shelf morphology changes direction from to SE to the NW.

This accumulated material is abundant in organic material changing from yellow to black by the reduction process and liberating H_2S when collected . All of this material in suspension originates from the Pará and Amazonas basins.

In a report recently published by the Oceanographic Institute of the University of São Paulo, it was established that the change in direction of the North coast from W to NW, changes the axis of the Guianas current, compressing fluvial waters which flow from the two rivers. The recognition of these facts create favorable conditions for fishing on the continental shelf in front of the Amazonas mouth.

In contrast to the low fertility of the Guianas current, the coastal waters directly characterized by rivers present a super-saturation of oxygen dissolved in the surface up to 10 m. The nutrients absorbed by material in suspension in those waters are partially liberated when the fluvial water is mixed with the ocean. Also the low penetration of light into the coastal waters limits production of oxygen for some meters from the surface (Magliocca, 1972).

II.4.2 - Interpretation

A non-controlled mosaic of the Barra Norte - Rio Amazonas was elaborated with 10 images of channel MSS-4 from a selection of repetitive material existing on this area. This mosaic was reduced for publication (Fig. II.30 and II.31). This material is very representative in view of what is above evidenced in generalizations. The discolorations observed from the Amazonas River basin and later distributed over the continental shelf cause an impact in the comparison of the images (Fig.II. 32). Evidently the different properties of the water masses in convergence are well defined by the information from only one MSS channel, namely the green-orange. Previous oceanographic research has shown that the ERTS-1 images of the considered region when mounted and compared repetitively will provide important material for control of future work. Observation in this way must together the necessary elements for perfect water regional dynamic recognition.

The processes involved in this eco-system involve seasonal problems which characterize the behavior of the whole extension of the basin, in reference to pluviometric regime (Fig. II.33). The annual run off

Fig. II.30 - Photographic reduction of the mosaic of the Amazonas Outfall region made up to MSS - channel 4 images.

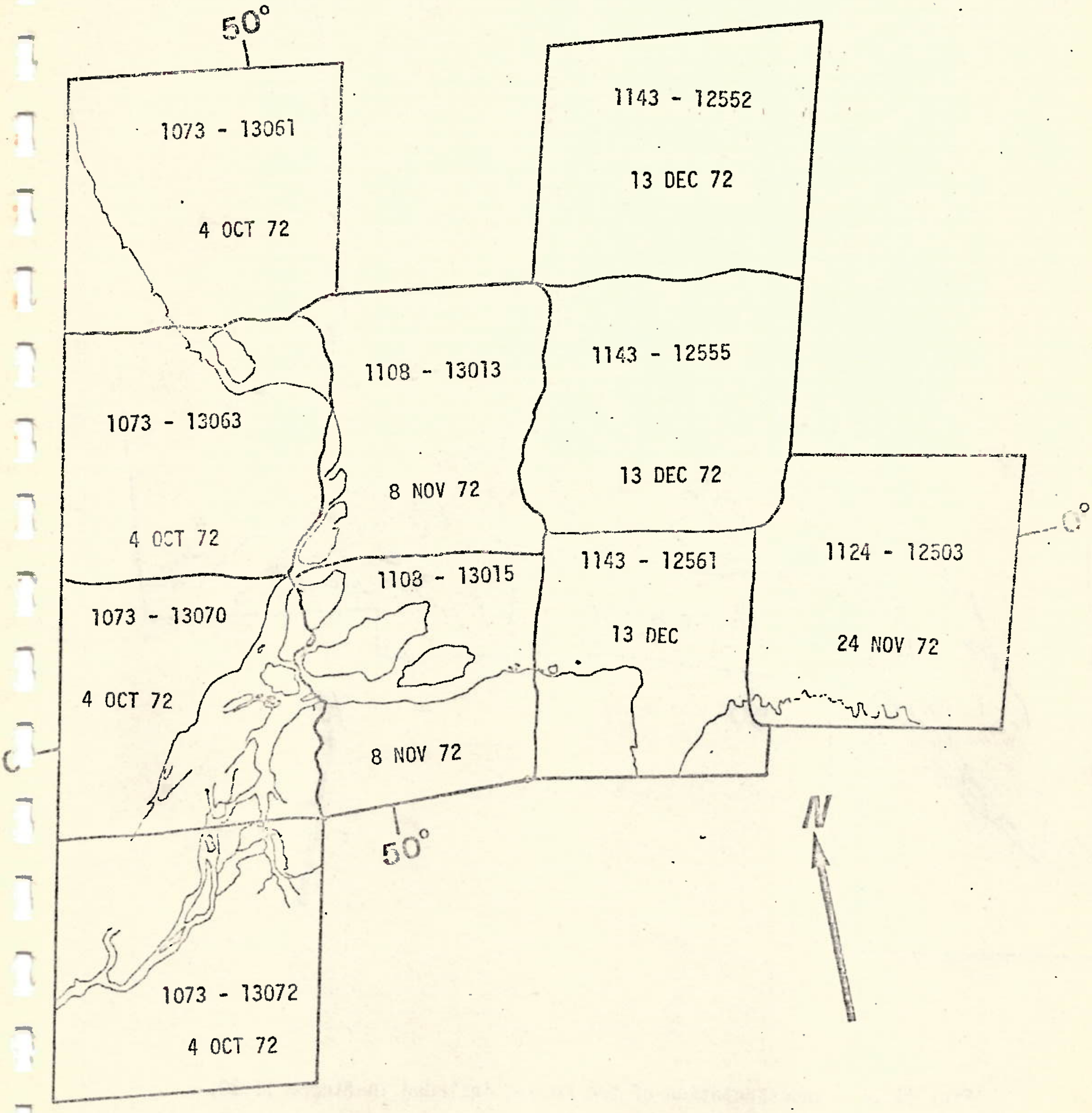


Fig. II.31 - Guide diagram for identification of the mosaic of figure II.30.

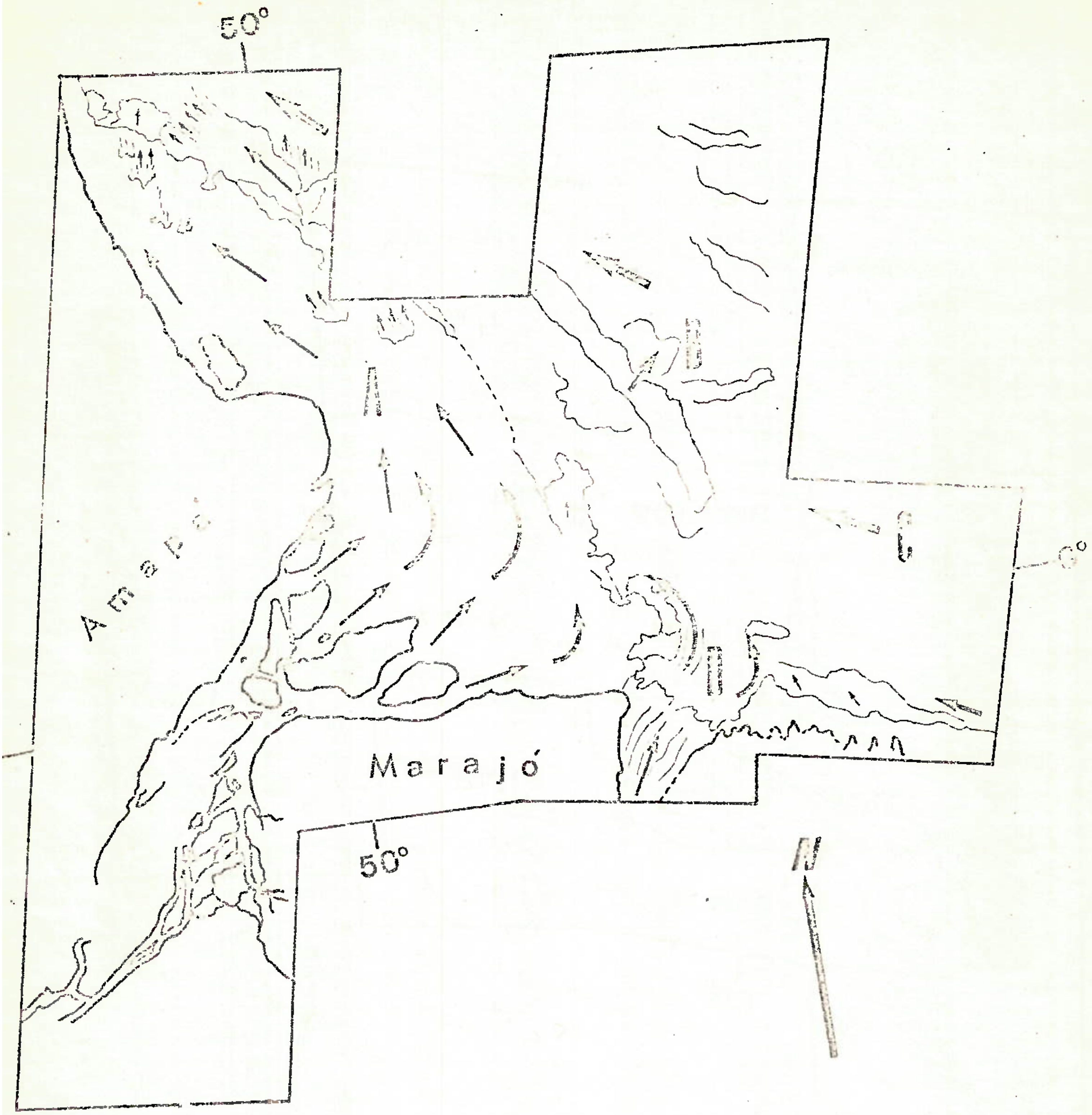


Fig. II.32 - Interpretation of the mosaic included in figure II.30.

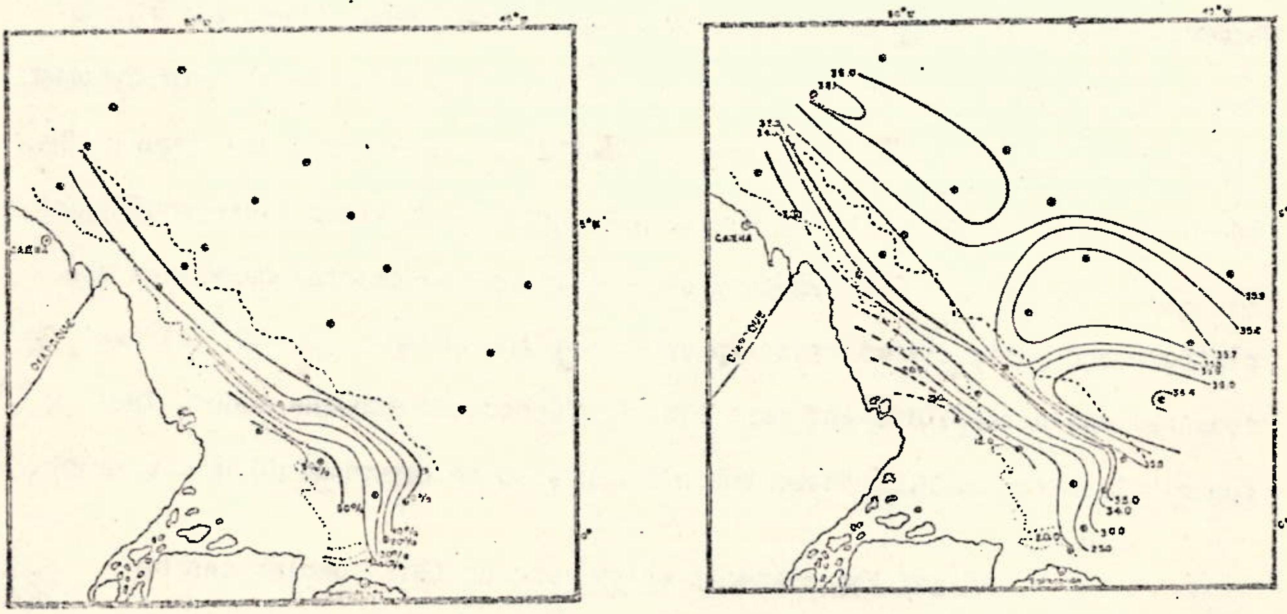


Fig. II.33 - Percentage distribution of fluvial surface waters and isohalines of the surface in April, according Magglioca.

varies in accordance with this, in a spatial order, where the extensive tributary of the Amazonas River, cross different annual pluviometric distribution areas.

The currents, winds and tides are responsible for the process of mixing and transporting of waters and materials in suspension. In Fig. II.32 "A" represents the Amazon river discharge transporting great quantity of suspended material close to the coast by the influence of the Guianas Current enabling the transport of this material over the Continental Shelf several miles from the great river's outfall. The isolated nucleous of fluvial water within the domain of the ocean possibly is connected to the flux and reflux of tides where precipitation is quite intense (B). The tendency of pilling up the coastal waters on the platform and their distribution toward NW by the Guianas Current (C) has seasonal characteristics and must also be connected with the tides. The contribution of the Pará River run off can also be determined (D) in this manner.

All of the elements which make up this complex can be accompanied and perhaps quantified in appropriate proportions to their participation, contributing for the knowledge of one phenomenon responsible for the fisheries productivity of the most important Brazilian region.

II.4.3 - Conclusions

Although only one multispectral channel was analyzed, some important conclusions were drawn which justify future hydro-oceanographic studies of system formed by the Amazonas and Pará Rivers in constant with tropical ocean waters on the Continental Shelf. It was verified that channel MSS-4 together with MSS-5 offer high resolution images for coastal oceanographic studies.

a. The ERTS-1 images can be applied to nautical cartography principally in coastal zones of difficult access where field work is difficult (Amapá);

b. The geodynamics of the processes while characterize the Barra Norte of the Amazonas River can be accompanied in evolution by the formation of deposits and their relocation;

c. The seasonal changes implicated in the run off of the river and the distribution of their waters on the shelf taking into account the currents and tides, can be accompanied by repetitive work;

d. Interest in the delimitation of coastal water distribution offers important elements of economical interest to fishing activities on the Northern coast.

II.5 - ABROLHOS PROJECT

Test Site Area 808 - Abrolhos Reef

II.5.1 - Description of the Test Area

The Abrolhos area is in the Southern coast of the Bahia State. The average latitude is 18°S. It is a dangerous area for navigation, with many banks and an irregular bottom configuration. With such characteristics this area presents problems for navigation and for hydrographic surveys.

The water in Abrolhos are quite clear and some photogrammetric and Remote Sensing flights have shown that it is possible to sense the bottom of the sea.

The climate is characterized by two seasons: a rainy and a dry season. The maximum precipitation occurs in the middle of the year with a cloud cover of about 80% during the season.

II.5.2 - Justification of the Area Selection

The main reasons to have selected this area are the bottom topography and the water transparency. It is also known that the area is rich in fine fishes and this is another reason for the study.

II.5.3 - Summary of the Project

The project consists mainly on the analysis of the ERTS-1 images of the test area, with respect to its hydrographic characteristics. These characteristics will be checked with aircraft imagery and also with data obtained with oceanographic vessels.

The data will be correlated with the purpose establishing a methodology towards obtaining nautical navigational information.

II.5.4 - Objectives of the Project

In terms of the utilization of the ERTS-1 images, the main objective is to establish systematic studies of the hydrographic characteristics of the area.

Unfortunately, all the images received so far, do not have an ideal cloud coverage for a good interpretation of the whole area. Thus no result can be given at present for this project which will continue in 1975.

Nevertheless, a region near Abrolhos corresponding to Ponta da Baleia (uncompleted for lack of images to the East) at 16^{o}S in the Southern coast of Bahia State, will be analyzed.

II.5.5 - South Offshore of Bahia State

II.5.5.1 - Introduction

The continental shelf adjacent to the South coastland of the State of Bahia has extremely different morphological characteristics in comparison with the rest of the Brazilian Coastland. A number of reefs are located in this region on a widening of the continental shelf reaching the longitude 37°00'W with an extension of 240 km from the coast. Average depths of 100 m indicate the edge of the shelf and originate an inclination which falls abruptly towards the center of Atlantic Ocean basin.

These characteristics represented on the submarine relief reflect in the distribution of the coastal streams, as for example the Brazilian stream in its flowing towards the South. The Abrolhos Reef, the Paredes Reef and other reefs formed by corals constitute real natural barriers whicn influence directly the dynamic distribution of the waters crossing this advanced portion of the Brazilian continental shelf.

Oceanographic expeditions up to the early 1920 to the South Atlantic did not pay attention to this fact. Only in 1925 the oceanographic ship "Meteor" made some observations about the profile described above for its major objective was to study the deeper streams to obtain an idea about the general circulation of the water mass of the Atlantic Ocean.

In a recent paper (Emilson, 1961) published by the Oceanographic Institute of the University of São Paulo, some new data are presented due to the surveys performed in February, March, June and November of 1956. The author discusses the possibility of the deviation of the Brazilian stream in its passage through the reefs of Abrolhos in the proximity of the latitude 18°S. This hindrance deviates an arm of the stream to the east and causes a disturbance in the vertical stratification which provokes some upwelling. The presence of these waters, rich in nutrients, are no doubt responsible for the development of sea-life encountered in this region.

To the South of this area the data collected during the International Geophysical Year by the Brazilian Navy indicate the existence of eddies occurrence as a consequence of the topographic irregularities of the bottom on the platform.

More to the South (latitude 22°S) the Brazilian Stream remains more regular and the distribution of the temperatures and salinity indicate that the main arm follows the continental shelf axis. The inner edge of the color difference of the waters which are green (little transparent) in one side and blue (transparent) in the other originate in the North.

II.5.5.2 - Interpretation

The images which were interpreted (E-1224-12.095 - Fig. II.34) represent a narrow band of sea and does not include the Abrolhos Reef. In spite of its being incomplete due to the lack of images to the east, four overlays and a photomontage of channels 4,5,6 and 7 (MSS) were made to allow a more complete comparison of the oceanographic and hydrographic occurrences adjacent to the Ponta da Baleia (Whale Point) (Figs. II.35 and II.36).

The MSS-7 image defines well the contours of the coast and part of the hydrographic basins, evidences some holocenic structures of sedimentary low coastal regions and delimitates some regions of humid sub-soil or sub-superficial water ground.

The necessary definition on the contours of the reefs of coral adjacent to the coast does not appear due to the permanent saturation of the material by the sea water.

The MSS-6 channel defines better this type of material and is more adequate for hydrographic studies where this type of problem occurs (Fig. II.37).

The MSS-5 clearly provides the necessary contrasts for the coastal phytogeographic mapping and adds important elements in the inter-

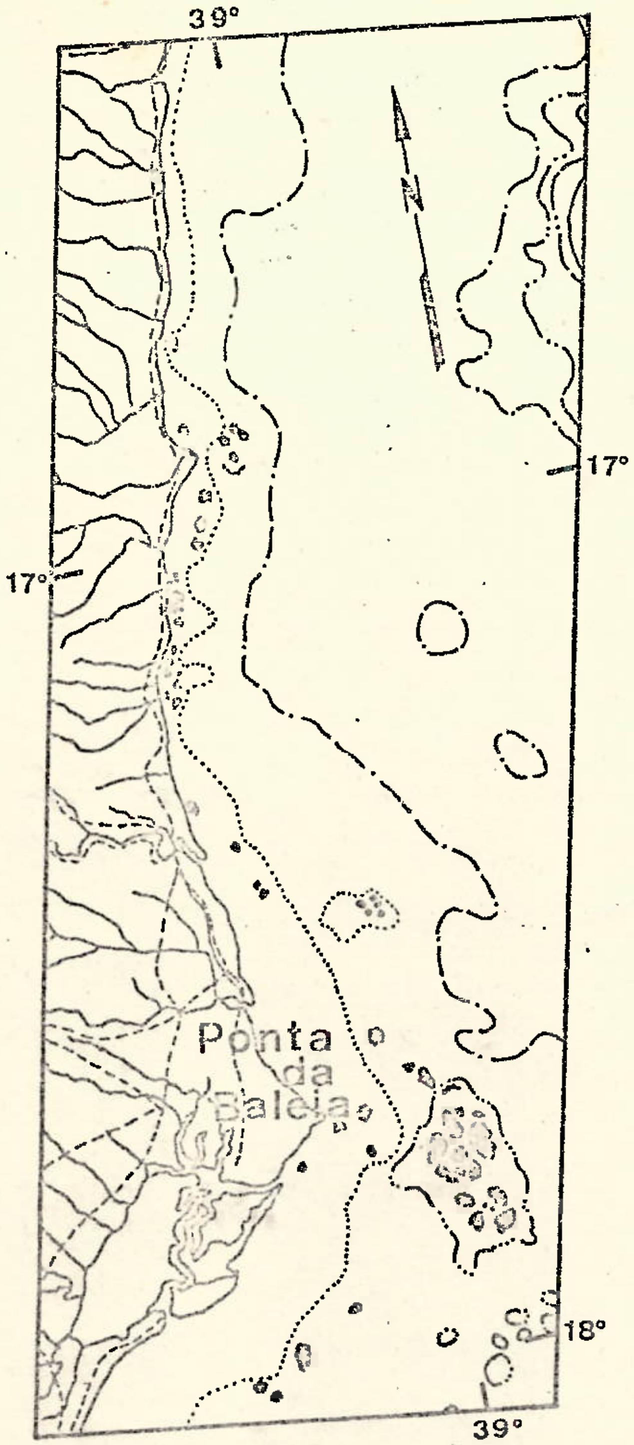


Fig. II.34 - Cartographic detail of the sheet SE-24, Rio Doce (36) of the International Chart of the World to the millionth (IBGE - 1972) about the coastland of the Bahia State.

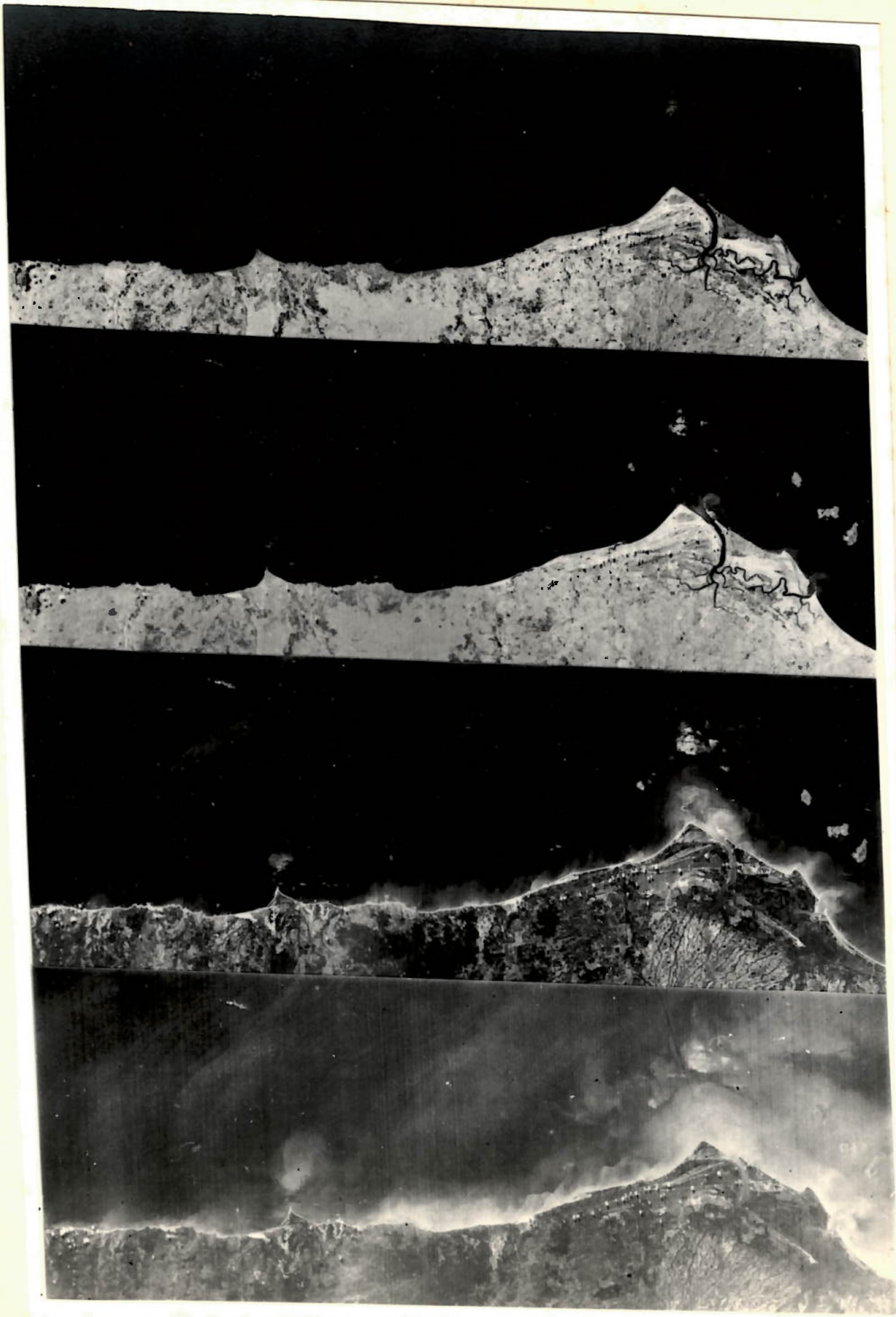


Fig. II.35 - Partial detail of images E-1224-12095 in the multispectral channels (MSS) 4,5,6 and 7.

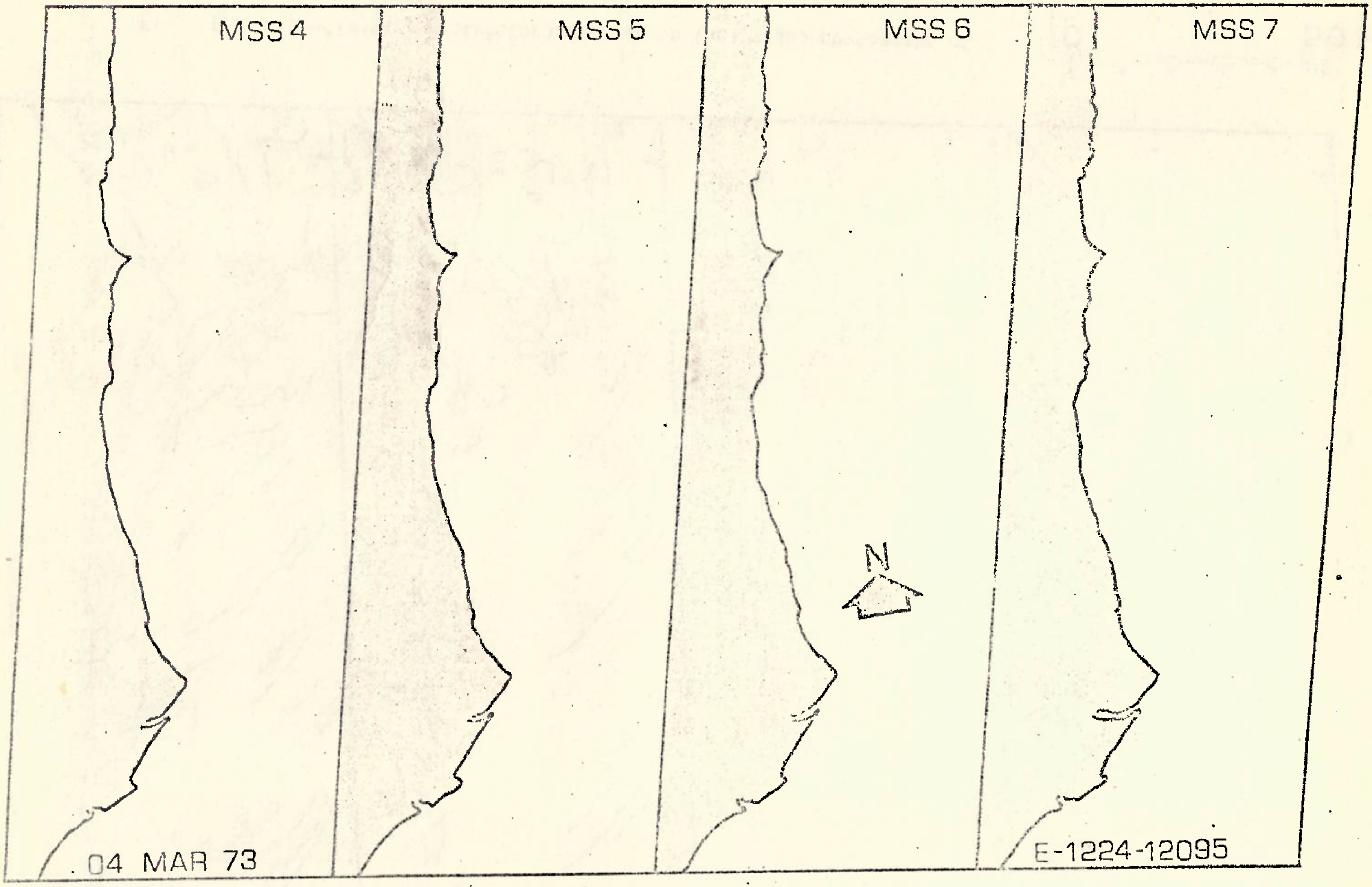


Fig. II.36 - Scheme indicating the order of the montage of the images of figure II.35.

Fig. II.37 - Preliminary photointerpretation on the images components of figure II.35 montage.

pretation of the structural tendencies of deposits from low coastal regions. In this channel the coastal distribution of the material brought by the rivers and in suspension adjacent to their mouths is well seen. The different contrasts indicate some dynamic tendencies. This occurs with lesser intensity in the MSS-6 where the selectivity to the red possibly indicates a distribution of argyllaceous suspension.

The MSS-4 is the channel which offers the image selection from green to orange. Hence, the material in suspension in the coastal waters with two origins, the organic (green) and the mineral (orange) ones, appear clearly represented in this image.

Most of the details of distribution of elements in suspension and color of water appear in channel MSS-4 where an attempt can be made to detect a possible contrast between waters coming from the North brought by the Brazilian Stream and the coastal waters with colors well differentiated.

Some tendencies of the streams which have come from the North are indicated in the overlays of channels MSS-4 and MSS-5, where the coastal waters are dragged to the South. The barriers constitute by the reefs on the continental shelf are clearly visible when the distribution of material in suspension close to the Reef of Paredes.

In comparing figure II.34 with the distribution of less dense contrasts of the image, the identification, in a general way, of the isobathymetrics of 10 and 15m can be determined in channel MSS-4.

Another fact resulting from the overlapping of the image MSS-5 and the cartographic detail is that the positioning of the reefs of the image does not coincide with the cartographic representation, mainly in the Reef of Paredes.

II.3.5.3 - Conclusions

a. From a hydrographic point of view, the image MSS-6 is the most appropriate for the mapping of the reefs of coral.

b. The coastal geomorphology should be studied through the use of channels MSS-7 and MSS-5 since the detailing of sedimentary structures and others becomes more defined with such association.

c. The distribution of the material in the coastal waters is detected in the channels MSS-5 and MSS-4 depending on the material in suspension, which results in a greater or lesser transparency of the waters. The quality and the quantity of this material in suspension owing to its color and the penetration of light into the sea water, results in different contrasts covering the visible spectrum in the bands from green to orange and from orange to red, respectively.

d. To better define the hydrographic and oceanographic problems of Abrolhos region it is necessary to construct a small mosaic taking into consideration the image for oceanic coverages up to 37°W approximately.

II.6 - MIDDLE NORTHERN REGION OF BRAZIL - MOUTH OF THE PARNAÍBA RIVER (BARRA DO RIO PARNAÍBA)

II.6.1 - Introduction

The ERTS-1 images analyzed in this report cover an extensive coastal area of approximately 100 nautical miles of the States of Maranhão, Piauí and Ceará, involving the middle Northern region of Brazil (Fig. II.38).

The interior of the region has a dominant vegetation of savanna established on Tertiary sedimentary ground. On the coast, the quaternary formations of sedimentary origin serve to support a varied vegetation, specific of each of the coastal sub-ambients. In this way, it

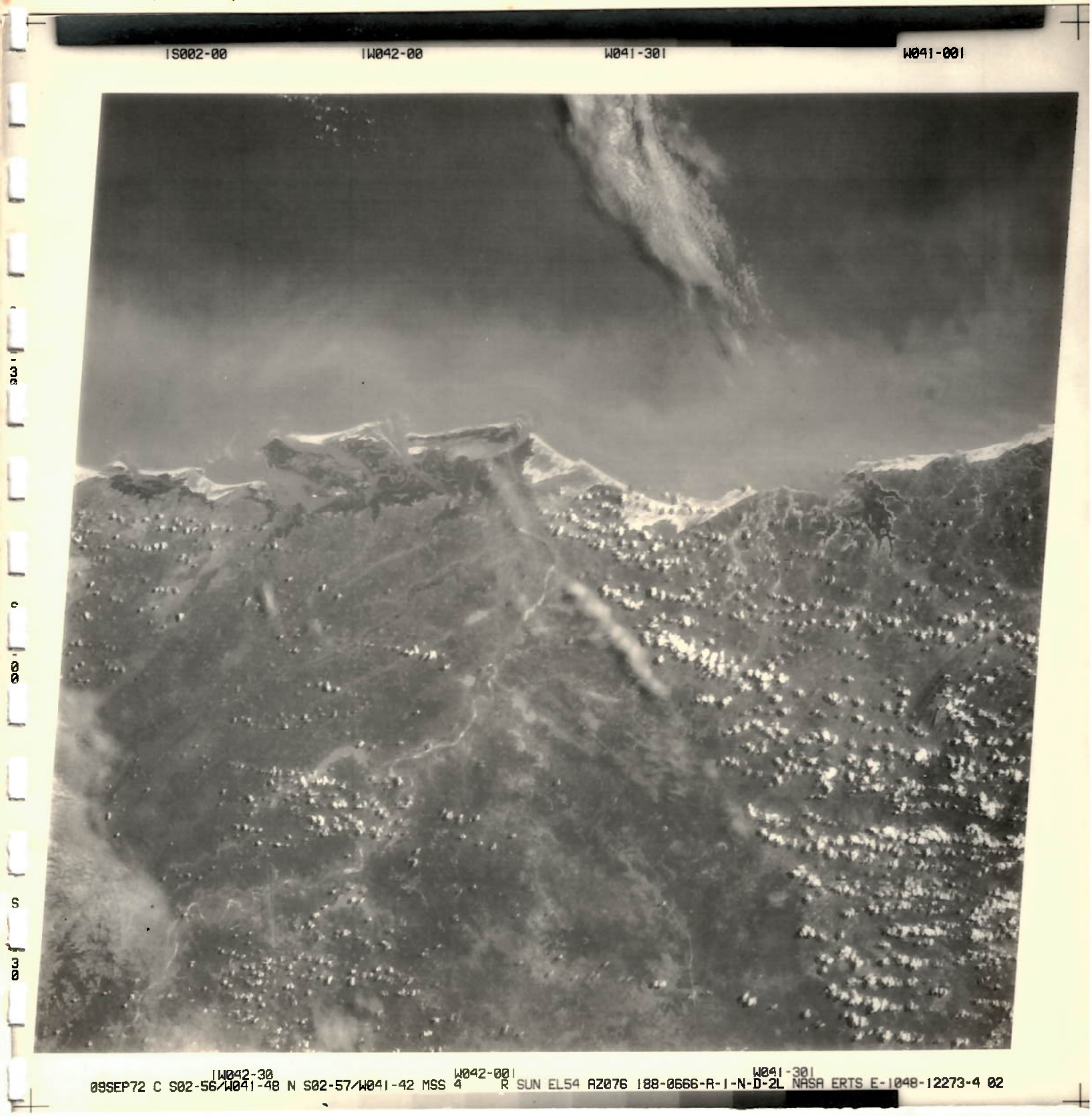


Fig. II.38 - ERTS-1048-12.273 image - channel 4 Northeast Offshore Area - Barra do Rio Parnaība.

is possible to classify in a general manner various types of coastal vegetation such as: the mangrove, dune vegetation, sand-bank vegetation, and beach vegetation, each being associated with a sub-layer characterized by the dominant coastal process.

The Parnaība River is a fairly large perennial river, crossing a tertiary sedimentary plain to the ocean where it enters in contact with more recent sediment of quaternary origin. Other rivers which drain the region have a more intermittent characteristic, being subject to seasonal regime and to porosity of sedimentary formations.

II.6.2 - Interpretation

The interpretation of images E-1048-12.273/4,5,6 and 7 is limited to the coastal zone principally near the Parnaība River estuary, where the coastal processes and the coastal and oceanic current distribution will be studied.

- Oceanography/Hydrography

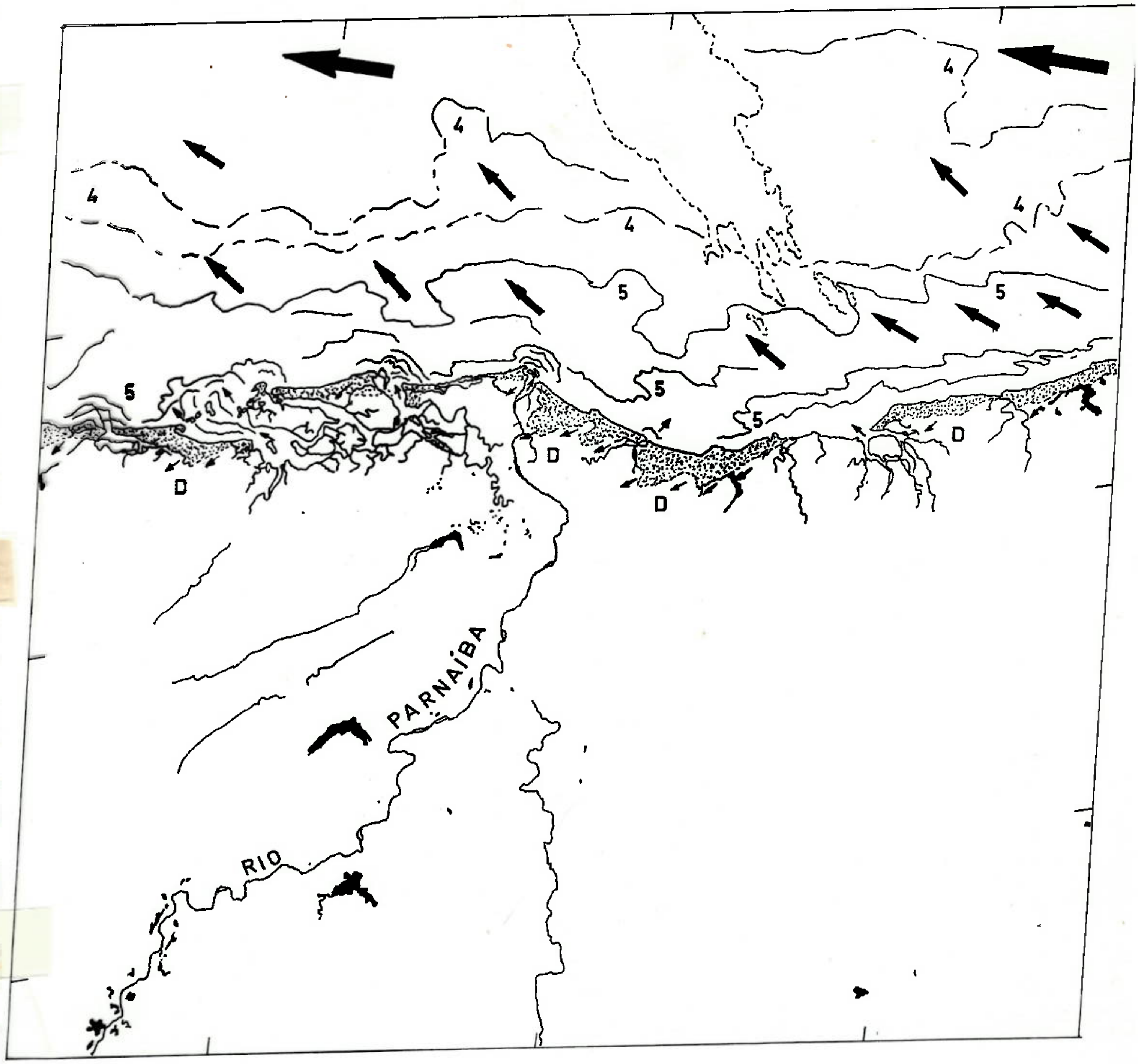
Channel MSS-6 indicates that the estuary complex of the Parnaība river works in a dynamic manner in relation to the tide flow. The discolourations noted in the estuary interior are relative to distribution of material in suspension in the interior waters, and conform to morphology of the estuary which has its mouths towards the NW.

Channels MSS-5 and MSS-4 show different levels of depth of sediment distribution. The identification of distribution sources (Ref. 4 and 5 of Figure II.39) indicates the direction or tendencies of preferential propagation of the coastal waters under the strong influence of oceanic waters from the Guianas current. In general, the water discolourations tends to NW.

The MSS-4 delimits the propagation of coastal waters containing sediment to ± 30 km from the coast, and the MSS-5 to ± 18 km depending on penetration of each sensor.

Comparing the MSS-7 image with some existing charts in the same scale, it can be noted that the estuary as per the image does not coincide with the cartographic representation. It is evident that the image leaves no room for doubt, although the cartography cannot totally be discredited since the dates of each survey are different. What actually happened was an evolution of coastal forms due to the geodynamic process or coastal process. The possibility arises here to study the morphology of this estuary using other aerophotogrametric surveys or future ERTS images to interpret the reasons and tendencies of an evolution of this type in the coastal area.

Channel MSS-7 permits clear definition of lakes, perennial rivers and the coastal line, defining precisely their contours. Some rivers are identified with less precision due to their intermittent character, originating from very porous sedimentary ground and dryer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PARNAÍBA

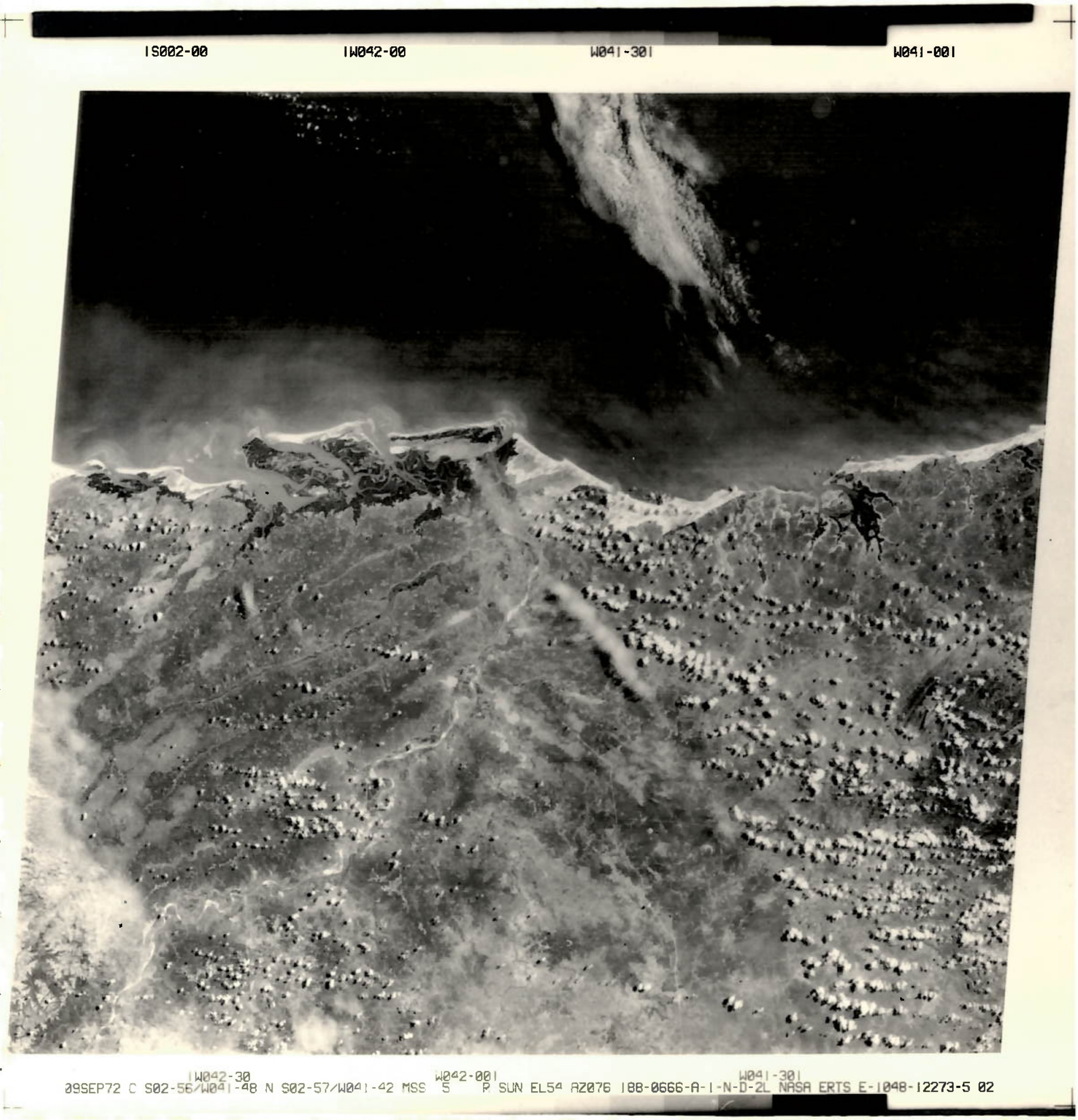

Fig. II.39 - Image E-1048-12273 - Preliminar interpretation on the channel MSS-5.

climatic periods, forming a chain of small lakes in the riverbeds.

- Coastal Processes

Quaternary soil is predominant along the ocean, and is formed by marine and fluviomarine sediment. The constant influence of oceanic currents due to the rivers and winds, modify the morphology of these coastal formations.

The sand deposited on the beaches is moved by the wind which is predominantly NE, creating a field of dunes which are shifted to the interior and even more mangroves. On the East margin of the Parnaība River the penetration of the dunes can be measured to be 14 km from the beach to the interior in the NE-SW direction. This eolic shifting follows and covers not only sedimentary formations but mangroves in some sections.

The dune fields indicated in the transparency of figure II.39 as per interpretation of the MSS-5 image, plainly establish a preferential direction of propagation from the NE following the predominance of winds along the coast.

Image MSS-5 demonstrates clearly the estuary problem near the Parnaība River. Fine sandy soil in the presence of high tides creates a specific mangrove vegetation (zones of more intense density in the image) with three principal species covering an area of 150 km^2 of forest.

II.6.3 - Conclusions

a. The observation of coastal sediment distribution and the tendencies of coastal current propagation can be observed in the MSS-5 images.

b. The coastal processes and their geodynamic evolution can be followed by the ERTS images.

c. The estuary complexes of the NE coast, of which the Parnaíba is the most important, constitute areas of well developed primary productivity, being areas with environmental conditions propitious to species of economical interest.

d. Ecological study executed within a program of regional research could establish directives for possible utilization and conservation of natural resources, principally in reference to fishing for shrimp and Crustacae in general.

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CHAPTER III

MINERAL RESOURCES

Principal Investigator:

Amaral, Gilberto - INPE/University of São Paulo

GSFC ID-F0388 MMC 326-02

CHAPTER III

MINERAL RESOURCES

III.1 - INTRODUCTION

The main activities of INPE's Geology and Mineral Resources Group from October 1972 through November 1974 are described in this chapter.

A proposal for participation in the ERTS-1 research program was submitted to NASA in April 1971 outlining an area of approximately 15 million sq. km located in central-eastern Brazil - the São Francisco River Basin (Figure III.1). Other areas in Brazil were studied also as described by the Addenda to the first proposal,however, the priority for geological study remained with the area mentioned above.

The intial work in a small area of the São Francisco River Basin was carried out by Messrs. C.C. Liu, C.C. Carraro, and S.K. Yamagata and the last paper available at the time of the preparation of this report is shown here as Appendix III.1. This work has been expanded to cover an area of 800.000 km^2 and is entitled "A Geological Interpretation of the Upper and Middle São Francisco River Area based on ERTS Imagery". This work is being completed at the present time (June 1975) and is not reproduced here.

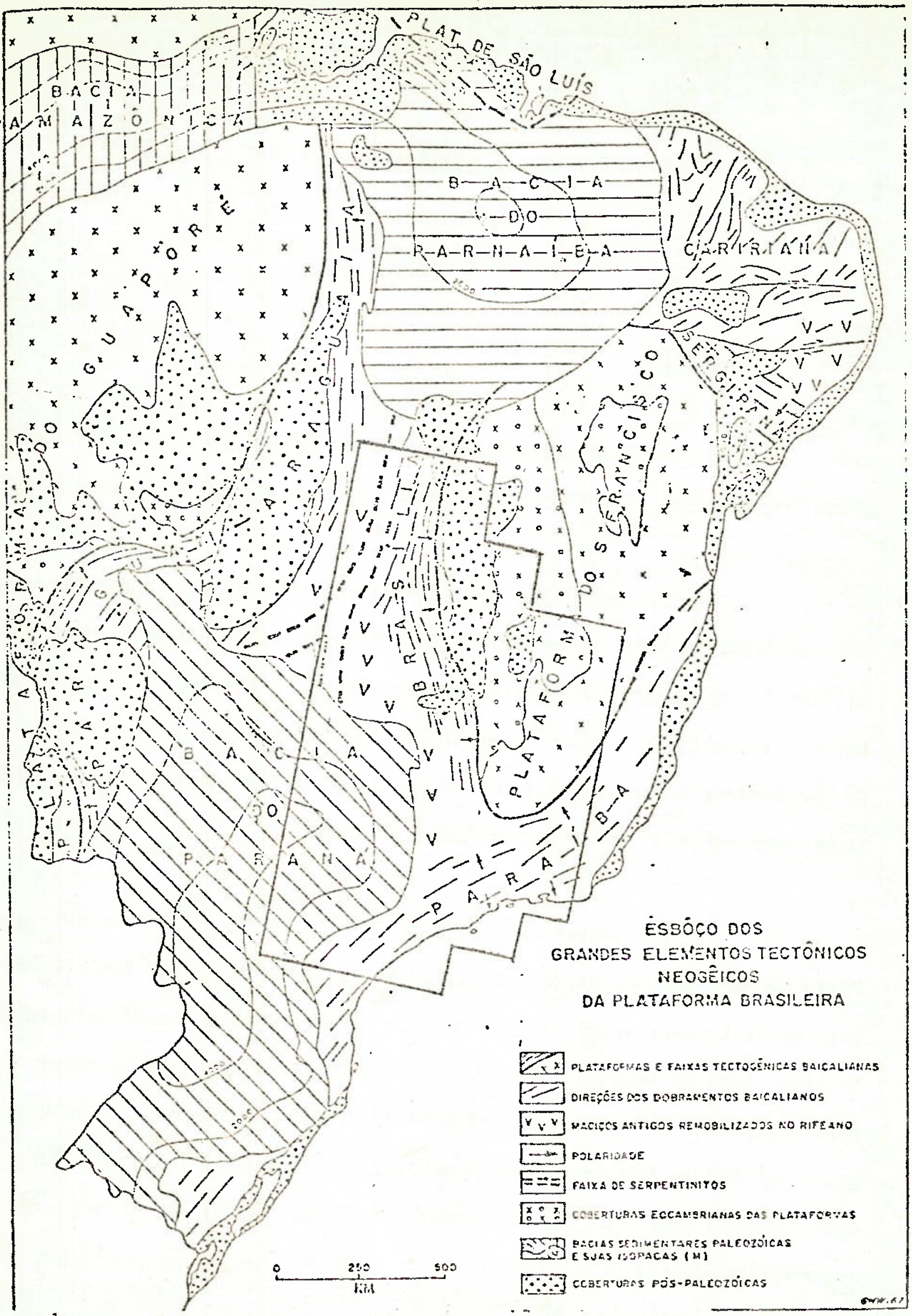

Fig. III.1 - First priority area for geological applications of ERTS-1 data.

ERTS-1 imagery provided basic data to the Principal Investigator to develop a scheme of the Precambrian development of the Amazon Region in Brazil. Additional data which were utilized in this study were provided by SLAR imagery, geochronological analyses, and field work.

Presently, INPE's geological team is headed by Dr. Aderbal C. Correa who is coordinating the efforts to do the structural mapping of Brazil at the 1:1,000,000 scale using remote sensing data. Professors of the University of São Paulo, including the author of this report, are cooperating with this work in the laboratory and field.

III.2 - MATERIALS AND METHODS

Most of the interpretation was carried out on bulk, black and white, 1:1,000,000 scale paper prints. Color composites, obtained in an additive color viewer or in diazo prints, were used in some cases. Mosaics at a 1:1,000,000 scale were used to enable the photointerpreter to have a synoptic view of large areas. A photo-index at a 1:3,690,000 scale was used as a reference for images available in Brazil. Enlargements at 1:500,000, 1:250,000 and 1:100,000 scales were used for comparison with already existing data. Except for special problems, such as sediment suspension in water bodies, and for producing color composites, only MSS bands 5 and 7 imagery were used. These proved to be the most suitable for geological interpretation, both yielding lithological as well as structural data. A list of ERTS-1 frames which were analyzed at INPE for the papers included with this report is given in Annex III.1.

The interpretation of a given area based on ERTS-1 imagery was followed by a careful checking against previous published work in the area. In general, important differences were observed between the already existing maps and the geological interpretation obtained in ERTS-1 imagery. The main differences concern the structural framework of these areas. In some occasions, specially within sedimentary basins where a monotonous rock association occurs, lithologic boundaries in ERTS-1 imagery were delineated more precisely than in conventional photo-interpretation.

Due to a series of obstacles, field work was severely restricted. The Principal Investigator carried out two months of field control at the Serra dos Carajás-Tocantins River area and at the northern Roraima Territory. Mr. Sergio K. Yamagata conducted a two field work at the Rio Verde region, within the São Francisco River area. The problem of field control for other test areas was partially solved by personal contacts with geologists who have worked in these areas.

Ektachrome, aerochrome infrared and panchromatic aerial photographs were available only for small areas within the São Francisco and Amazon regions, but were not used due to difficulties in correlating them to ERTS imagery.

Computer analysis of the ERTS computer compatible tapes are in an embrionary stage. The main reasons for that were the initial difficulties in reading the tapes; the long time required for the development and implementation of software; and the capabilities of our computer system. Most of our actual efforts are being directed towards the development of an automatic interpretation system for ERTS data. INPE has acquired a G.E. Image-100 system which will be operational in August 1975.

In summary, only visual interpretation aided by literature analysis and some field data was used for geological examination of ERTS imagery up to now. It was verified during the program development that drainage analysis, performed in the same way as in conventional photogeology, is perhaps the most important method for visual extraction of geological information from ERTS imagery. Because of that, a complete drainage pattern was delineated on most of the frames in order to obtain lithological as well as structural information. The second important aspect was the geomorphological analysis of the images, aiming also the extraction of structural and lithological data. Finally, tonal analysis was used mainly for delimitation of different geologic units.

In many cases it was not possible to decide upon the nature of the linear features observed on the images (faults, fractures, schistosity, bedding, fold axis, etc..). In such cases the resulting maps indicate only the position of the lineament. The identification of intrusive bodies and contacts between sedimentary basins and their basements are generally an easy task.

Under favorable conditions ore bearing geologic units can be discernible in ERTS imagery. The main examples are:

a. Uranium-phosphate-niobium-aluminium bearing alkaline intrusions in Minas Gerais and Goiâs States;
b. Nickel-chromium-cobalt-asbestos bearing ultrabasic intrusions in the Goiâs State;
c. Zinc-lead-silver-copper bearing limestones in the Minas Gerais and Goiâs States.
d. Iron and manganese bearing metamorphic rocks in the Parâ and Minas Gerais States.
e. Tin-wolframium bearing granites in the Parâ State;
f. Molibdenium-copper bearing sub-volcanic granites at the Roraima Territory.

As no scene corrected (precision) imagery were used, it was somewhat difficult to fit the interpretation results within the quadrangles of the International Chart of the World on the Millionth Scale which uses the Lambert conformal conical projection. This problem was partially solved by transferring the data for each 30' x 30' quadrangle on a standard base grid map. For some regions this was almost impossible due to the low confidence of the millionth base charts and the differences between the coordinates annotation system of ERTS imagery relative to them. Due to the size of the region (about 5 million sq.km) the data for the Amazon region were transferred to a 1:5,000,000 scale base map, which presented no major problems.

III.3 - DISCUSSION OF THE RESULTS

Most of the comments and conclusions of the group on mineral resources, geological structure and landform surveys of the II ERTS-1 Symposium (March, 1973), can be applied to the results now presented. However, in the case of Brazil a significant amount of new geological information was added as a result of the program conducted by INPE. This is an important point to be considered when a country is geologically poorly known. In such cases ERTS imagery interpretation can be considered an operational program instead of an experimental one. A similar line of thinking lead the Brazilian government to develop the RADAM Project, which has surveyed about 4.8 million sq. km of the nation's territory (approximately 55% of the total area). About US$ 25 million were spent for acquisition of radar imagery alone.

Comparative studies between SLAR and ERTS-1 imagery, performed by INPE's staff, indicate that the second can yield about the same amount of information at a cost many times less than the first. Considering the ERTS applications to natural resources by developing countries these conclusions stresses the importance of orbital remote sensing for such countries.

After these introductory remarks we will turn to the discussion of the results obtained in each of the programs conducted by INPE's geology group.

III.3.1 - <u>São Francisco River Basin</u>

Appendix III.1 is the last available report on the ERTS imagery interpretation results for that region. The justifications for the selection of that area were presented in the proposal to NASA, and can be summarized as follows:

a. It encloses great part of the country's known mineral resources;
b. It presents no problems regarding cloud coverage;
c. A large number of publications regarding its geology is easily available.

The program is still in development, extending the interpretation to neighboring areas of Goiás, Bahia, Piauí, Minas Gerais and São Paulo States. The main conclusions are:

a. ERTS-1 MSS imagery are an excellent tool for regional geologic mapping in savanna-type areas;
b. Bands 5 and 7 are the best ones for that purpose;

c. Comparison with already existing maps indicate an excellent correlation with ERTS interpretations. The correlation was directly proportional to the intensity of the field work from which the map derived;

d. Uncertainties still exist for those areas lacking field control, due to difficulties in lithological interpretation;

e. The imagery proved to be excellent for the delineation of different geotectonic units;

f. Almost without exception the already existing maps were corrected with respect to morphology, location of reference points, dimension of geographic features, etc.;

g. Due to the low geometric resolution of the ERTS-1 MSS system it was not possible to locate precisely the known ore deposits.

III.3.2 - Amazon Region

Appendix III.2 reports the main findings on ERTS-1 applications to geology and mineral resources in the Brazilian Amazon Region, and its comparison with SLAR imagery performance.

The geologic map from Appendix III.3 synthetizes the main results obtained by the combination of remote sensing (ERTS and SLAR), geochronology, literature and field data directed towards the establishment of a model for the geologic development of the region during the Precambrian. Such a map at a 1:5,000,000 scale was obtained mainly by remote sensing data interpretation and was made in three months. As a by-product of this work it was possible to elaborate an attempt of metallogenic regionalization and to study the relationship of Precambrian structures with the Phanerozoic development of the region.

The main conclusions regarding the ERTS-1 MSS imagery performance for such purposes are included wit-in Appendix III.2. Nevertheless, some additional comments should be made:

a. Band 7 images proved to be the best ones for geological mapping in heavily forested areas, as opposed to savanna type areas where the band 5 images present better results;
b. Differences in forest density are well marked in band 7 imagery and can be used for geological units delineation or drainage pattern analysis;
c. Darker tones in band 7 images can be interpreted as soil exposures or lower reflectance of the vegetation over soils containing anomalous amounts of economically important elements. Examples for both cases are the lateritic crusts associated with iron deposits of the Serra dos Carajãs, and the vegetation over the bauxite deposits of the Trombetas River Valley;

d. If a multi-disciplinary program is under consideration, ERTS imagery will show an even better performance when compared with SLAR imagery.

III.3.3 - Structure Project

The main objective of the Structure Project is the structural mapping of the whole country at a 1:1,000,000 scale using ERTS-1 MSS imagery. This project intends to be the INPE's collaboration to the geological mapping of Brazil at that scale which is being conducted by the Departamento Nacional da Produção Mineral. This program is using the 4^o by 6^o quadrangles of the International Chart of the World on the Millionth Scale.

This program began in March 1974 and reports are not available yet. Four quadrangles are being interpreted at the present moment:

SD-22 - Goiãs (12^o-16^oS; 48^o-54^oWG)
SC-23 - São Francisco (8^o-12^oS; 42^o-48^oWG)
SD-23 - Brasīlia (12^o-16^oS; $42^o 48^o$WG)
SE-23 - Belo Horizonte (16^o-20^oS; 42^o-48^oWG)

From these, only the Goiãs quadrangle is ready for discussion. The other three quadrangles present some superposition with the São Francisco River Basin Project and the main conclusions were discussed earlier. Additional comments for the Goiãs Quadrangle are:

a. ERTS-1 MSS imagery proved to be very suitable for the proposed objectives. However once again it is stressed the necessity of field work for improving the quality of the results, particularly with respect to the diagnosis of lineaments;

b. As in geologic mapping, structural interpretation is better performed in band 5 and band 7 images;

c. The synoptic view characteristic of ERTS images made it possible to identify large structures previously unknown;

d. Intrusions, domes, faults, folds, lineaments, sediment-basement contacts, were the main structures identified. As a consequence it was possible to delineate the contours of the main geotectonic units present in the area.

III.3.4 - Other Areas

During the period covered by this report, imagery of other regions of the country were interpreted for geological purposes.

One of the most important works thus performed was the first ERTS-1 SLAR comparison in the Teresina region (Piauí State) and the coastal area of Maranhão-Piauí States. Interpretation of ERTS-1 and SLAR imagery was conducted separately by two geologists using all the available field and literature data. As a consequence the superiority of ERTS over SLAR data for geological mapping in savanna-type regions was demonstrated for the first time.

At the same time a group of the System Analysis Division of INPE performed a cost analysis of both systems considering the investments for acquisition and maintenance of our ERTS receiving and processing facilities. These studies have demonstrated that one sq. km of ERTS data (not including the space segment) costs about US$ 0.15 while the SLAR imagery acquisition have cost about US$5,00 per sq. km. It was also demonstrated that the amount and quality of the geological information was superior on the ERTS imagery, when compared with the SLAR data. As a result of this study we concluded that the use of ERTS imagery for geological mapping in such regions could be done with a cost/effectiveness ratio several orders of magnitude smaller when compared with the SLAR ratio.

Another important area was the central Rio Grande do Sul State and its bordering region with Uruguay. At this area occurs an important sequence of sedimentary, volcanic and plutonic rocks of Precambrian age. A NE trending fault system encloses important copper deposits. Geological maps at a 1:250,000 scale are available for most of the area, permitting a good comparison with the ERTS images.

The most important conclusions of this work were:

a. Band 5 images are the best for lithological mapping, allowing the distinction between basalt, granodiorite, granite, rhyolite, metasediments, sandstones, etc.;

b. Band 7 images were the best for structural interpretation and its use resulted in the definition of several new lineaments and faults, specially those NE trending which are important for mineralization;

c. Color composites are generally less suitable for geological interpretation as compared to the individual black and white paper prints;

d. Enlargements to 1:500,000 scale yielded a better definition for lithology, geological units boundaries and structural features.

Finally, several ERTS-1 frames from the southern portion of the Maranhão Sedimentary Basin were interpreted to test their applicability to geological mapping of monotonous sedimentary sequences. The main conclusions were:

a. Rock unit delineation was best performed in band 5 image due to the association between different lithologies and vegetation units;

b. In some areas band 6 image yielded better lithological identification;

c. Band 7 was the best one for structural interpretation;

d. The resulting geological map was more detailed than the previously available map.

The additional frames from the central part of Amazonas State were the first ERTS-1 images interpreted at INPE. At that occasion the potentialities of ERTS imagery was demonstrated for cartographic as well as for geological purposes. The conclusions of this work are very similar to those from item III.3.2 above.

The studies carried out at the northern part of the Goiãs State are very recent (November 1974) and were directed towards the comparison between ERTS-1 and SLAR imagery and pre-existing maps. The main efforts were directed towards the structural interpretation from remote sensing data. The conclusions of this work were:

a. It was possible to construct a structural map at a 1:1,000,000 scale with much more detail than present in previously existing maps;
b. ERTS-1 imagery yielded more structural data when compared with SLAR data. The same was true when compared with conventional photo-interpretation of 1:60,000 aerial photographs;
c. Previously mapped structural features could be extended and better located;
d. It was possible to delineate different geotectonic units based on the structural features extracted from the imagery.

III.4 - CONCLUSIONS

1 - The results previously discussed are self-explanatory with regard to the large amount of new geological information which resulted from ERTS-1 imagery interpretation;

2 - The programs, in most part, were carried out in a semi-operational basis resulting in several new geological maps which are being used by the country's geological community;

3 - These programs demonstrated that ERTS-1 imagery can be used at a lower cost/effectiveness ratio when compared to SLAR imagery and conventional aerial photographs. Related to this is the generally shorter time involved in the interpretation of ERTS-1 data;

4 - Conventional photo-interpretation techniques were used almost exclusively. Bands 5 and 7 proved to be the most effective for geological problems. Bands 4 and 6 yielded very few additional data when compared with the other two. Field control was made only in very restricted areas;

5 - As by-products of the programs it was possible to introduce important corrections on the already existing cartographic maps, thus permitting a better

location of the geological features. It was also possible to delineate areas with higher probability to enclose mineral deposits.

III.5 - ACKNOWLEDGEMENTS

The development of the INPE's Group for Geology and Mineral Resources would not be possible without the support received from several national organizations, mainly the Ministry of Mines and Energy, the Ministry of Interior and the Bank for National Economic Development.

During all the phases of the program we received the incentive and the support from Dr. Fernando de Mendonça, General Director of the Institute for Space Research - INPE.

ANNEX III-1

1 - SÃo Francisco River Region

E-1424-12195	E-1424-12201	E-1371-12240	E-1371-12242
E-1371-12245	E-1371-12251	E-1065-12253	E-1371-12260
E-1389-12255	E-1047-12262	E-1371-12263	E-1371-12265
E-1047-12271	E-1048-12294	E-1426-12284	E-1048-12300
E-1048-12303	E-1048-12305	E-1048-12312	E-1066-12312
E-1426-12302	E-1048-12314	E-1066-12314	E-1426-12305
E-1048-12321	E-1048-12323	E-1048-12330	E-1049-12352
E-1391-12351	E-1049-12355	E-1391-12353	E-1373-12361
E-1391-12360	E-1373-12364	E-1391-12362	E-1391-12365
E-1391-12371	E-1391-12374	E-1373-12382	E-1391-12380
E-1391-12383	E-1050-12411	E-1338-12420	E-1392-12412
E-1338-12422	E-1392-12414	E-1374-12422	E-1392-12421
E-1338-12431	E-1392-12423	E-1392-12430	E-1338-12440
E-1392-12432	E-1392-12435	E-1339-12472	E-1339-12474
E-1339-12481-	E-1339-12483		

2 - Amazon Region

E-1387-13551	E-1387-13544	E-1418-13271	E-1417-13203
E-1387-13558	E-1417-13214	E-1417-13220	E-1418-13232
E-1418-13235	E-1361-13084	E-1361-13091	E-1360-13033
E-1360-13035	E-1360-13042	E-1360-13044	E-1372-12561
E-1372-12564	E-1372-12570	E-1376-12505	E-1376-12512
E-1376-12514	E-1376-12521	E-1376-12523	E-1532-13554
E-1380-13135	E-1380-13141	E-1380-13144	E-1380-13150
E-1380-13153	E-1381-13192	E-1381-13200	E-1417-13194
E-1224-13465	E-1224-13472	E-1224-13474	E-1224-13501
E-1134-13500	E-1008-13490	E-1008-13493	E-1008-13495

E-1224-13513	E-1058-13234	E-1058-13241	E-1058-13243
E-1146-13124	E-1218-13125	E-1218-13132	E-1218-13134
E-1221-13303	E-1239-13304	E-1221-13301	E-1239-13310
E-1077-13302	E-1149-13322	E-1221-13324	E-1239-13324
E-1239-13331	E-1239-13333	E-1239-13340	E-1237-13184
E-1237-13191	E-1237-13193	E-1399-13194	E-1093-13210
E-1399-13201	E-1399-13203	E-1381-13211	E-1381-13214
E-1240-13371	E-1240-13374	E-1096-13381	E-1240-13385
E-1168-13381	E-1168-13383	E-1240-13392	E-1096-13384
E-1168-13390	E-1096-13390	E-1240-13394	

3 - Structure Project (Goiās Quadrangle)

E-1339-12481	E-1339-12483	E-1339-12490	E-1088-12535
E-1376-12535	E-1376-12541	E-1377-13000	E-1377-12593
E-1377-12591	E-1360-13053	E-1360-13051	E-1360-13044

4 - Additional Frames

E-1048-12282 - Terezina, Piauī State
E-1048-12273 - Coastal area of Piauī and Maranhão States
E-1107-13011 - Araguainha Dome - Goiās State
E-1105-12532 - Central Rio Grande do Sul State
E-1105-12535 - Central Rio Grande do Sul - Uruguay
E-1048-12294 - South Piauí - North Bahia
E-1049-12343 - Boa Esperança Dam - Maranhão - Piauī Border
E-1050-12411 - SW part of the Parnaība Basin - Maranhão-Goiās
E-1008-13481 - Solimões-Purus Rivers - Amazonas State
E-1008-13484 - Purus-Madeira Rivers - Amazonas State
E-1376-12521 - Northern Goiās State
E-1376-12523 - " " "
E-1123-12472 - " " "
E-1123-12474 - " " "

APPENDIX III.1

to Chapter III

INPE-395-LAFE
Project SERE

GEOLOGY OF THE AREAS OF THE UPPER SÃO FRANCISCO BASIN AND FURNAS DAM (BRAZIL) BASED ON INTERPRETATION OF ERTS-1 IMAGERY

by

C.C. Liu
C.C. Carraro*
S.K. Yamagata

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* Universidade Federal do Rio Grande do Sul, I.G.
cursando pós-graduação no INPE.

cc.:100

PRESIDÊNCIA DA REPÚBLICA
CONSELHO NACIONAL DE PESQUISAS
INSTITUTO DE PESQUISAS ESPACIAIS
São José dos Campos - Estado de S. Paulo - Brasil

GEOLOGY OF THE AREA OF THE UPPER SÃO FRANCISCO BASIN AND FURNAS DAM (BRAZIL) BASED ON INTERPRETATION OF ERTS-1 IMAGERY

The present work is a result of research being carried out at this Institute, within the Program of Natural Resources Survey of its SERE Project, using images produced by the Multispectral Scanning System (MSS) on board the first Earth Resources Technology Satellite (ERTS-1).

Printing of the report has been authorized by the undersigned

Fernando de Mendonça
General Director

RESUMO

Esta é a primeira tentativa de utilização de imagens produzidas pelo "Multispectral Scanning System" (MSS) do primeiro Satélite Tecnológico para Recursos da Terra (ERTS-1), como uma ferramenta de mapeamento geológico. O reconhecimento geológico estendeu-se da região do Alto São Francisco até à borda Noroeste da Bacia do Paraná, numa área de aproximadamente 300.000 km^2.

As imagens MSS do ERTS foram analisadas visualmente pela técnica convencional de interpretação de fotos aéreas. O intérprete reconhece unidades geomórficas pela análise e interpretação de elementos tais como padrão de drenagem, formas de relevo, tons de cinza, vegetação e feições características. Pelo estudo dos elementos, continuidade de feições geomórficas ou litológicas e lineações topográficas, podem ser diferenciadas unidades de mapeamento e identificadas feições tectônicas. As imagens MSS do ERTS provaram ser uma ferramenta de sensoriamento remoto efetiva para reconhecimento geológico regional no Brasil.

Abstract

This is the first attempt to use the imagery produced by the Multispectral Scanner Subsystem (MSS) of the first Earth Resources Technology Satellite (ERTS-1) as a geological reconnaissance tool in mapping a broad region from the upper drainage area of the São Francisco basin to the northeast rim of the Paraná basin.

The ERTS' MSS imagery was studied and evaluated by visual means. Conventional techniques of photointerpretation have been used since the MSS imagery can be studied as a photo-like image. The interpreter recognizes terrains from it by analysing and interpreting the photo-like elements drainage patterns, landforms, tonality characteristic features, vegetation, and so on.

From the study and analysis of such elements, the continuity of the geomorphy or lithology, and the topographic lineaments, a series of satellite mapping units can be differentiated, and various tectonic features can be identified.

ERTS' MSS imagery is proving to be an effective remote sensing tool for regional geologic reconnaissance in Brazil.

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CHAPTER I

INTRODUCTION

In the space age, a new technology has been and is being developed fast. This new technology is remote sensing, which is used to increase knowledge about the earth without actually touching it.

Various forms of remote sensing, including conventional and unconventional photography and imagery, cover a wide field of scientific and practical applications, geology being one of the most important.

Geologic maps are essential to prospect for mineral resources and important aids in agronomy, civil engineering, etc. Geologic mapping with the new techniques is fast, economic and can be carried out independently of local conditions such as climatic and geographic. It is most adaptable in the case of remote areas not geologically mapped and even completely uncharted.

Brazil has participated in cooperative aircraft remote sensing programas with the U.S., in the earth resources field, since 1968. In order to participate in remote sensing from satellites a complete earth receiving station has been installed at Cuiabá, in Mato Grosso, and the processing system is at Cachoeira Paulista, in

São Paulo, where the tapes from Cuiabá are processed into computer compatible tapes for automatic data interpretation and images.

The Earth Resources Technology Satellite (ERTS) has been designed as a research and developement tool for the Earth's resources on a global basis. The four channels Multispectral Scanner Subsystem (MSS) is one of the sensors carried by the ERTS. The MSS collects data by continually scanning the ground directly beneath the spacecraft. The width of the strip is 185 km. During ground processing, framed images in the format of 70 mm (scale 1:3369.000) or 23 cm (scale 1:1000.000) are constructed from the continuous strip. INPE gets copies of the MSS film from the Ground Data Handling Systems (GDHS) at the NASA Goddard Space Flight Center in Greenbelt, Md, USA. INPE'S Laboratory produces black and white copies of the MSS films from each spectral band for use in research work.

The areas of this study, the upper drainage of São Francisco River and the Furnas Dam are parts of the research scheme that was scheduled by the RECMI group of the SERE - INPE. The first area is covered by two neighboring orbits with seven sets of images and the second, by one orbit with two sets of imagery. Each set of images has four images in different spectral bands. Each image covers approximately 185 x 185 km.

The geological interpretation of the ERTS imagery was conducted by visual examination. The conventional technique of interpretation of aerial photos is used to interpret ERTS-MSS imagery. During the visual examination of the imagery the following techniques were tried: 1) each individual spectral band print was studied by close visual inspection with or without magnifier; 2) comparing these four spectral band prints; 3) interpretation of these prints on an overlay and comparing with geological map, if any; 4) interpreting the regional geology on an overlay of the mosaic covering the whole area of study.

Geologic maps were prepared assigning symbols to each remote sensing unit representing different rock type and various geologic structural features were obtained also. There is an indication, from this work, that reconaissance geologic maps can be made by visual interpretation using ERTS'MSS imagery.

CHAPTER II

REMOTE SENSING, ERTS, AND MSS IMAGERY

2.1 - REMOTE SENSING

Remote Sensing may be defined as the detection, recognition or evaluation of objects by means of distant sensing or recording devices.

An early and still the most useful form of remote sensing is photography. Conventional photo techniques record scenes on film sensitive to visible electromagnetic energy. With the development of space age, a number of devices, sensitive to various portions of electromagnetic spectrum, have been and are being developed. These devices can produce magnetic tapes, photographs, or other types of images and may be carried either on aircraft or on satellites.

2.2 - ELECTROMAGNETIC RADIATION AND ELECTROMAGNETIC SPECTRUM

Electromagnetic radiation is energy transferred both as waves travelling at a constant speed through free space and as distinct quanta of energy; it is characterized chiefly by wavelength and frequency.

The concept of electromagnetic spectrum is that of a continuum consisting of the ordered arrangement of radiation according to wavelength or frequency. At present the electromagnetic energy used in remote sensing is in the portion of electromagnetic spectrum shown in Figure 1.

2.3 - ERTS

ERTS in an abbreviation of Earth Resources Technology Satellite. The ERTS program is one of the American space programs scheduled by NASA (National Aeronautics and Space Administration).

The first one, ERTS-1, was launched on July 23, 1972 and has been operative since then (Figure 2).

2.4 - ERTS-1 ORBITAL DATA

1. Shape of orbit: circular
2. Altitude: 920 km.
3. Period: The satellite circles the Earth in 103.3 minutes
4. Ground speed of sub-satellite point: 6,47 km/sec.
5. The ERTS orbit is sun-synchronous, i.e., the local time along the orbit is a constant. It is 09:30 a.m. on the day time side
6. Inclination of orbit: 99^0

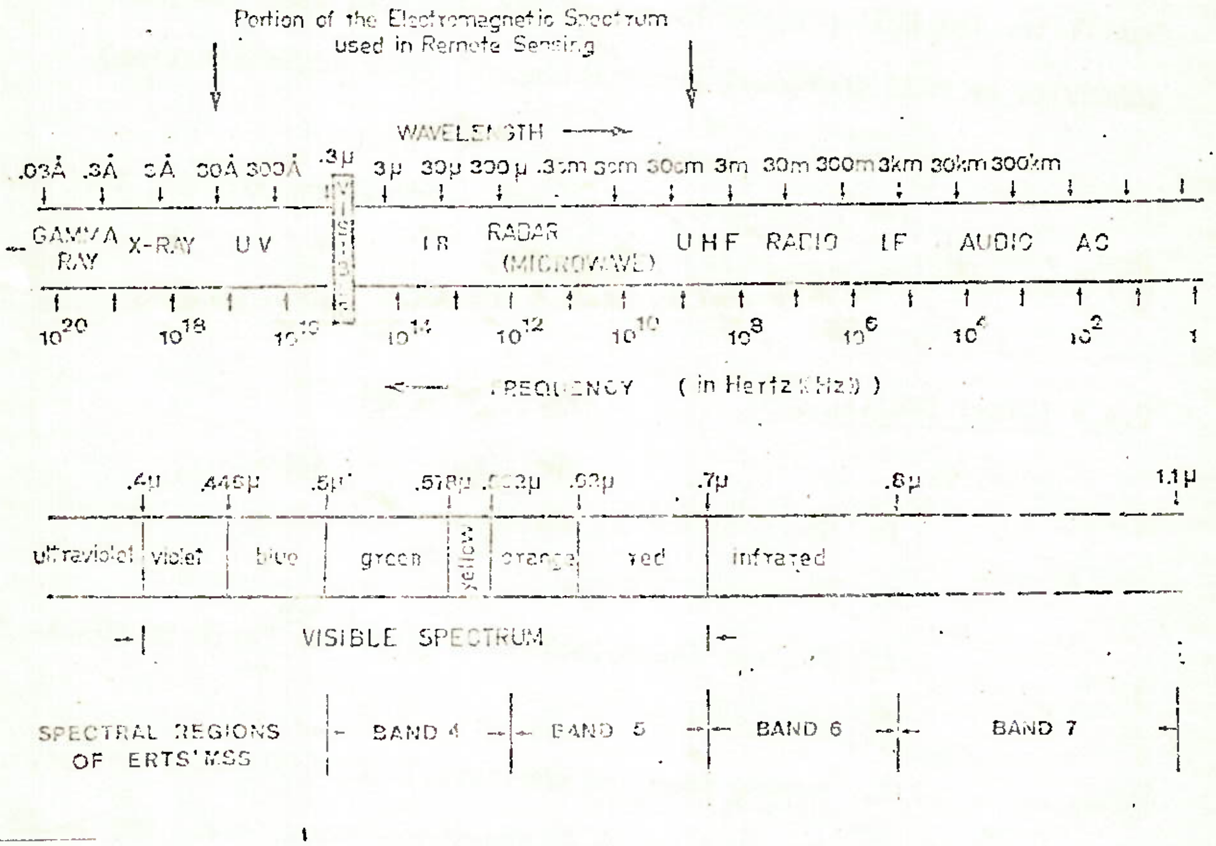


Figure 1 - Portion of the electromagnetic spectrum used in remote sensing.

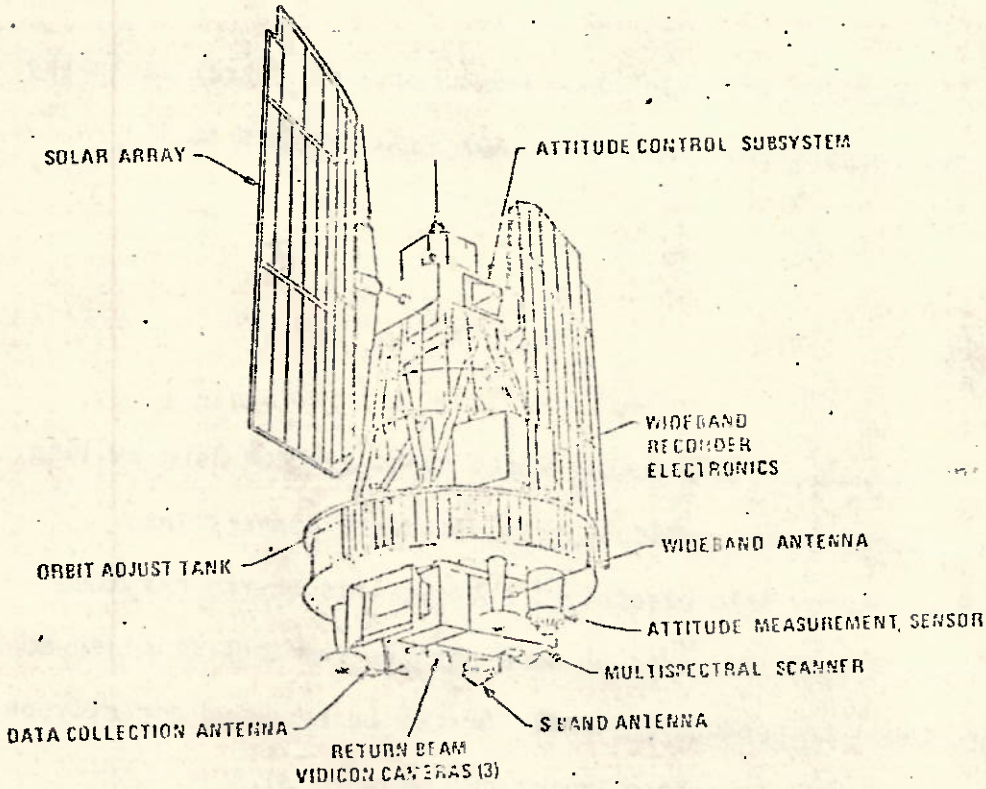


Figure 2 - Schematic ERTS-1 configuration.

2.5 - MSS

ERTS carries three kinds of sensors to survey the Earth's surface, one of them is the MSS, an abbreviation of "Multispectral Scanner System" (Figure 3).

The MSS for ERTS-1 is a 4-band scanner operating in the solar-reflected spectral band region from 0.5 micrometers to 1.1 micrometers.

2.6 - SCANNER

A scanner is a sensor which scans a scene line by line. Unlike conventional photographic cameras, scanners convert the electromagnetic energy into electrical energy. This energy may then either activate a light source such as a cathode ray tube (similar to a TV picture tube) to produce an image, or may be recorded directly on magnetic tape (similar to a tape recorder). (Figure 3).

2.7 - MSS OPERATION

As the scan mirror oscillates plus and minus 2.89 degrees about its nominal position, an 11.56 degrees crosstrack field of view is scanned at a right angle to the direction of the satellite motion. Six detectors are assigned to each spectral band, so that six scan lines are recorded simultaneously (Figure 4).

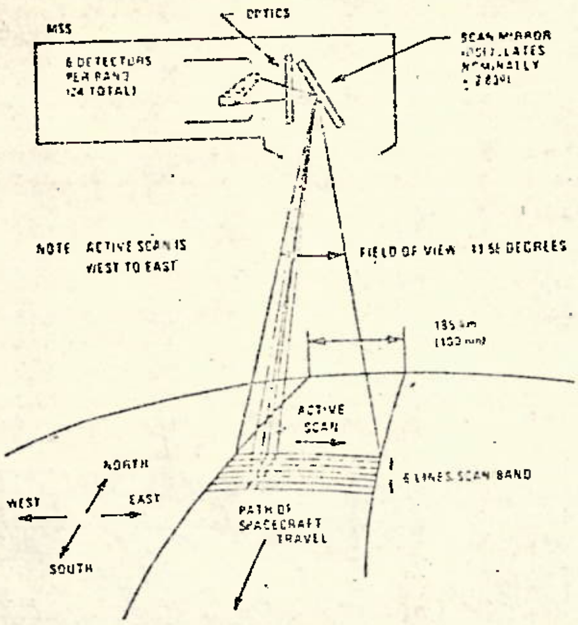


Figure 3 - MSS Scanning arrangement.

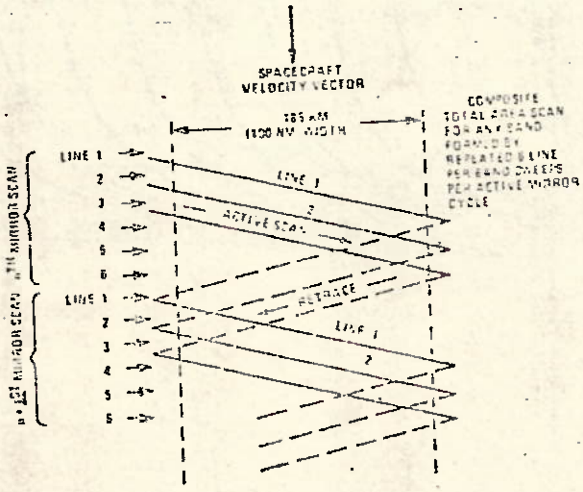


Figure 4 - Ground scan pattern for a single MSS detector.

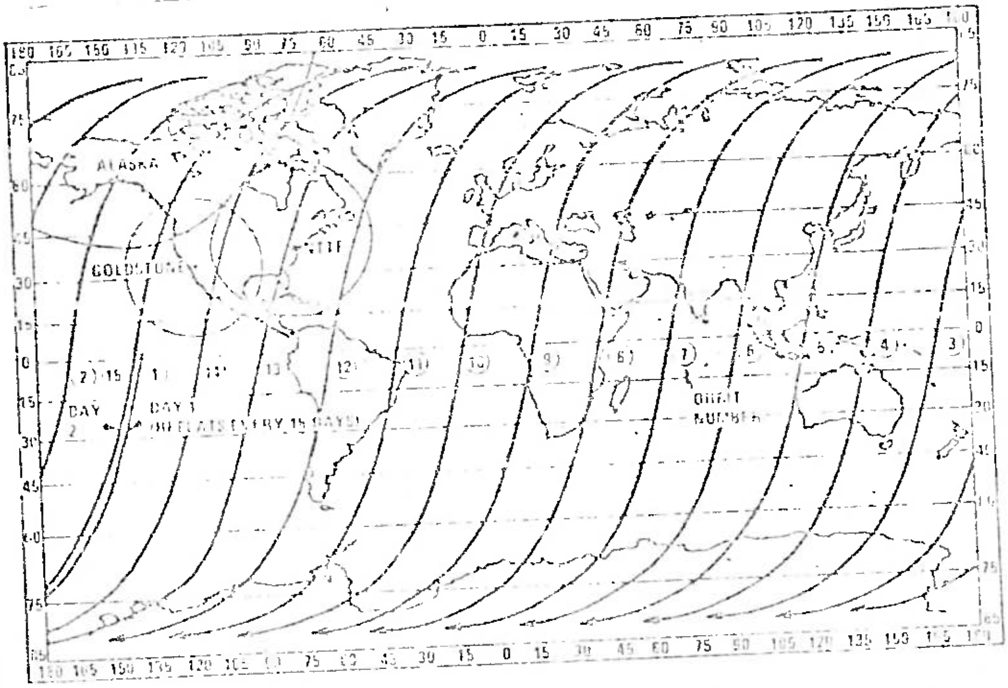


Figure 5 - Typical ERTS Daily ground trace (daylight passes only).

ERTS' MSS scans crosstrack swaths of the ground coverage of 185 kilometers width in continuous fashion along the direction of the track. As the satellite circles the Earth every a hundred and three minutes, it completes 14 orbits per day. Therefore, the westward subsatellite trace progresses 25.8^{o} from one orbit to the next. The gaps are filled in successively during an 18-day period and so, on each 19th day the satellite duplicates the pass made at the beginning of the period. As a result, the sensor views the entire Earth every 18 days (Figure 5), and may produce 20 complete coverages per year at the Equator and low latitudes.

2.8 - MSS IMAGERY MANAGEMENT

At present, data acquired over the Earth are transmitted in real-time to Earth, on command, when the spacecraft is within sight of one of the ground receiving stations. The MSS produces continuous strip imagery. During image data reduction, the continuous strip imagery is transformed into framed imagery with a 10% lengthwise overlap and a area coverage of approximately 185 x 185 kilometers. Sidelap of adjacent orbits is 14% at the Equator, increasing toward the poles.

The linear resolution capability of MSS imagery is of the order of 70-100 meters.

CHAPTER III

IMAGERY INTERPRETATION METHODS

3.1 - ELEMENTS ANALYSIS

The interpretation of the MSS imagery was conducted by visual examination. With the output array of MSS imagery, basic techniques developed for photogeologic interpretation are quite applicable. The interpreter identifies features by observing and analysing elements such as:

a) drainage patterns - arrangements of ramified channels
b) landforms - surface features of the Earth.
c) tonality - color values of terrain objects on the imagery translated into different tones ranging from pure white to black and all gray shades in-between.
d) characteristic features, such as erosional escarpments, sink holes, etc.
e) vegetation - often representing texture, moisture and topographic nature.
f) land use - often associated with soil types, related to underlying mother rocks.

3.2 - CONTINUITY ANALYSIS AND OUTLINING THE REMOTE SENSING MAPPING UNITS

Construction of a geologic map is based upon the distribution and attitude of the remote sensing units which have to be identified and outlined on the imagery. The analysis and interpretation of above mentioned elements are aids for tracing units and outlining their boundaries.

The sharpness of a boundary depends mainly on the different resistance to erosion between two units. Delineation of a boundary is limited to the visible features, and the ability to follow it depends on the continuity expression of the imagery.

It is quite possible to outline boundaries on the imagery when a distinctive difference in drainage pattern exists. A tonality contrast is frequently a good guide in the outlining process. The role of different density of vegetation coverage is often of help in outlining units because vegetational zones may indicate different types of soil, each associated to specific kind of rocks. The contact between depositional and erosional areas, or, in other words, between hilly terrain and floodplain of river deposits, is usually easy to follow on the imagery.

In geological mapping it is important to observe the continuity of geomorphic or lithologic units which is fundamental in the structural and geologic evaluation of an area.

Identification of rock types from the MSS imagery is, for the most part, impossible, because of

i, the low linear resolution capability of MSS (70-100 meters)

ii, the absence of stereoscopic vision

iii, the small scale (1:1,000,000).

Such scale also fails to present the minor or detailed topographic features and the characteristic surface textures.

Based on the drainage pattern analysis, tonal contrast and vegetation density, we can only give a roughly petrologic evaluation of the remote sensing units even those units are mainly lithologic.

3.3 - STRUCTURE ANALYSIS

MSS imagery, because of its extensive coverage, enables the interpreter to discover subtle topographic differences over long distances, thus providing a distinct advantage for delineating linear features which are usually indicative of faulting. Fault interpretation from MSS imagery is based on the following main recognition categories:

a) scarps, which are the most conspicuous and common fault indications.

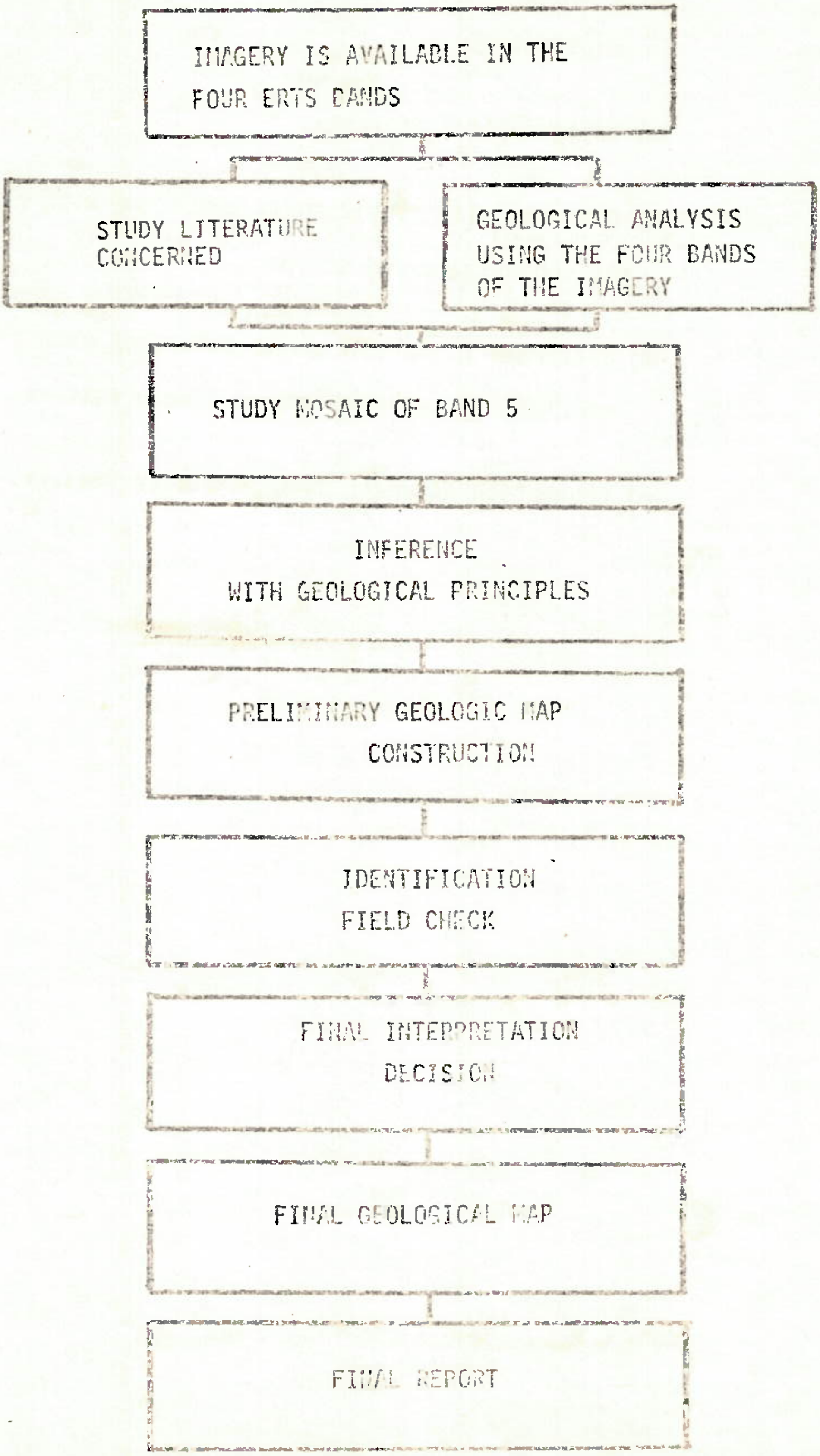
b) topographic lineaments

c) different lithologic units contacted with rather straight or smoothly curved scarps

d) different lithologic units contacted with a rather straight or smoothly curved linear feature

e) truncation of units along a linear feature.

3.4 - STUDY PROCEDURE



CHAPTER IV

COMPARISON AMONG THE FOUR BANDS

4.1 - BAND 4

1 - Tonal contrast is not as clear as in band 5
2 - Water bodies show uniform dark gray or light gray tones. Their boundaries are not clear and sometimes cannot be distinguished from the vegetation
3 - Drainage patterns are shown but not clearly
4 - Remote Sensing unit boundaries are not as clear as in band 5
5 - Topographic lineaments are not clear
6 - Highways and cities can be identified partly.

4.2 - BAND 5

This band is more valuable than the other in terms of geologic mapping.

1 - Tonal contrast is good
2 - The boundary of water bodies is very sharp and can be outlined easily
3 - Drainage patterns show very well

4 - Remote sensing units can be distinguished, and their boundaries can be traced
5 - Topographic lineaments show clearly
6 - Cities and highways can be identified.

4.3 - BAND 6

1 - Tonal contrast is poor
2 - Water bodies appear clearly
3 - Drainage pattern is obscured
4 - It cannot be used for mapping lithologic units
5 - Topographic lineaments can be examined
6 - Cities and highways are obscured.

4.4 - BAND 7

1 - Tonal contrast is poor
2 - Main river courses show clearly
3 - Drainage patterns rather obscured
4 - Remote sensing units can be distinguished
5 - Topographic lineaments can be examined
6 - Cities and highways are not shown clearly

Table 1 - Comparison among the four bands

ELEMENTS \ BAND	4	5 *	6	7
Tonal contrast	**	***	*	*
Waterbodies & their boundaries	*	**	***	***
Drainage patterns	**	***	*	**
Separation of remote sensing units	*	***	*	**
Topographic lineaments	*	***	**	***
Highways & cities	**	**	*	**

* Band 5 is the most valuable in terms of geologic mapping among the four bands

*** EXCELLENT

** GOOD

* POOR

CHAPTER V

GEOLOGICAL INTERPRETATION OF THE UPPER SÃO FRANCISCO BASIN (MAP 1)

5.1 - REMOTE SENSING UNITS

UNIT A and UNIT B belong to the basement complex. Their differentiation is chiefly based on different tonal appearance.

The boundary of UNIT C is not clear.

UNIT D displays dark gray tone, prominent topographic features and it contacts with other units by erosional scarps.

UNIT E is differentiated from UNIT D by different topographic features displayed.

UNIT F shows medium gray tone, even surface texture and wide-spaced dendritic drainage pattern.

UNITS G_1, G_2, G_3, G_4 and C_5 are differentiated by such different elements as: tonality, drainage pattern, surface texture, and so on (Plate 1).

UNIT G shows a spotted tonal pattern and wide-spaced drainages. It connects with UNIT G_2 and UNIT G_4 as their continuation. Therefore, UNIT G has the facies change into G_1, G_2, G_3, G_4 and G_5. (Plate 2).

UNIT H is discordantly overlaid on UNITS G_{1-5}. It shows light gray tone and dendritic drainage patterns.(Plate 1).

UNIT J shows smooth surface texture, light to medium gray tonal pattern and well spaced drendritic drainage (Plates 1,2,3).

UNIT K is covered by dense vegetation (bare fields show light tone) and is bordered by sharp erosional escarpments. It is discordantly overlaid on the units above mentioned (Plate 1).

UNIT L denotes older floodplains which are developed on both sides of the São Francisco River and differentiated from UNIT M by straight and sharp erosional scarps (Plates 2, 3 and 4).

UNIT M is distributed along both sides of São Francisco River. This unit represents younger floodplains, on which, abandoned channels, sand bars, oxbow lakes, and scars of former stream course are well seen (Plates 2, 3 and 4).

5.2 - THE AREA OF TRES MARIAS: A SUB-BASIN

The area of Tres Marias is surrounded by mountain ranges and rolling hills. Numerous drainages, originated from the surrounding mountain ranges are all running down into Tres Marias dam. This minor tectonic province can be identified on the MSS mosaic.

5.3 - FAULTS AND FRACTURES

Based on the recognition categories of faulting features mentioned previously, numerous big faults are shown on the geologic map by longer dashed lines. When identification is uncertain, these fault or joints are shown by shorter dashed lines.

CHAPTER VI

COMPARATIVE ANALYSIS BETWEEN IMAGERY INTERPRETATION AND GEOLOGIC FIELD WORKS IN THE UPPER SÃO FRANCISCO BASIN

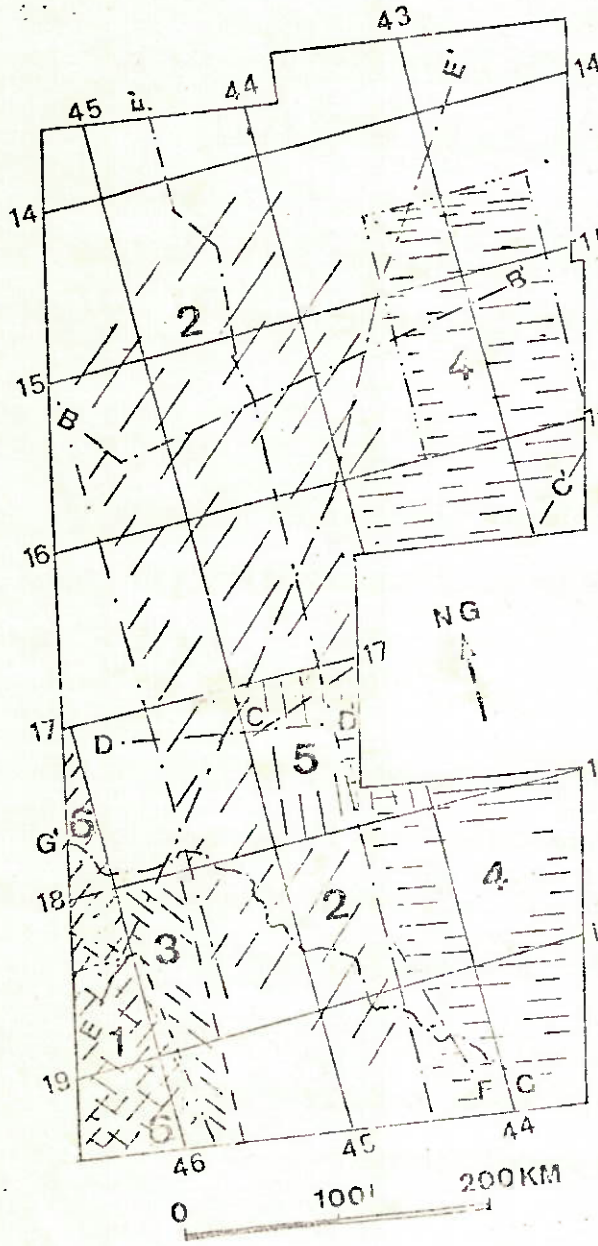
6.1 - Oliveira, M.A.M - contribuição à geologia da parte Sul da Bacia do Rio São Francisco, e áreas adjacentes (1967) Profiles BB', CC', DD', EE' and FF (Figure 6).

The main object of this geologic work was to delineate the calcareous rocks of the Bambuí Group and to study the possibility of oil occurrence in the São Francisco Basin.

The pre-Cambrian rocks of Minas Series, distributed in the north of Belo Horizonte, are correlated to Units A and B; the sandstones of the bottom of Lavras Series to Unit D and the glacial, fluvio-glacial and glacio-lacustrine deposits of the Jequitaí Series to Unit E.

The Unit G, north of Tres Marias, is correlated to the dolomitic limestones and lutites of the Bambuí Series.

The Units J and K, distributed in the northern corner of the area, are correlated to the Urucuia Formation. Oliveira described this lithologic unit as a sequence of subaqueous and eolian clastic deposits such as shale, arenaceous mudstone and argillaceous sandstones.



1. Hasui, Y. (1968)
2. Barbosa, O. et al (1937)
3. Ladeira, E.A. Brito, OEA (1968)
4. Pflug, R. & Renger, F. (1973)
5. DNPM (1967)
6. Braun, D.P.G. (1968)

BB', CC', DD', EE', FF' — Oliveira, M.A.M. (1967)

GG' — Branco, J.J.R. (1961)

Figure 6 - Geologic works in the upper São Francisco Basin Area.

Oliveira also described that the top of the Formation is highly silicified and this formation is discordantly overlaid on the limestones of the Bambuī Group. The surface of discordance dips gently to the east, from altitude 750 m in the Geral de Goiãs Mountain Range down to 500 m near the São Francisco River.

That the writer divided this formation into two aerogeologic Units (J and K) is based upon the different landforms, the different tonality, and the different drainage patterns shown in the ERTS' MSS imagery mentioned in the previous chapter. Different landforms and different drainage patterns reveal different erosional processes. Therefore, taking these characteristics into account it is possible to identify this formation in two mapping units.

Unit L is interpreted in this work as older alluvial sediments overlaying on the Bambuī Group.

Unit G, distributed near Pirapora, and Unit G_4, along the Indaiã River, are correlated to the Três Marias Formation. Oliveira described the Três Marias Formation as consisting of arkosic, sandstones, arkoses, sometimes fine grained greenish gray graywackes which are associated with siltstones and slates.

Unit F, distributed in the West of Carmo do Paranaîba, corresponds at the profile to Santa Helena Formation,are mainly slates (Plate 4).

Unit G_2 is correlated to Lagoa do Jacarē Formation, a sequence of metamorphosed muddy siltstone, silty slates and dark gray oölitic limestones.

6.2 - HASUI, Y - A formação Uberaba (1968) Area 1 (Figure 6).

The part of Unit K, distributed in the southwestern corner of the area, is correlated to the Uberaba Formation. According to Hasui's description, this formation is composed mainly of volcanic sandstone with calcite cement or green argillaceous matrix, siltstone, mudstone, conglomeratic sandstone and conglomerate. Oliveira (1969) states that all the plateaus or mesas distributed in the southern part of the area of study from Carmo do Paranaîba to Pirapora are of this formation. This lithologic unit is unconformably overlying on the sandstone layers of the Areado Group which is correlated to Unit H.

6.3 - LADEIRA, E.A. & BRITO, O.E.A de - Contribuição ã geologia do Planalto da Mata da Corda, Area 2 (Figure 6) According to Ladeira et al., the Areado Group consists of three Formations: Abaetē - eolian sandstone, Quiricō - shale and mudstone, and Tres Barras - sandstone. Unit H is correlated to the Tres Barras Formation.

Ladeira et al. designated the tuffs and lavas which are overlying on the Tres Barras Formation as Mata da Corda Group.

6.4 - PFLUG, R & RENGER, F - A evolução geológica da margem SE do Craton São Francisco (1973) Area 4 (Figure 6).

An advanced copy at the geologic map of the Serra do Espinhaço was used to compare with the photo-interpretation. Due to the complexity of the geology in this area, the resultant photo interpretation did not show the same detail as the map. Otherwise, it was possible with band 5 imagery to discriminate phyllite (light gray tone) from quartzite (dark gray tone) of the Minas Series (Unit D), distributed along the western scarp of the Serra do Espinhaço.

In general, Units A, B and C are correlated to pre-Minas basement rocks, mainly gneisses and granites; Unit E is correlated to Macaúba Group, and Units G, and G_2 are correlated to Bambuí Group.

6.5 - DNPM - Folha de Pirapora MG. Area 5 (Figure 6).

The Unit G, distributed in the east of Pirapora, is correlated to the slates and arkoses of the Bambuí Group. The Unit L, according to the geologic map of the area, corresponds to older alluvial sediments overlying on the Bambuí Group; the Unit K is correlated to the Macaúbas Group and the Unit D corresponds to be quartzites and phyllites of the Minas Series, as mentioned before.

6.6 - BRAUN, O.P. - Contribuição ā estratigrafia do Grupo Bambuī (1968).
Area 6 (Figure 6)

There is the following correlative relationship between the imagery and the geologic map prepared by Braun. The Unit G, distributed near the Paracatu River, is correlated to the Tres Marias Formation, which was described by Braun as a sequence of arkose, micaceous siltstone, siltic grayWacke and arkosic sandstone. The Unit L and G, distributed southwardly, are correlated to the Paraopeba Formation, both carbonatic and clastic rocks. The Unit F, distributed in the area west of Carmo do Paranaība, is correlated to Paraopeba Formation, but the contact between this Formation and the granite and gneisses wasn't observed in the imagery.

6.7 - BRANCO, J.J.R. ed. - Roteiro para a Excursão Belo Horizonte - Brasilia (1961) Profile GG' (Figure 6).

The profile, made by Branco along the BR-040 highway and presented at the Congress of Geology held in Belo Horizonte, was used by the authors to establish a correlation. The lower boundary of the Bambuī group, in contact with granitic rocks in the north of Belo Horizonte and the upper boundary in contact with cretaceous sandstones, at west of Abaetē River, were delineated thoroughly by the interpretation of the imagery.

Otherwise, it was not possible to correlate the remote sensing Units G_1, G_2, G_3, G_4, I and L to the lithologic units mapped by Branco.

6.8 - BARBOSA, O. & OPPENHEIM, V. - Sobre a geologia da Bacia do São Francisco no norte de Minas Gerais (1937) Area 2 (Figure 6).

An extensive preliminary geological survey was held by Barbosa in the São Francisco Basin, from Belo Horizonte to Rio Carinhanha. The limestone of the Bambuí Group is correlated to Unit G and the continental sandstone of the Bauru "Series" is correlated to Units J and K.

TABLE 2 - CORRELATION OF THE REMOTE SENSING UNITS TO THE GEOLOGIC MAPPING UNITS IN THE UPPER SÃO FRANCISCO BASIN

	OLIVEIRA, M.A.M (1967)	HASUI, Y (1963)	LADEIRA, E. A. et. al. (1968)	PFLUG, R. et. al. (1973)	D.N.P.M. (1967)	BRAUN, O. (1968)	BRANCO, J. J. R. (1961)
L	Sete Lagoas F. (Bambuí G.)				Alluvium/ Bambuí G.	Paraopeba G.	
K	Urucuia F.	Uberaba F.	Mata da Corda G.			Cretaceous SS.	
J							Cretaceous SS.
I							
H			Areado G. Tres Barras F.			Cretaceous SS.	
G	Tres Marias F. Bambuí G.				Bambuí G.	Tres Marias F. Paraopeba F.	
G_5							Bambuí G.
G_4	Tres Marias F. Bambuí G.						Bambuí G.
G_3							Bambuí G.
G_2	Lagoa do Jacaré F. Bambuí G.			Bambuí G.			Bambuí G.
G_1				Bambuí G.			
F	Santa Helena F. Bambuí G.					Paraopeba F.	
E	Jequitaí S.			Macaúbas F.	Minas S.		
D	Lavras S.			Minas S.	Minas S.		
C				Pré-Minas			(Gneisses)
B	Minas S.			Pré-Minas			
A	Minas S.			Pré-Minas			

CHAPTER VII

GEOLOGICAL INTERPRETATION OF THE REGION OF FURNAS DAM (MAP 2)

7.1 - REMOTE SENSING UNITS

UNIT A and B are basement complex separated mainly by tonality, the former shows darker and the latter brighter (Plate 5).

UNIT C shows gray tone and dendritic drainage pattern (Plate 6).

UNIT D is unconformable overlaying on UNIT C, folded and faulted independently. It shows even surface texture and prominent uplands and flat ridge landforms (Plate 6).

UNIT E_1, E_2, E_3 and E_4 are separated by their different gray tone, drainage pattern, and the vegetation distributed. These units are in unconformable contact with Unit C (Plate 6).

UNIT F_1 is easily separated from UNIT B because of the following elements (Plate 5).

UNIT F_1	UNIT β
lighter gray tone	darker gray tone
wide-spaced drainage pattern	no drainage
smooth surface texture	rough surface texture
cultivated	less cultivated

UNIT F_2 shows darker gray tone, wide spaced drainage pattern and less cultivation (Plate 5).

UNIT β appears topographically higher than the surrounding terrain and can be outlined by the erosional scarps. It also shows darker gray tone and rough surface texture (Plates 5 and 6).

UNIT α shows a circular feature. It is covered by thick soil (Plate 5).

UNIT G can be separated from the surrounding terrain by the drainage pattern. On UNIT G, gullies are much shorter (Plate 6).

UNIT H shows light gray tone and dendritic drainage pattern (Plate 6).

UNIT I shows dark gray tone, smooth surface texture and table-land topographic feature fringed with erosional scarps (Plate 6).

UNIT J shows gray tone and even surface texture. It is unconformably overlying on the units mentioned above. (Plates 5 and 6).

7.2 - TECTONIC PROVINCES

The area north of the Furnas Dam belongs to São Francisco Basin. This sedimentary basin connects with basement complex by a big transverse fault zone as shown in the Geologic Map.

The margin of the Paraná Basin extends to the West of Poços de Caldas.

7.3 - FAULTS AND UNKNOWN CIRCULAR FEATURES

Based on the recognition categories of faulting features mentioned previously, numerous big faults are shown on the geologic map by longer dashed lines, and fractures are shown by shorter dashed lines.

There are many previously unknown circular features in the area of the Basement Complex.

CHAPTER VIII

COMPARATIVE ANALYSIS BETWEEN IMAGERY INTERPRETATION AND GEOLOGIC WORKS IN THE FURNAS DAM REGION

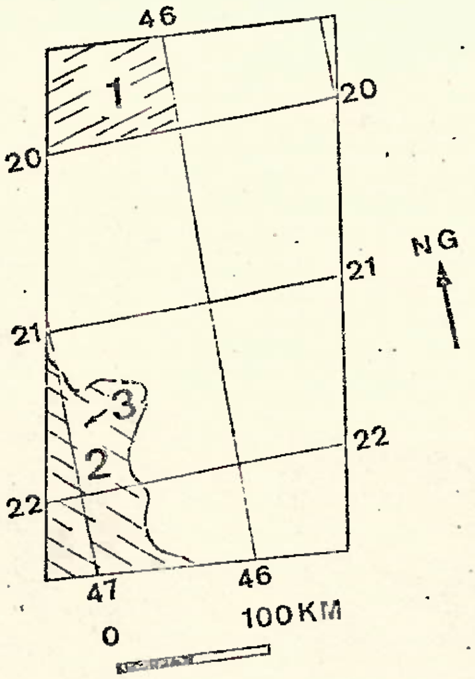
8.1 - BARBOSA, O. et al - Geologia da região do Triangulo Mineiro (1970) Area 1 (Figure 7).

The geologic map of the Araxa Quadrangle was used by the authors to correlate to the imagery interpretation.

The Units C and D are correlated to the Canastra Araxã and Ibiã Group. The Units E_3 and E_4 are correlated to the Paraopeba Formation which was described by Barbosa as slate, siltstone and calcareous argillite. The lower boundary of the Areado Formation (Unit I), in contact with the Bambuí Group, was located along the erosional scarp.

8.2 - Instituto Geográfico e Geológico - Mapa geológico do Estado de São Paulo (1963) Area 2, (Figure 7)

The boundary between the Paranã Basin rocks (Unit F_1) and the rocks of the basement complex (Units A and B) is evident in the imagery and coincides thoroughly with the geologic map. Unit F_1 is correlated with Tubarão Group and Unit B, to intrusive basic rocks.



1 1. BARBOSA, o. et.alii(1970)

2 2. I.G.G. (1963)

3 3. OLIVEIRA, MAF de (1972)

Figure 7 - Geologic works in the Furnas Dam Area

8.3 - OLIVEIRA, M.A.F. de - Geologia e petrologia da Região de São José do Rio Pardo, Estado de São Paulo (1972) Area 3 (Figure 7).

This work represents a detailed petrographic survey of metamorfic rocks, mainly gneisses, which are correlated to the Unit B.

Table 3 - Correlation of the Remote Sensing Units to the Geologic Mapping Units in the Region of Furnas Dam

	BARBOSA, O. et. alii. (1970)	IGG (1963)	OLIVEIRA M.A.F. de (1972)
J			
I	Areado F.		
H			
G			
α		Alkaline Intrusive Rocks	
β		Diabase	
F_2	Paraopeba F. (Bambuí G.)	Tubarão G.	
F_1			
E_4			
E_3			
E_2			
E_1			
D	Ibiá G. Canastra G. Araxá G.		
C			
B		Pre-Cambrian	Gneisses
A		Pre-Cambrian	

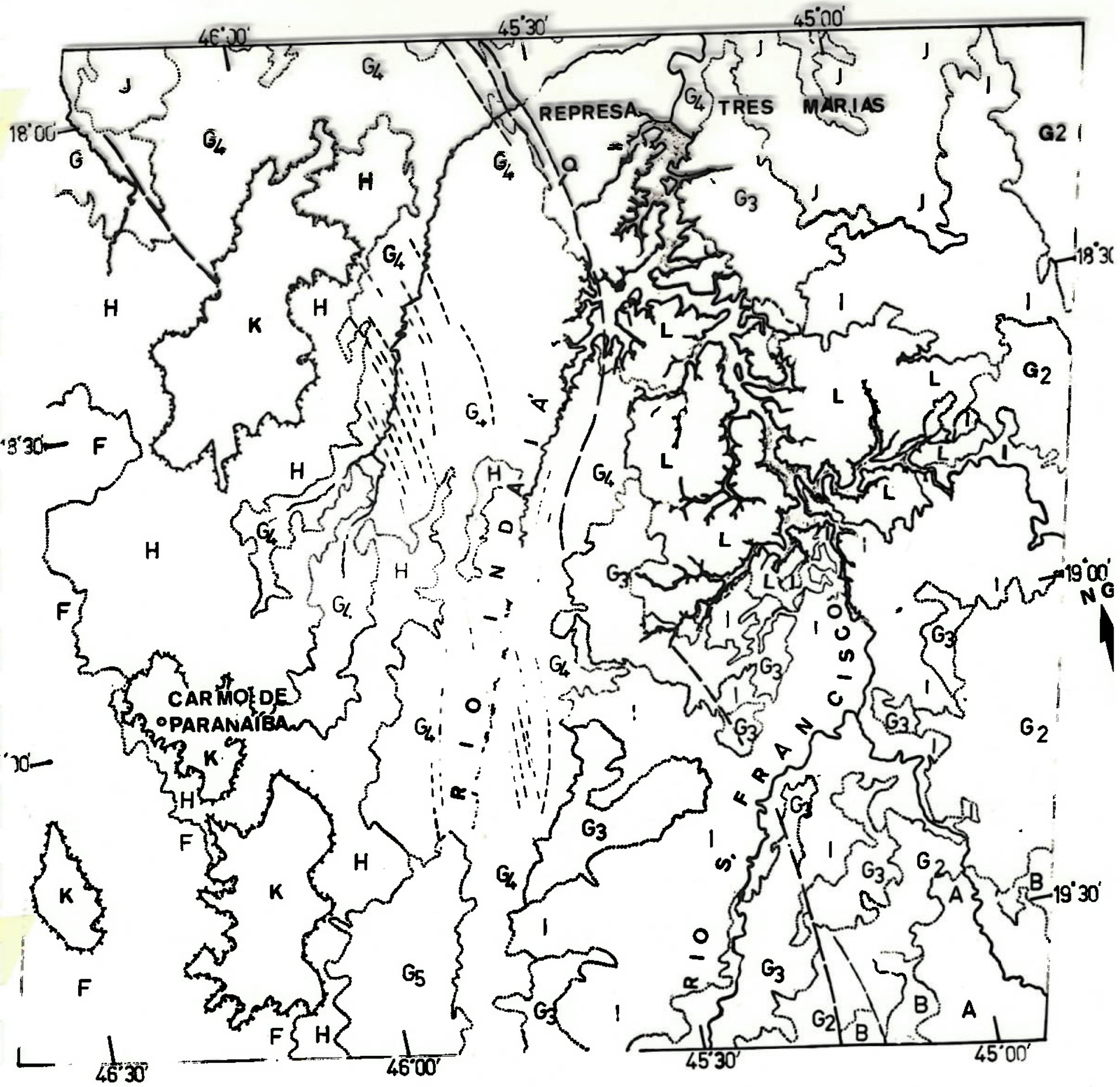
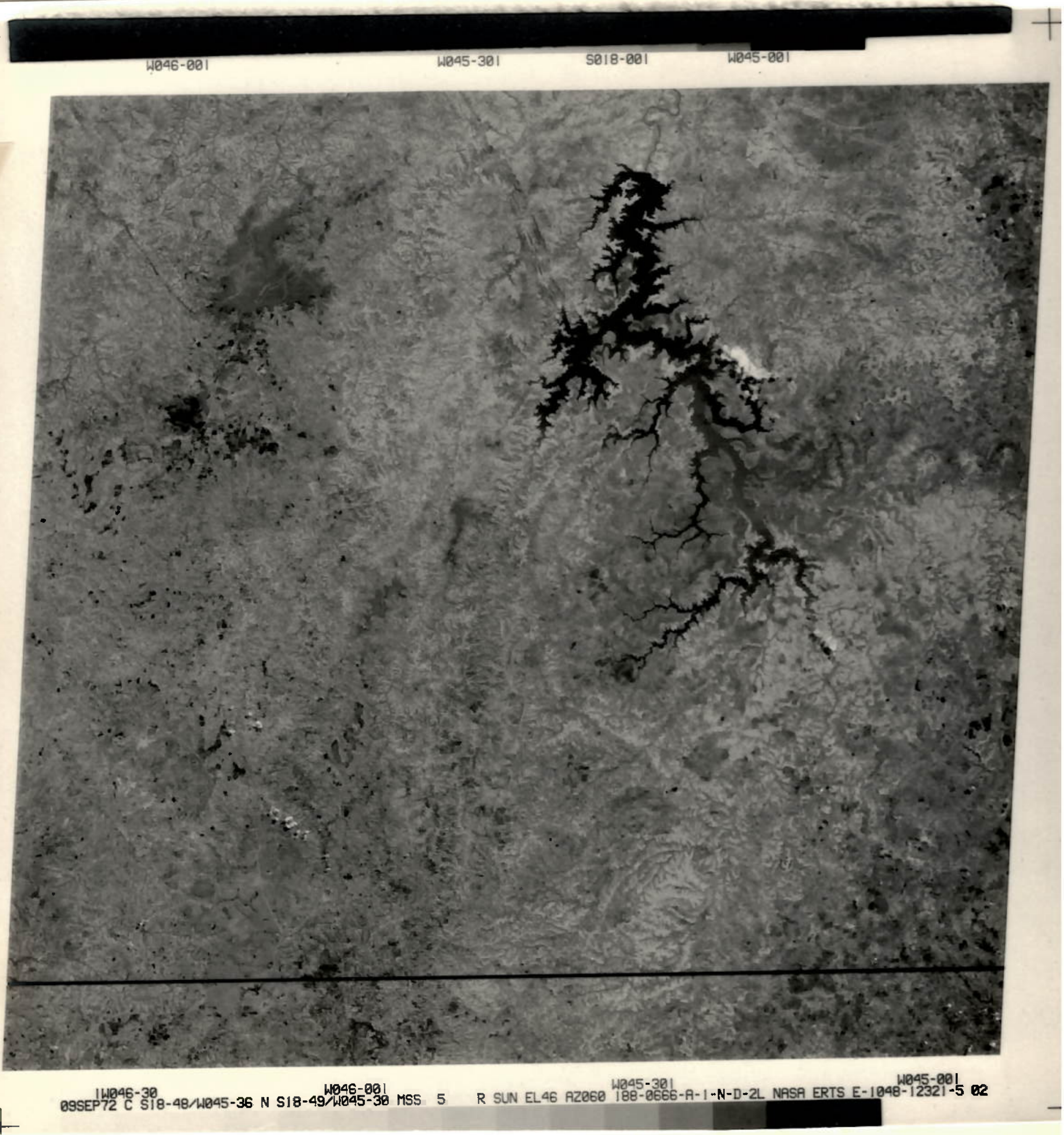
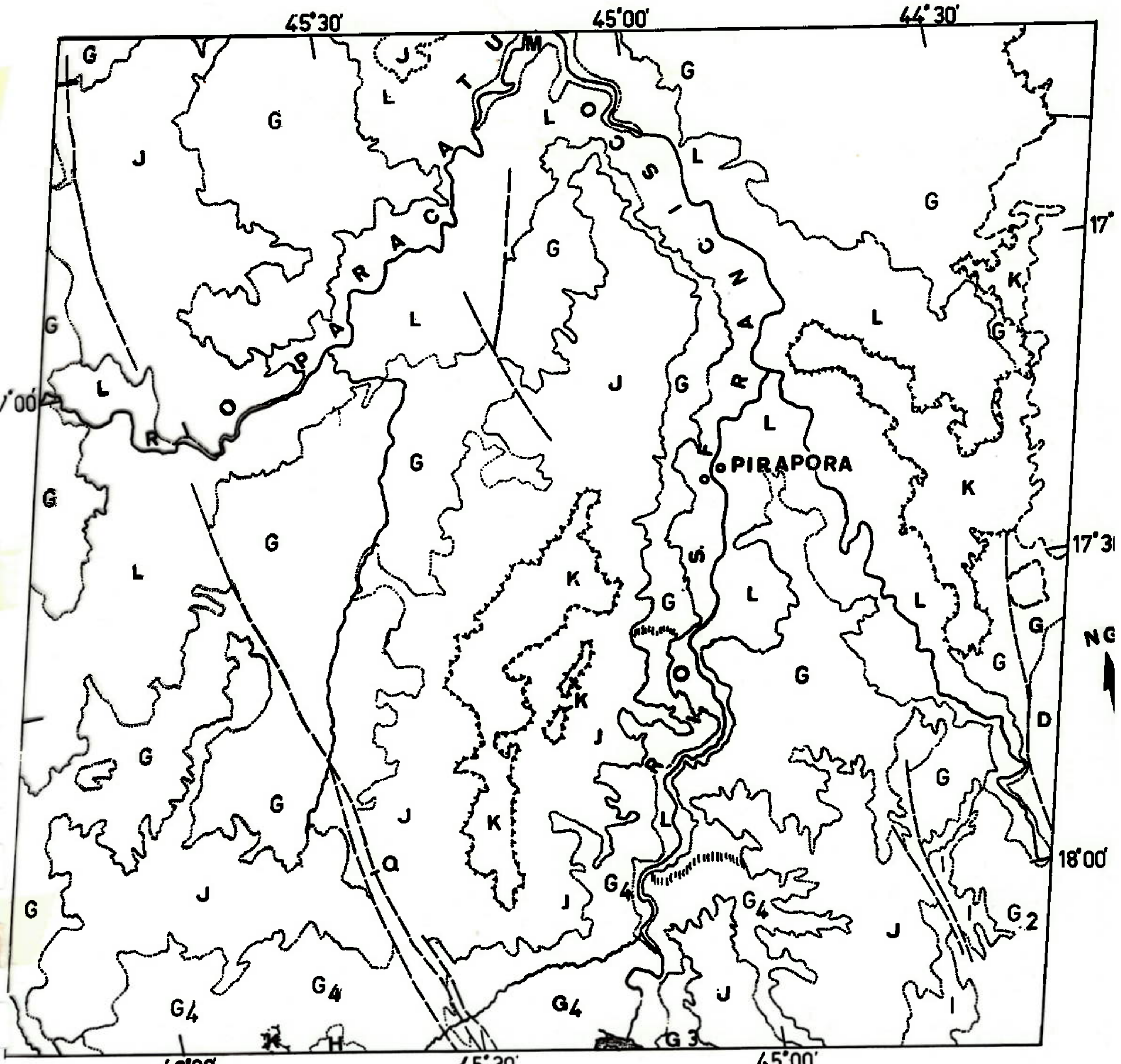

46°00'
45°30'
45°00'
18°00'
18°30'
19°00'
19°30'
46°30'
REPRESA TRES MARIAS
CARMO DE PARANAIBA
RIO INDAIÁ
RIO S. FRANCISCO
NG

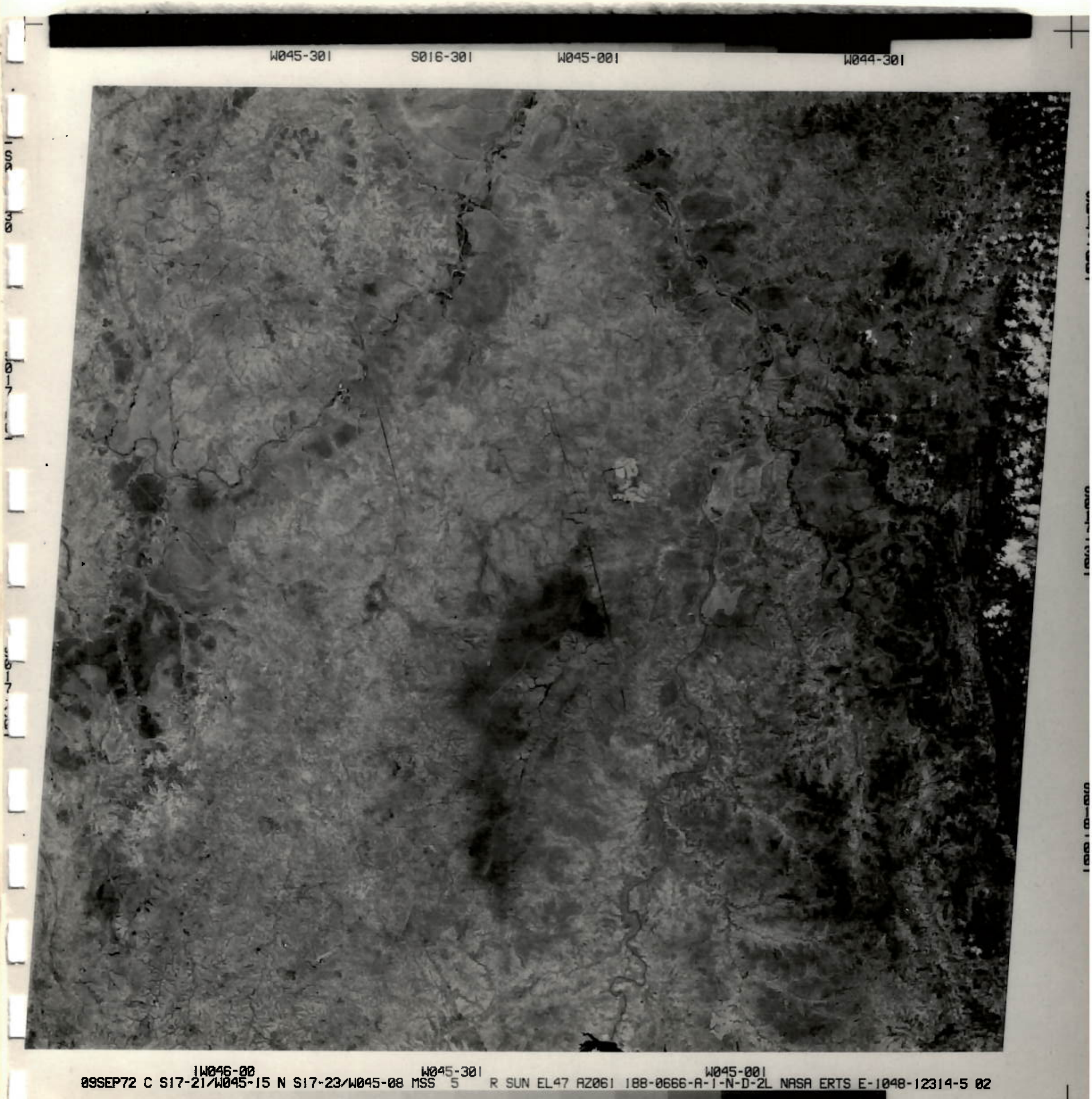
PLATE 1

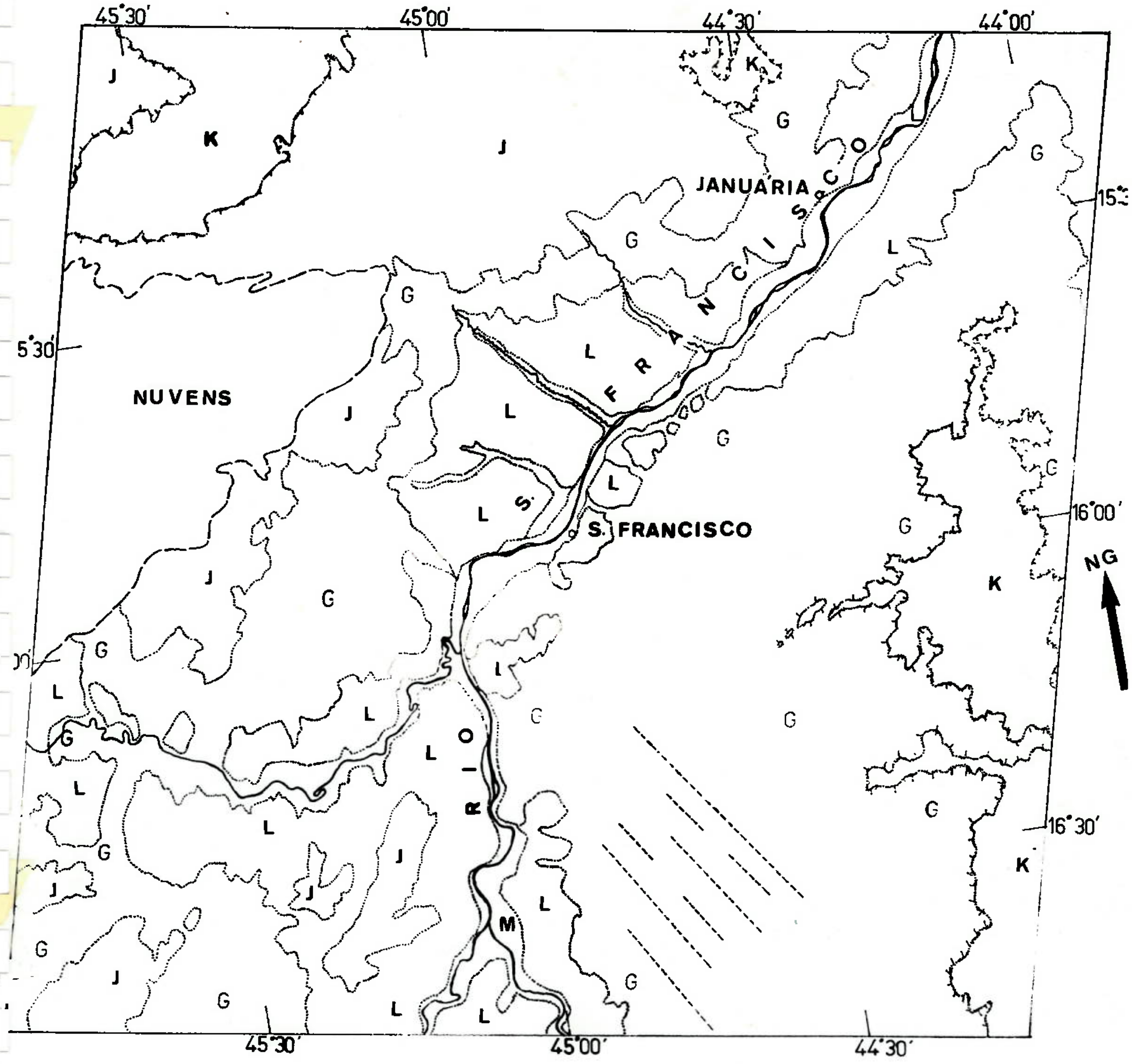

W046-001
W045-301
S018-001
W045-001
1W046-30
W046-001
W045-301
W045-001
09SEP72 C S18-48/W045-36 N S18-49/W045-30 MSS 5 R SUN EL46 AZ060 188-0666-A-1-N-D-2L NASA ERTS E-1048-12321-5 02



45°30'
45°00'
44°30'
17°00'
17°
17°30'
18°00'
46°00'
45°30'
45°00'
PIRAPORA
RIO PARACATU
RIO SAO FRANCISCO
NG
G
J
L
K
D
Q
G4
G2
G3
H
I

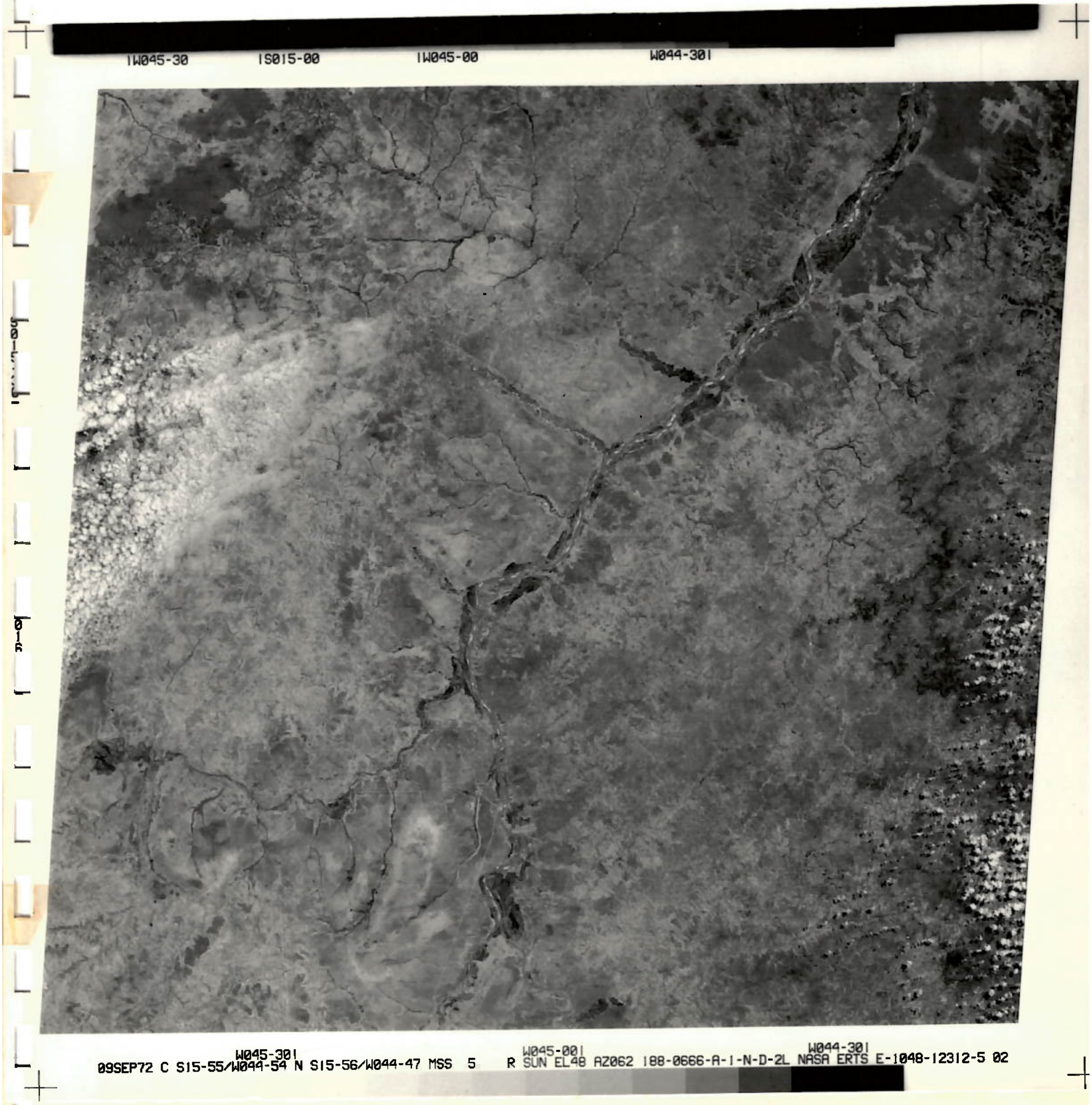
PLATE 2


W045-301
S016-301
W045-001
W044-301
1W046-00
W045-301
W045-001
09SEP72 C S17-21/W045-15 N S17-23/W045-08 MSS 5 R SUN EL47 AZ061 188-0666-A-1-N-D-2L NASA ERTS E-1048-12314-5 02

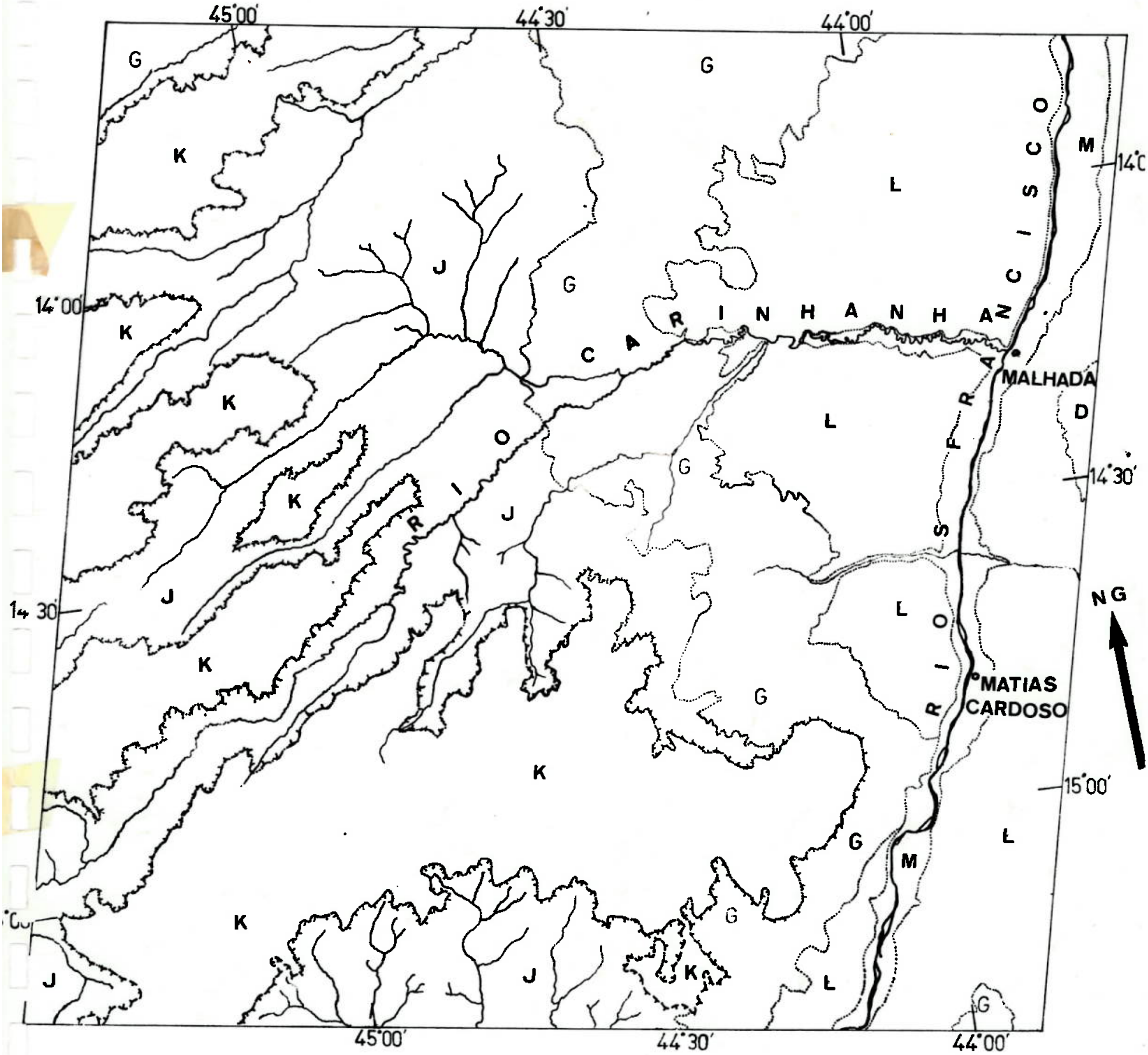


45°30'
45°00'
44°30'
44°00'
JANUARIA
NUVENS
S. FRANCISCO
RIO S. FRANCISCO
15°30'
16°00'
16°30'
NG
45°30'
45°00'
44°30'
J
K
L
G
M

PLATE 3

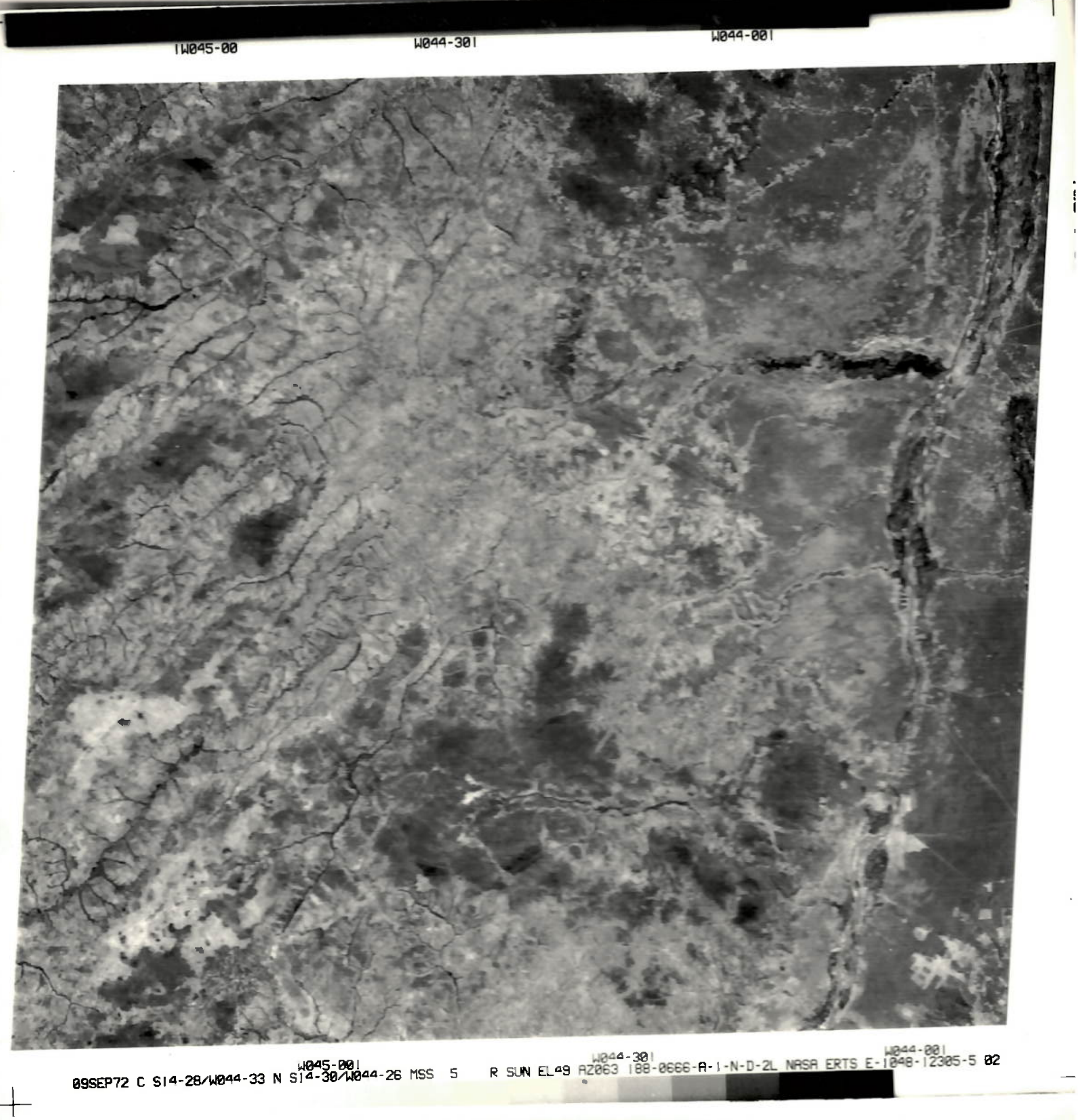


1W045-30
1S015-00
1W045-00
W044-301
W045-301
W045-001
W044-301
09SEP72 C S15-55/W044-54 N S15-56/W044-47 MSS 5 R SUN EL48 AZ062 188-0666-A-1-N-D-2L NASA ERTS E-1048-12312-5 02



45°00'
44°30'
44°00'
14°00'
14°30'
15°00'
G
K
J
L
M
D
RIO CARINHANHA
RIO SÃO FRANCISCO
MALHADA
MATIAS CARDOSO
NG

PLATE 4


W045-00
W044-30
W044-00
W045-00
W044-30
W044-00
09SEP72 C S14-28/W044-33 N S14-30/W044-26 MSS 5 R SUN EL49 AZ063 188-0666-A-1-N-D-2L NASA ERTS E-1048-12305-5 02

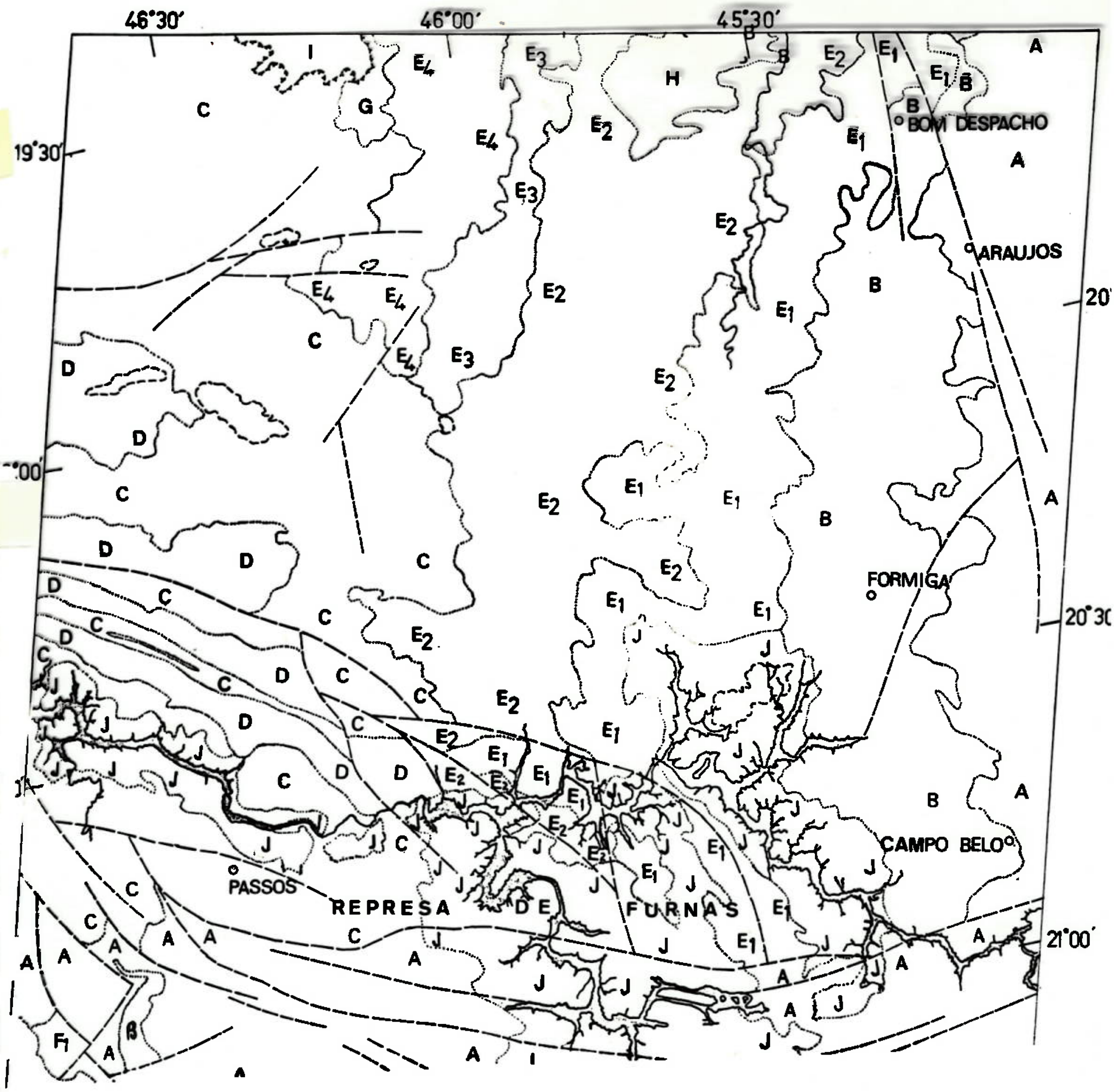
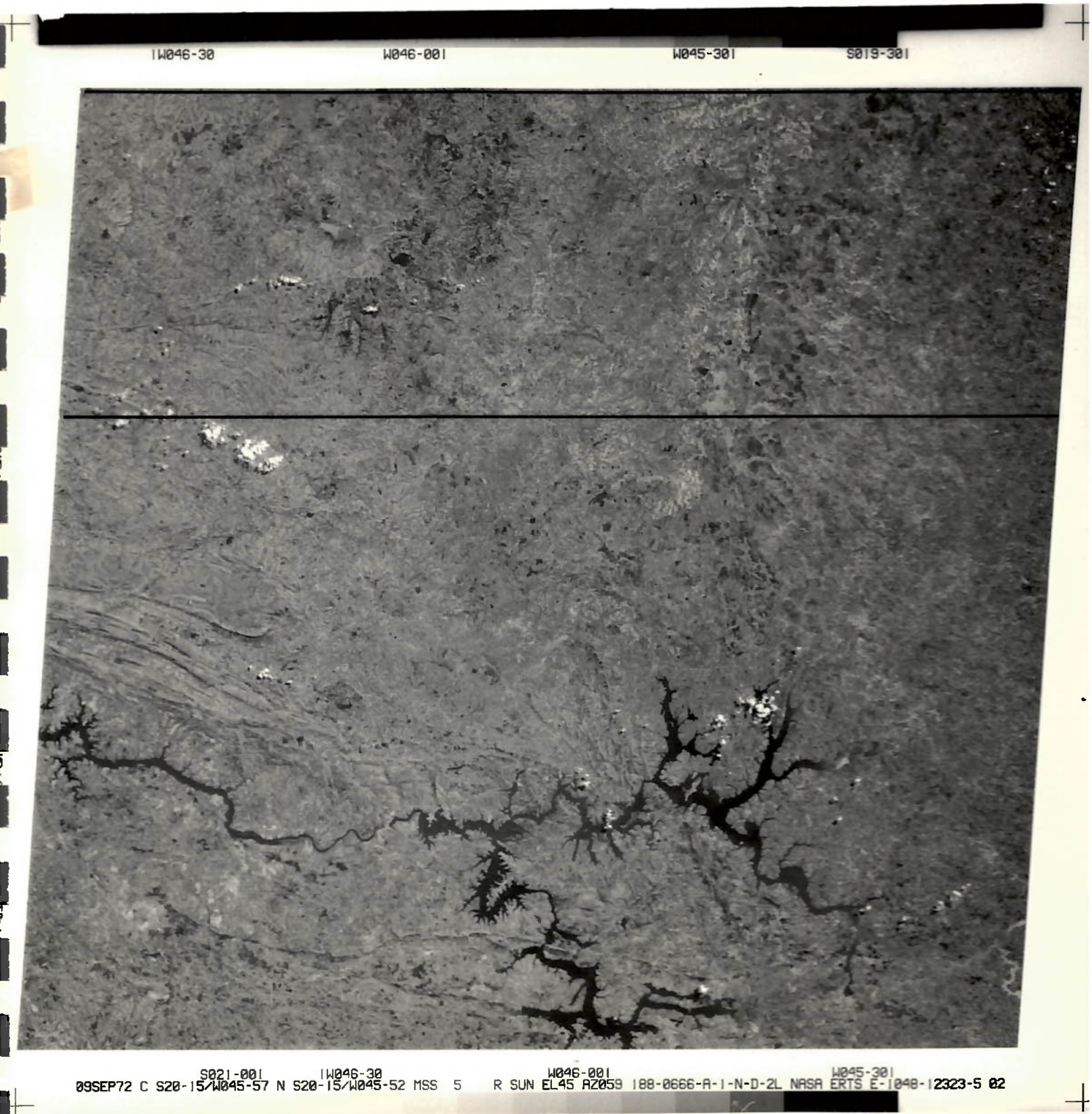
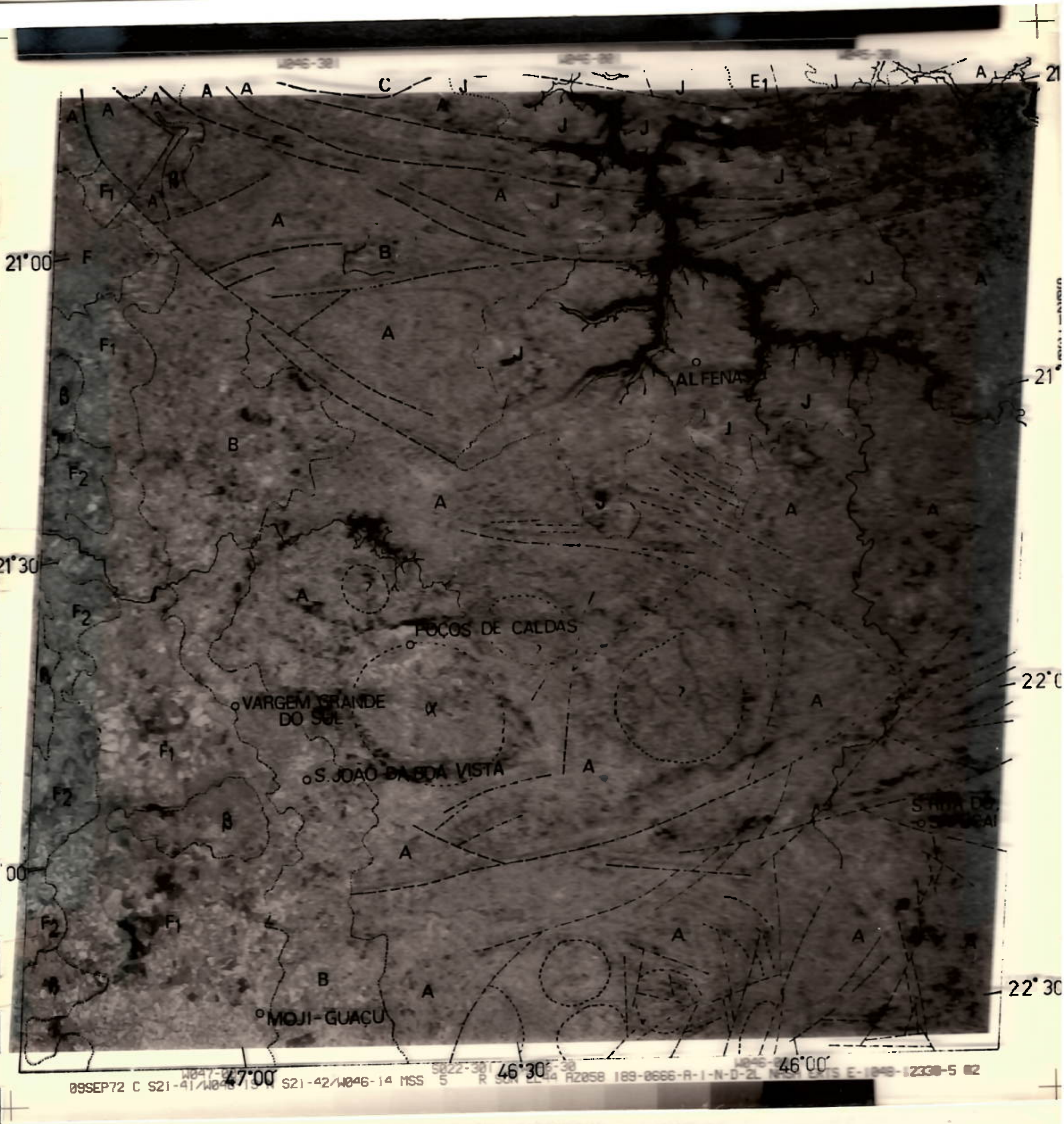

46°30′
46°00′
45°30′
19°30′
20°
20°30′
21°00′
BOM DESPACHO
ARAUJOS
FORMIGA
CAMPO BELO
PASSOS
REPRESA DE FURNAS

PLATE 5



1W046-30
W046-001
W045-301
S019-301
S021-001
1W046-30
W046-001
W045-301
09SEP72 C S20-15/W045-57 N S20-15/W045-52 MSS 5 R SUN EL45 AZ059 188-0666-A-1-N-D-2L NASA ERTS E-1048-12323-5 02

PLATE 6



ALFENAS
POÇOS DE CALDAS
VARGEM GRANDE DO SUL
S. JOÃO DA BOA VISTA
MOJI-GUAÇU
21°00'
21°30'
22°30'
47°00'
46°30'
46°00'

MAP 1

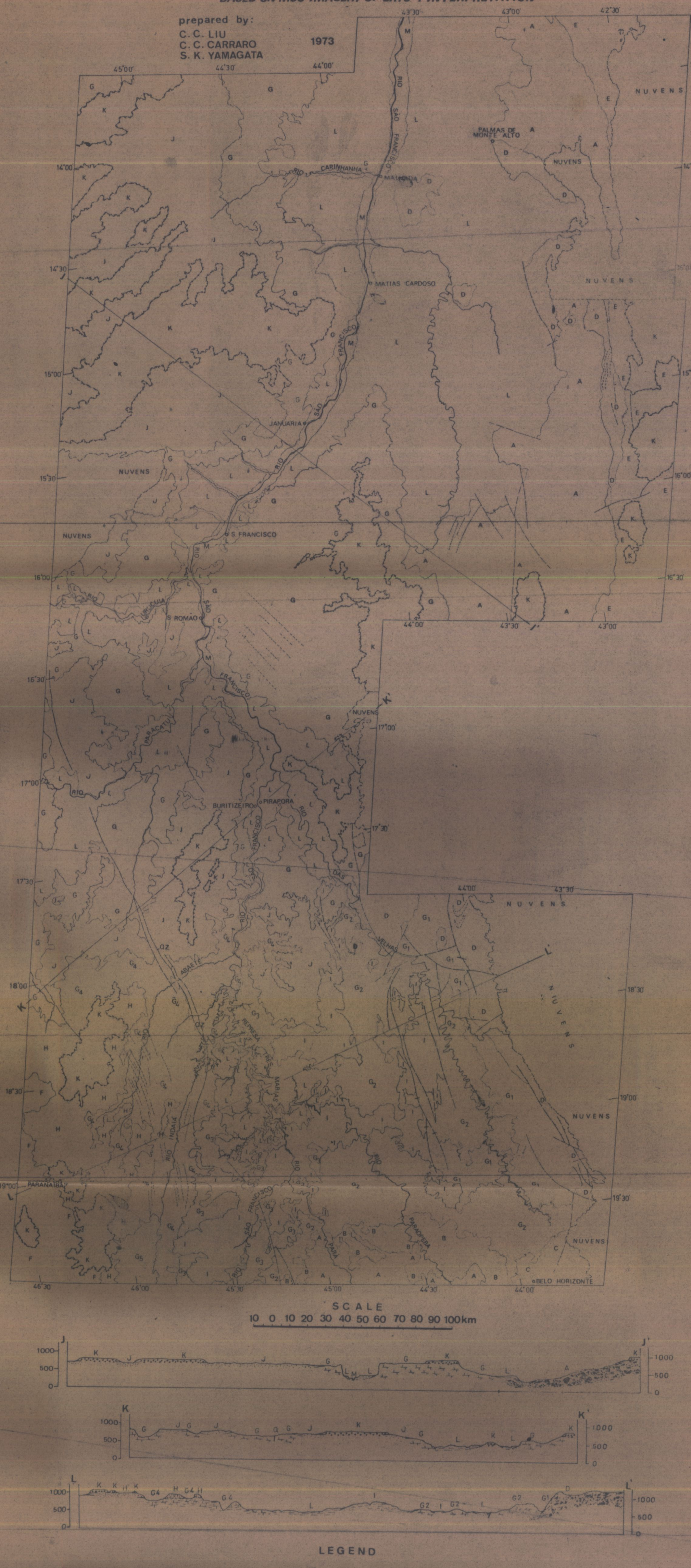
INSTITUTO DE PESQUISAS ESPACIAIS (INPE) PROJETO SENSORES REMOTOS (SERE)

MAPA GEOLOGICO DA REGIÃO DO ALTO SÃO FRANCISCO BASEADO NA INTERPRETAÇÃO DE IMAGEM MSS DO ERTS-I

GEOLOGICAL MAP OF THE AREA OF THE UPPER SÃO FRANCISCO BASIN BASED ON MSS IMAGERY OF ERTS-1 INTERPRETATION

prepared by:
C. C. LIU
C. C. CARRARO
S. K. YAMAGATA

1973



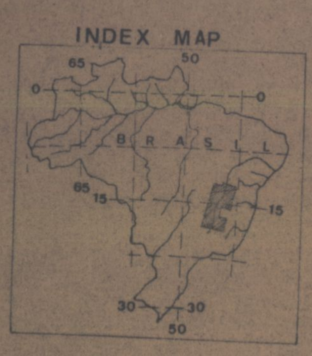
LEGEND

M	REMOTE SENSING UNIT	M
L	REMOTE SENSING UNIT	L
K	REMOTE SENSING UNIT	K
J	REMOTE SENSING UNIT	J
I	REMOTE SENSING UNIT	I
H	REMOTE SENSING UNIT	H
G5	REMOTE SENSING UNIT	G5
G4	REMOTE SENSING UNIT	G4
G3	REMOTE SENSING UNIT	G3
G2	REMOTE SENSING UNIT	G2
G1	REMOTE SENSING UNIT	G1
F	REMOTE SENSING UNIT	F
E	REMOTE SENSING UNIT	E
D	REMOTE SENSING UNIT	D
C	REMOTE SENSING UNIT	C
B	REMOTE SENSING UNIT	B
A	REMOTE SENSING UNIT	A

G5–G1: G REMOTE SENSING UNIT G

GN

- unit boundary
- infered unit boundary
- lineation
- erosional scarp
- infered fault trace
- infered thrust
- drainage
- city or town
- cloud



APPENDIX III.3

to Chapter III

REMOTE SENSING APPLICATIONS FOR GEOLOGY AND MINERAL RESOURCES IN THE BRAZILIAN AMAZON REGION

Gilberto Amaral *

COSPAR

VIIth Meeting

Seminar - Paper B.4.1

June 21, 1974

Auditorium INPE, P.M.

São José dos Campos

(*) INPE and University of São Paulo

REMOTE SENSING APPLICATIONS FOR GEOLOGY AND MINERAL RESOURCES IN THE BRAZILIAN AMAZON REGION

GILBERTO AMARAL
Instituto de Pesquisas Espaciais (INPE)
São José dos Campos - S.P.
Instituto de Geociências
Universidade de São Paulo - S.P.
São Paulo - Brasil

ABSTRACT

The utilization of ERTS-1 and SLAR imagery for geological mapping and prospection of mineral resources in the Brazilian Amazon region is discussed. The repetitive capability of the ERTS system has proved successful for obtaining an almost complete cloud-free coverage for the 5 million sq.km. of that region. Extensive comparison between both systems has shown that the multi-spectral data of the ERTS-1 program has higher capabilities for those objectives, since it gives similar amount of structural information, but gives a larger amount of lithological information. Some large mineral deposits and highly prospective geologic units, such as the 17 billion tons iron deposits of the Serra dos Carajás District and the tin bearing circunscrite granites of the Xingu River Valley are clearly discernible in the ERTS-1 imagery. With aid of the remote sensing data, and using literature analysis as ground truth, it was possible to made a geological map of the region, at a 1: 5 000 000 scale, in about three months.

INTRODUCTION

The objective of this paper is to demonstrate the applicability of remote sensing techniques to geological and mineral forecast mapping in the Brazilian Amazon region. A discussion on the performance of side looking airborne radar - SLAR (Radam Project) and multi - spectral scanner (ERTS-1) imagery for such purposes will be presented.

In the selection of examples, emphasis was given to their geological interest, instead of the technical quality of the data. For that motive the Serra dos Carajás, Rio Fresco and Roraima regions were selected.

The technical aspects of the SLAR system used by the Radam Project were discussed by CRAIB (1972), GOODYEAR AEROSPACE CORPORATION (1971), GRAHAM (1971) and PETERSON (1971). For the ERTS system, the readers are referred to the ERTS Data Users Handbook (GENERAL ELECTRIC 1971).

Briefly, the SLAR system was a modified version of Goodyear Aerospace sinthetic aperture radar model APQ - 102 T, working in X-band (9.6 GHz). The aircraft's flight height was about 11,000 m, and a 37 km wide terrain strip was imaged continuosly. The illumination angles ranged between 45^0(near range) and 13^0(far range). The scale of first generation products was 1: 400 000, with an expected resolution of 16 m. The ERTS-1 satellite is in a circular orbit 920 km above the surface and with an inclination of 99^0. The orbit's plane is sun-synchronous which permits observation of the whole earth at approximately the same local time. The main sensor system is a four channel multispectral scanner, operating in the following regions of the electro - magnetic spectrum:

Channel 4 - 0.5 to 0.6 micrometers

Channel 5 - 0.6 to 0.7 "

Channel 6 - 0.7 to 0.8 "

Channel 7 - 0.8 to 1.1 "

Each of the two remote sensing systems has its peculiar characteristics. The ERTS channel 5 image enhances cultural features and extent of vegetation cover. Channel 7 images are usually of a lighter tone due to the vegetation high reflectivity in the infrared region, enhancing the morphology and drainage pattern. SLAR images exhibit very well the terrain morphology, as a result of the low illumination angle.

Densitometric measurements indicate that radar images have a small dynamic range when compared with those of ERTS, the former with 4 - 5 and the latter with 10 - 18 (for each channel) gray tones. This is the main reason for the better performance of ERTS imagery in lithology identification.

In the case of structural interpretation, three factors must be taken in account: morphology, drainage pattern and sharp contacts between different lithologies. For the first one the superiority of SLAR images is out of question. However, careful examination of ERTS channel 7 images can lead to similar results. Moreover, as the shadowing is uniform in the case of ERTS images, the apparent morphology is closer to reality, reducing interpretation errors originated by the variable shadowing typical of radar images.

For drainage analysis the SLAR images present some problems due to the excess or lack of shadowing, respectively in high relief and plane areas. With the exception of permanent rivers, it is usually difficult to integrate the drainage lines in radar images. ERTS channel 5 and 7 are excellent for drainage analysis, even in heavy vegetated areas. Rivers and creeks show up very well in channel 7, even when small and covered by jungle ("igarapēs"). In this case, the excess of water causes a decrease in the density of the forest, resulting in a darker toned zone. When dry, the rivers are well marked in channel 5 due to the lack of vegetation cover and exposition of the bottom.

The distinction of structural features by sharp contacts between different lithologies is almost exclusive of ERTS imagery. It should be mentioned here that multi-spectral and false color photographs taken by Radam Project present several similarities with ERTS images. However, due to heavy cloud cover and lack of repetibility near 60% of these photos could not be used.

DISCUSSION OF RESULTS

A - Serra dos Carajās Region

The ERTS channel 5 and 7, and respective SLAR mosaic are shown respectively in figures 1, 2 and 3. Figure 4 presents the corresponding geologic map, obtained by interpretation of ERTS imagery with aid of field data. The main comments are:

1 - Channel 5 of ERTS is excellent for the delineation of features resulting from human occupation (roads, farms, etc.), cloud coverage

and main drainage lines;

2 - The low vegetation areas ("clareiras") developed over the iron deposits of the Serra dos Carajãs District are perfectly shown in both ERTS images, but not in the radar mosaics;

3 - ERTS channel 7 is excellent for drainage pattern analysis, even when the rivers are covered by jungle. In this image there is some penetration through cloudiness;

4 - The large unconformity existing between the Tocantins and Serra dos Carajãs Groups is clearly shown by ERTS channel 7 and SLAR mosaic. It is due to a thrust fault striking N-S and dipping $40^{O}E$;

5 - The several geologic units shown in figure 4 were identified by its spectral, morphologic and structural expression.

B - Roraima Region

Figures 5, 6, 7 and 8 show, respectively the ERTS channels 5 and 7, the SLAR mosaic, and the corresponding geological map (obtained by interpretation of ERTS imagery with aid of field data), for the northernmost portion of the Roraima Territory and adjoining portions of Venezuela and Guyana. The main comments that can be made are:

1 - The dominat vegetation is of savanna type ("cerrado"), which results in a better definition of different features in channel 5 image, as opposed to the corresponding image of the previous example. In such conditions this image allows excellent lithologic and structural interpretation;

2 - Amazonic type forest occurs only in the west part of the region, and appears black in channel 5 and nearly white in channel 7 of

ERTS images;

3 - An intermediate type of vegetation is developed over soils derived from granites and basic rocks. Vegetation on the alluvial plain is almost non-existent;

4 - A mottled texture and curved lineations characterize areas of occurrence of volcanic rocks;

5 - A dike swarm of Mesozoic age is conspicuously shown by ERTS channel 5 image;

6 - A fault of probable Quaternary age is clearly discernible in the southeast portion of the region, affecting the alluvial sediments, in both ERTS images, but not in the SLAR images.

C - Rio Fresco Region

Figures 9, 10, 11 and 12 show, respectively, ERTS channel 5 and 7 images, the SLAR mosaic and the corresponding geologic map for the Rio Fresco region, in the southern portion of the Pará State. The main comments, derived from the analysis of the remote sensing data, are:

1 - The Gorotire Formation (sandstones) is perfectly identified on both ERTS images, due to its spectral characteristics. In the SLAR mosaic it is delineated by its morphological expression, but not so well as in the former case;

2 - The iron deposits of the São Felix District are distinguished in the same way of those of the Serra dos Carajás region, and cannot be identified in the SLAR mosaic;

3 - Two different granite types can be individualized in ERTS images

by their spectral characteristics and shape of the intrusion. One exhibits a light tone in channel 7, a dark tone in channel 5, and irregular boundaries. The other has opposite tonal characteristics and well delineated boundaries, which present a rounded shape. The former are associated with the volcanic rocks of the Rio Fresco Formation. The latter are younger and, in two cases, are mineralized in tin;

4 - The volcanic rocks of the Rio Fresco Formation are characterized by a mottled texture in ERTS channel 7 image. The sedimentary rocks of this unit exhibit a light tone and uniform texture;

5 - A dike swarm cutting the Gorotire Formation is clearly discernible on both ERTS images, but not in the SLAR mosaic.

CONCLUSIONS

The examples presented above are self-explanatory and do not need detailed discussion. They demonstrate the applicability of remote sensing techniques to small scale geological mapping and mineral prospection in the Amazon region.

If remote sensing data is used from the initial stages of systematic geological mapping programs, it will result in the optimization of field work, and therefore in a significant reduction of costs.

With the objective to elaborate a synthesis of the Pre-Cambrian geology of the Amazon region, the author interpreted about 120 SLAR mosaics and 80 pairs of ERTS images in about three months (AMARAL 1974). Ground truth data were provided by literature analysis and data collected in previous field work. During the work emphasis was given only to those features relevant to the problem and representable in a 1: 5 000 000 scale. It is the author's opinion that for such purposes the ERTS images are much more effective than SLAR mosaics. In the case of Brasil, one square kilometer of ERTS imagery costs about US$ 0.15 , which includes the costs of acquisition and maintenance of our ground receiving and processing system. The costs of SLAR imagery acquisition are approximately US$ 5.00 per sq.km.

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GRAHAM, L.C. - 1971 - Synthetic aperture radar. Part 1 - System principles. Goodyear Aerospace Corp. Publ. GIB-9215: 1-88.

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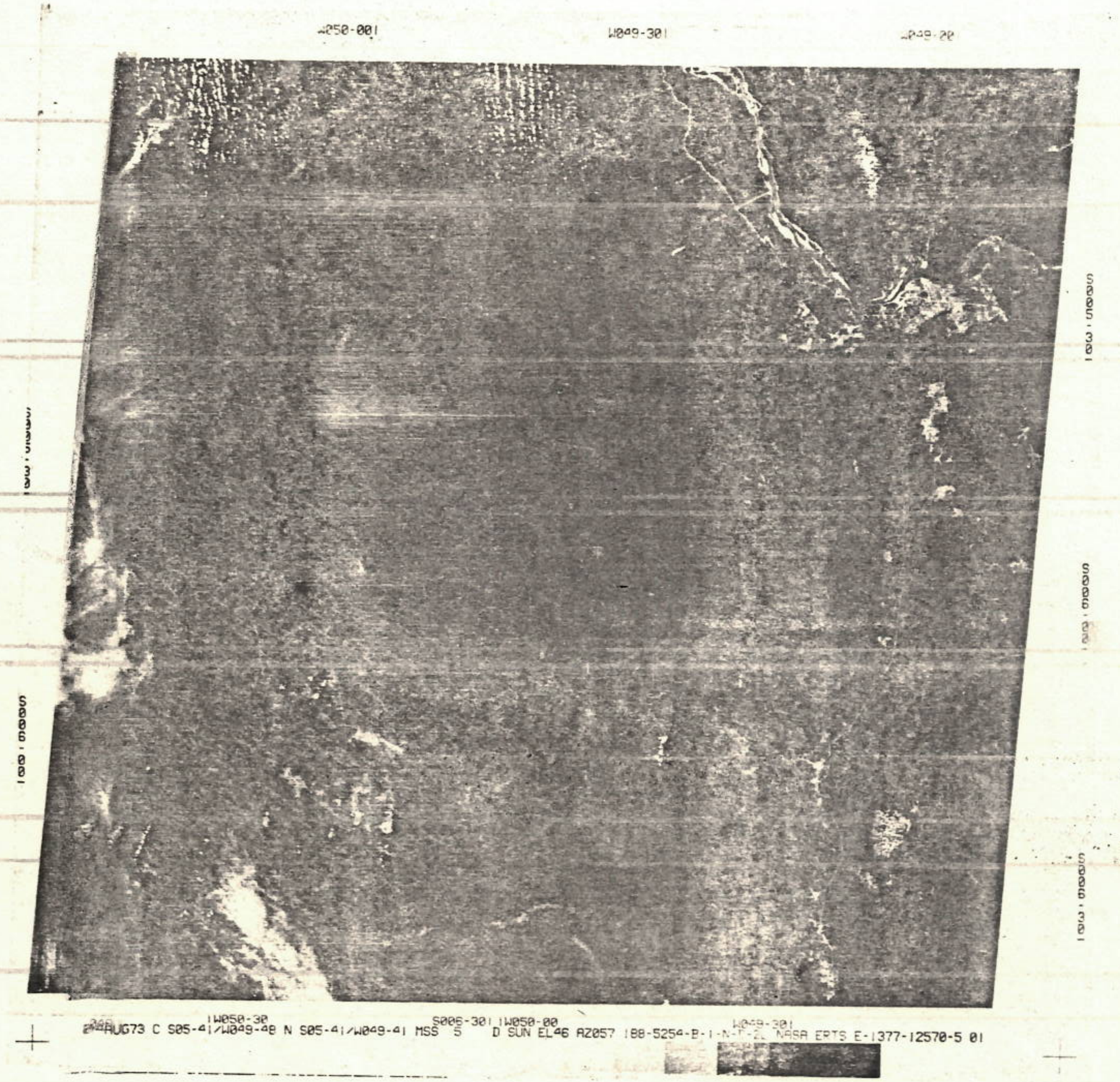

Figure 1 - ERTS-1 band 5 image for the Serra dos Carajás region, Pará State, Brazil.

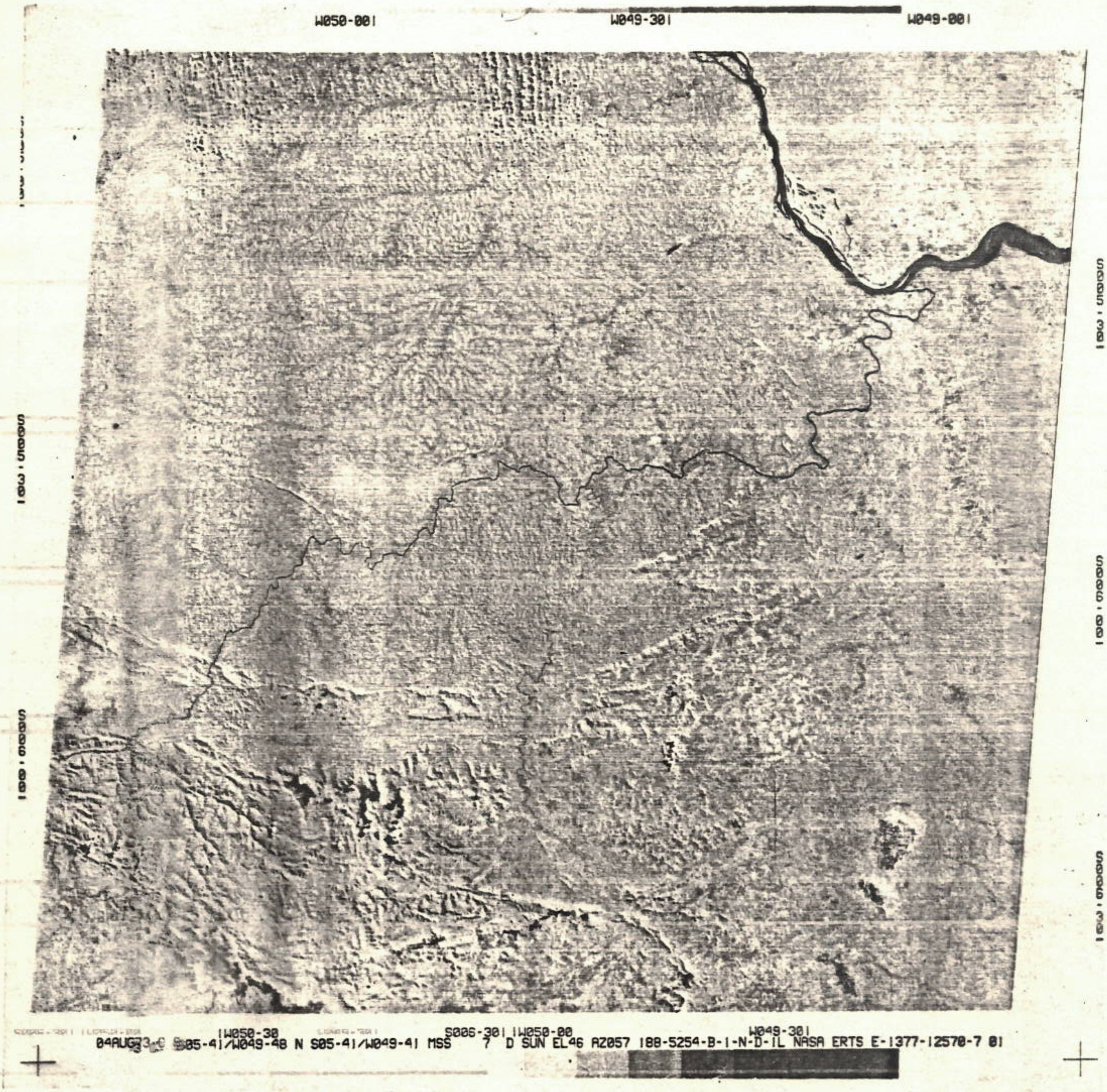

Figure 2 - ERTS-1 band 7 image for the Serra dos Carajás region, Pará State, Brazil.

Figure 3 - Side looking airborne radar mosaic for the Serra dos Carajás, Pará State, Brazil.

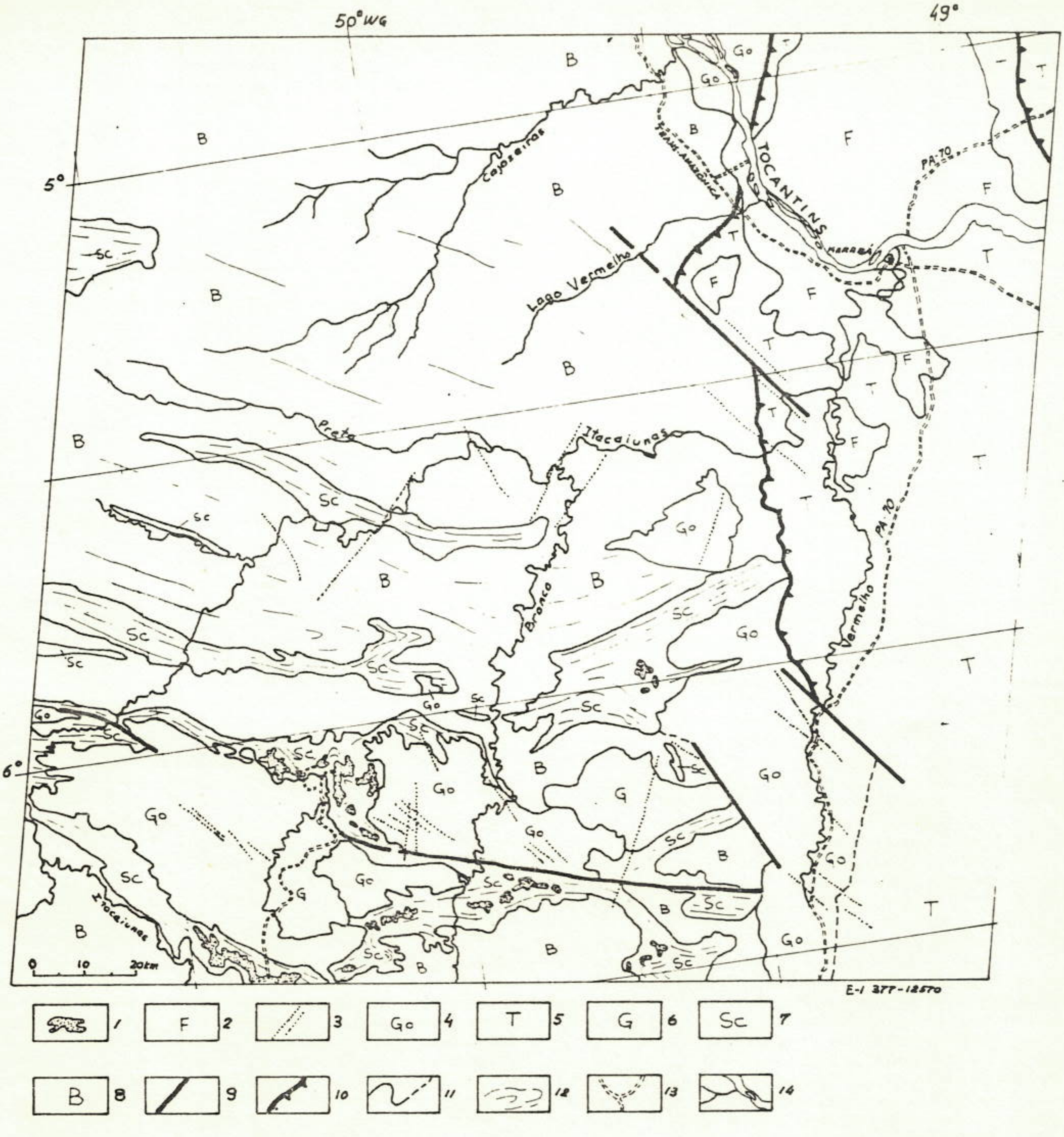

Figure 4 - Geologic Map of the Serra dos Carajãs region obtained by interpretation of ERTS-1 images and field data. Conventions: 1-Laterite crusts (canga) associated with iron deposits; 2-Phanerozoic rocks; 3-Diabase dikes; 4-Gorotire Formation; 5-Tocantins Group; 7-Serra dos Carajãs Group; 8-Cristalline complex; 9-Faults (in general); 10-Thrust faults;11-Contacts 12-Lineations; 13-Roads; 14-Rivers.

Figure 5 - ERTS-1 band 5 image for the northern part of the Roraima Territory, Brazil.

Figure 6 - ERTS-1 band 7 image for the northern part of the Roraima Territory, Brazil.

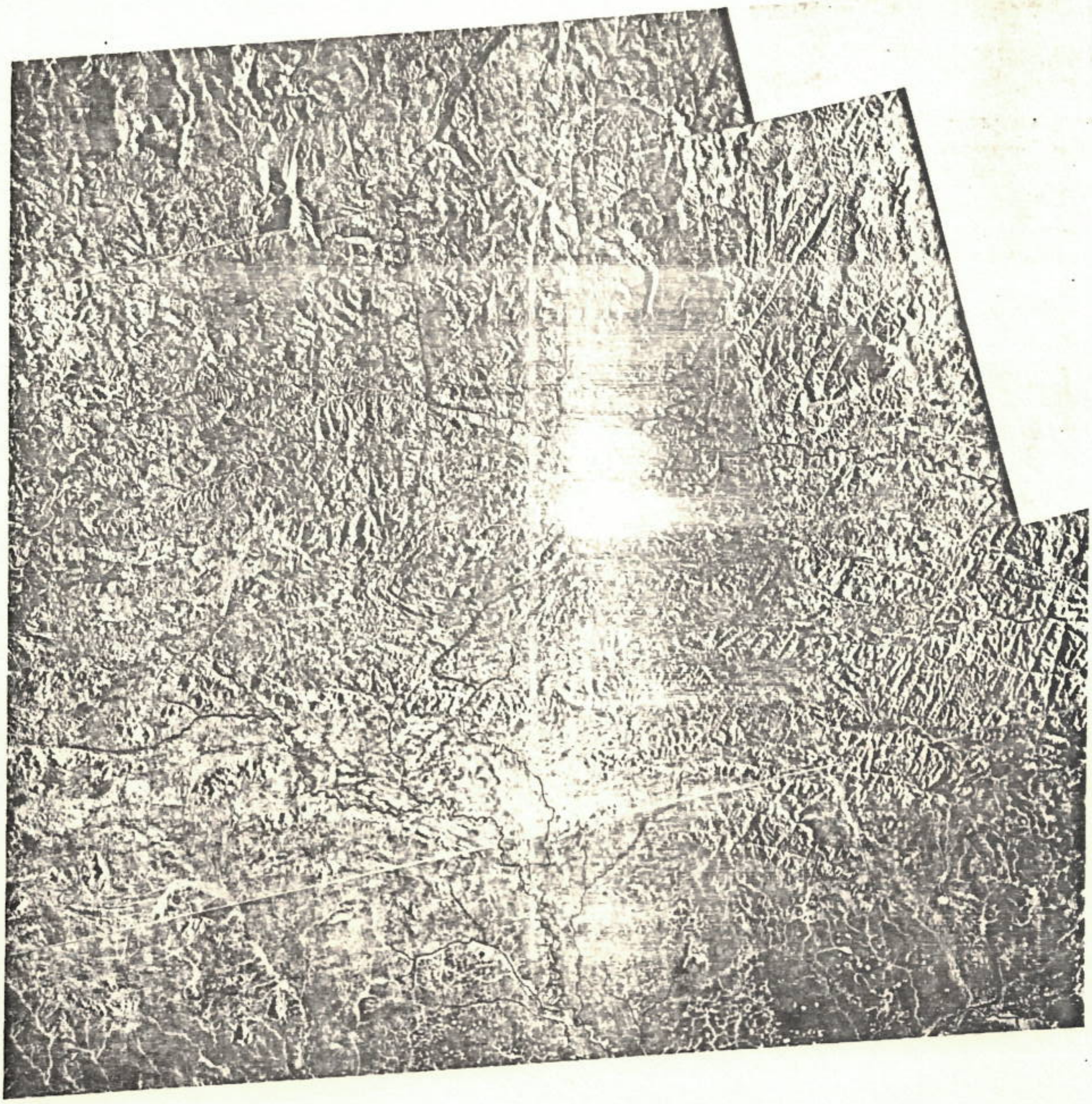

Figure 7 - Side looking airborne radar mosaic for the northern part of the Roraima Territory, Brazil.

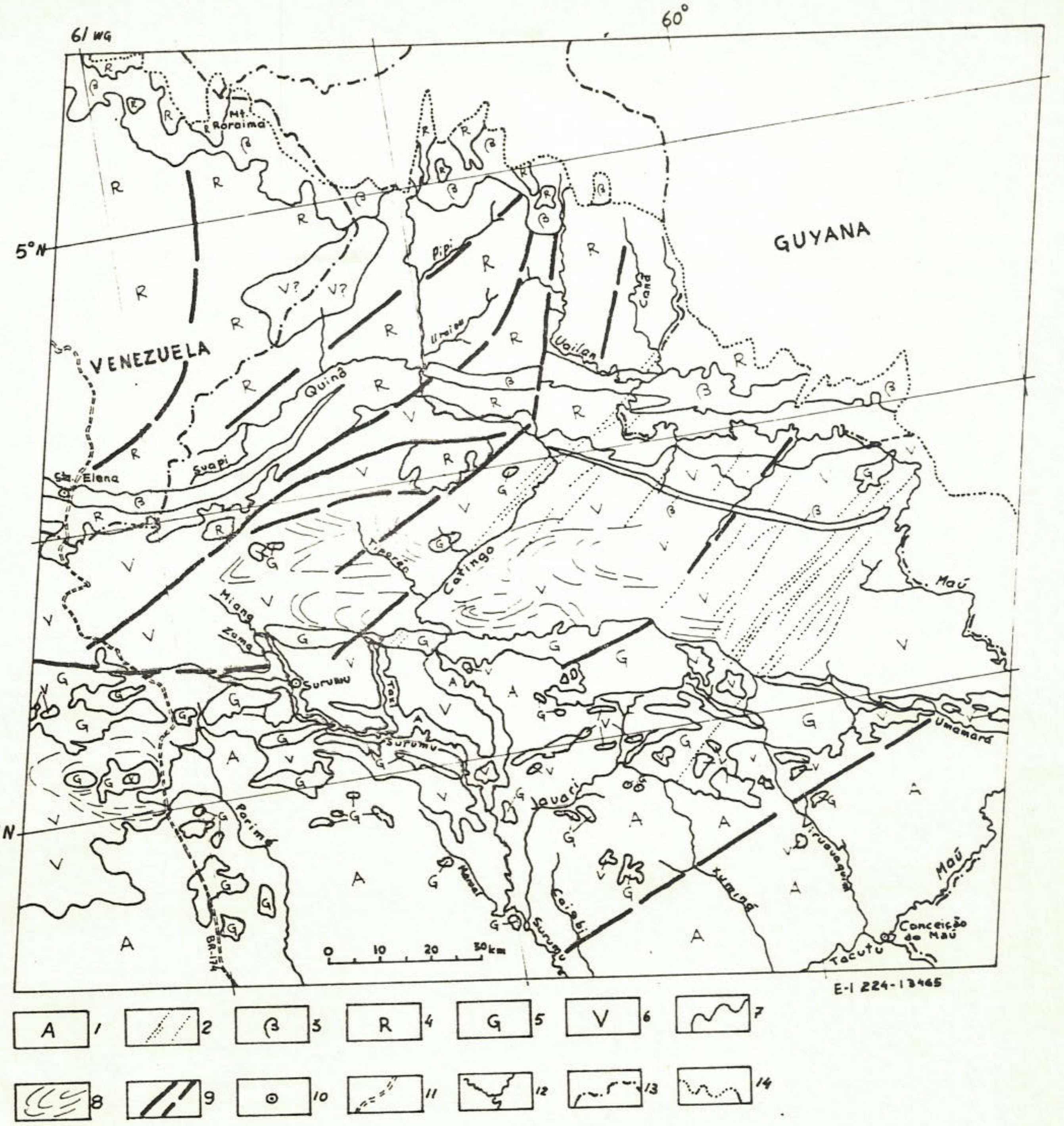

Figure 8 - Geologic map of the northern part of the Roraima Territory, obtained by interpretation of ERTS-1 images and field data. Conventions: 1-Alluvial deposits; 2-Diabase dikes; 3-Basic dikes; 3-Basic intrusives; 4-Roraima Formation; 5-Granites; 6-Volcanic rocks; 7-Contacts; 8-Lineations; 9-Faults; 10-Villages; 11-Roads; 12-Rivers; 13-International boundaries; 14-Limits of cloud coverage.

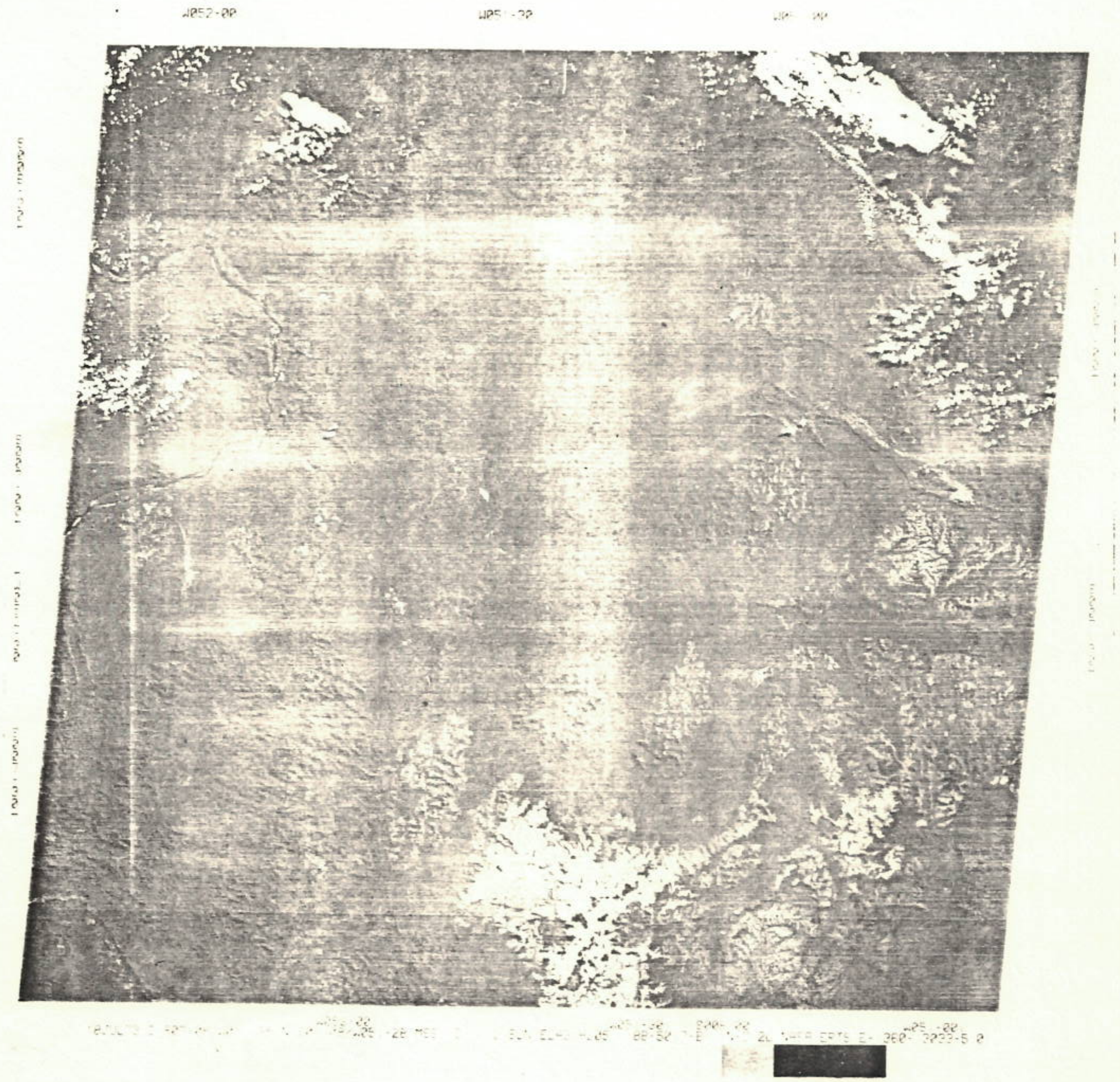

Figure 9 - ERTS-1 band 5 image for the Rio Fresco region, Pará State,Brazil.

III.3

Figure 10 - ERTS-1 band 7 image for the Rio Fresco region, Pará State,Brazil.

Figure 11 - Side looking airborne radar mosaic for the Rio Fresco region, Pará State, Brazil.

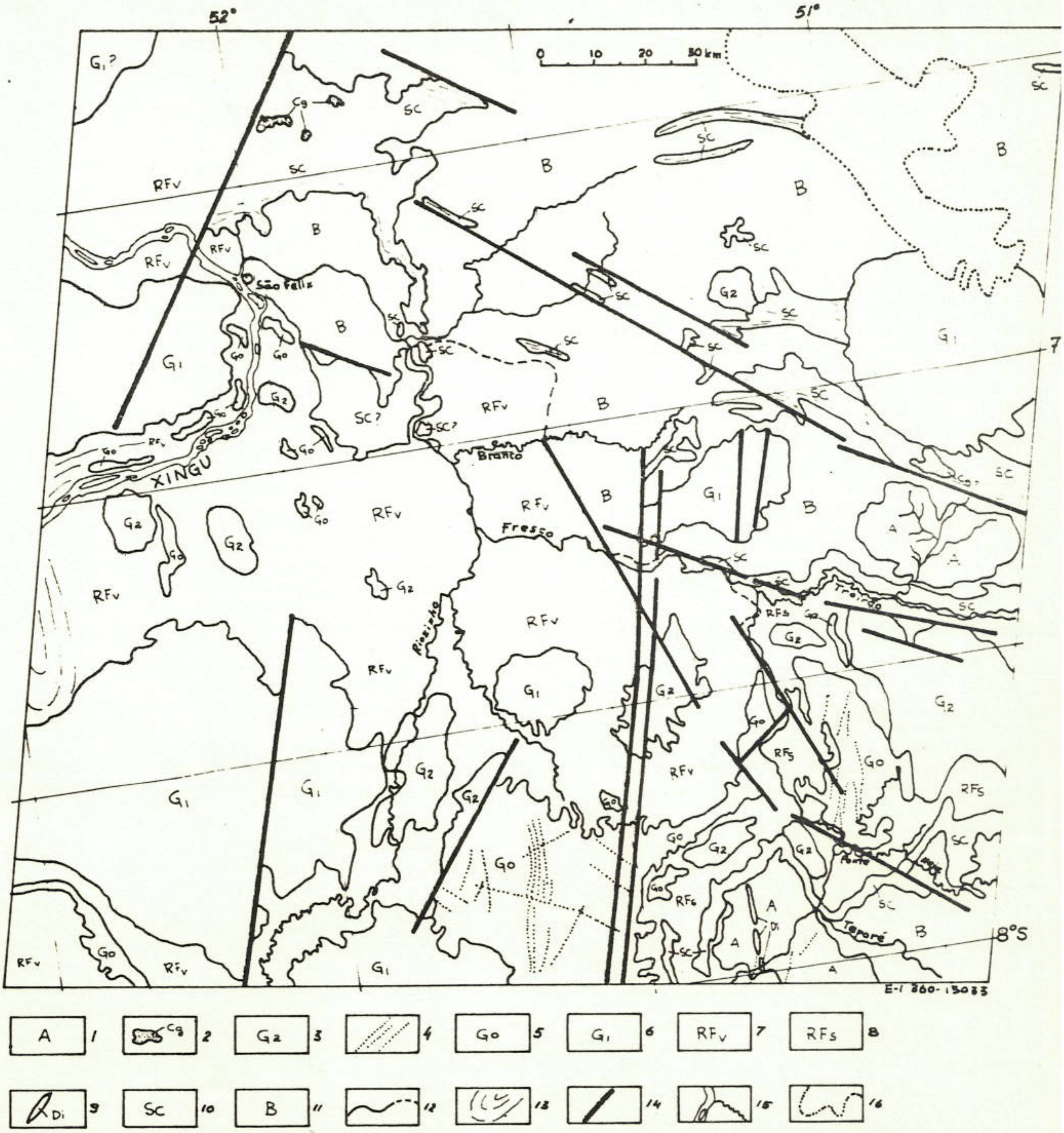

Figure 12 - Geologic map for the Rio Fresco region, obtained by interpretation of ERTS-1 images and field data. Conventions: 1-Alluvial deposits; 2-Lateritic crusts associated with iron deposits; 3-"Younger" granites; 4-Diabase dikes; 5-Gorotire Formation; 6-"Older" granites; 7-Volcanic rocks of the Rio Fresco Fm.; 8-Sedimentary rocks of the Rio Fresco Fm.; 9-Diorite intrusions; 10-Serra dos Carajás Gr.; 11-Cristalline complex; 12-Contacts; 13-Lineaments; 14-Faults; 15-Rivers; 16-Cloud coverage Limits.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

REPLY TO ATTN OF: Code 902

[illegible]
MAY 28 1976

Dr. Fernando de Mendonca
Director General, I.N.P.E.
C.P. 515 - Sao Jose dos Campos
Sao Paulo, Brazil

Dear Dr. de Mendonca:

In accordance with the Provisions for Participation in the NASA LANDSAT (ERTS) Project, a review was made by the Scientific Monitor of the drafts of the Type III Final Reports which represented the completion of the Institute for Space Research's (INPE) multidisciplinary program for the study of LANDSAT imagery. The volume of the reports demonstrated that an in-depth study of the utility of this imagery was made. It was noted that the large amount of information produced by the three Principal Investigators was screened and combined into a single report. This is an excellent mechanism for cataloging the relevant results of the INPE program. It effectively demonstrated the outstanding contribution of the Brazilian investigators to the LANDSAT program.

In his review of the Volume I, Chapter II, SEA RESOURCES (CF Emmanuel Gama de Almeida) investigation, the Scientific Monitor stated that it was a complete, well prepared and well organized report with an appropriate format that adequately addressed each of the objectives outlined in the original proposal. The report gives a good introduction to the investigation and touches lightly on the interaction of LANDSAT, Nimbus, Apollo-8, and Skylab video data products. Elaborate background information is supplied for each study area. Excellent use is made of transparent overlays on the LANDSAT images. The major detriment in this chapter is the lack of an introductory map of Brazil showing the locations of the five test sites.

Unfortunately, there are a number of content deficiencies that should be corrected before the Final Report is submitted. These are:

- Page 27 to 30: Reference is made several times to MSS channel 4, 5, and 6 imagery but only a channel 5 image is included in the text. In fact, channel 5 imagery is duplicated on pages 24 and 28. Is this in error?

- Page 45, first paragraph: Last sentence, "1500 m" should read "15.00 m".

o Page 45, third paragraph: Author refers to oceanic tides of the "daytime kind". Author probably means "diurnal - a tide having only one high water and one low water each tidal day (every 24.84 hours)".

o Pages 56, 67, and 59: Reference to Fig. 11.20 and 11.22 is made by stating the acquisition date of the image, 26 June 1973. Reference to this illustration should be by Fig. number. Near bottom of page 56, reference to this Fig. is 26 July 1973. One of these must be incorrect.

o Page 62, Paragraph II.3.1: The first sentence in this paragraph needs clarification.

o Page 76, Paragraph II.3.5.3: Reference is made to a blowup of Guanabara Bay showing river discharges. No LANDSAT image is included to show this important result.

o Page 81, third paragraph, line 3: "the isoline of 35% surface salinity" should be "isohaline of 35 0/00 "since salinity is measured in parts per thousand (0/00).

o Page 88, third paragraph: Reference is made to items B, C, and D in Fig. II.32 but not to item A.

In his review of the Volume I, Chapter III, MINERAL RESOURCES (Dr. Gilberto Amaral) investigation, the Scientific Monitor stated that it represented a detailed and well illustrated report with an appropriate format that addressed most of the objectives outlined in the original proposal. An objective not addressed was the proposed study of the "main geotectonic units of central and southern Brazil and their relation to known mineral deposits". No discussion of the application of the structural data to these mineral deposits was made. In addition, no information regarding the "establishment of the best parameters for aircraft mission planning for specific problems" was presented.

In addition, there are some content deficiencies that should be corrected before the Final Report is submitted. These are:

o Page 114, line 12: The sentence "The main differences..." is not a complete sentence.

o Page 114, line 22: "geologists who have"

o Page 115, line 8: "implementation of software..."

o Page 117, line 19: "... has surveyed..."

- Page 117, line 20: "... were spent for the acquisition of the imagery alone."

- Page 122, line 7: "... diagnosis..."

- Page 123, line 9: "...maintenance..."

- Page 123, line 11, 12: "costs about US $0.15 while the... have cost about..."

- Page 123, line 16: "cost/effectiveness ratio... when compared with the SLAR ratio.

- Page 123, line 21: "Cambrian age"

- Page 125, line 3: "...the previously available map."

- Page 126, line 11: "...geological community."

- Page 126, line 14: "...cost/effectiveness..."

- Page 126, line 18: Should read: "Only conventional photo-interpretation techniques were used."

APPENDIX III

- Page 13, line 15: "different"

- Page 25, line 10: A period should follow "differentiation." The next word, "they" should be the first word of the following sentence.

- Page 25, line 19: "fine grained", "graywackes"

- Page 26, line 2: "are mainly dates"

- Page 26, line 11: "argillaceous", "siltstone"

- Page 27, line 1: "Ladeira et al", "designated"

- Page 28, line 7: "graywacke and arkosic sandstone."

- Page 31, line 3: "...separated mainly by tonality;..."

- Page 31, line 12: "...are in unconformable contact with..."

- Page 32, line 21: "It is unconformably overlying the units mentioned above."

- Page 33, line 1: "The area north of the Furnas Dam belongs to..." (no comma needed).
- Page 34, line 16: "thoroughly"

No reference is made to Plate 2 in the text. Also, the plates are referred to in a random order (Plate 3, Palte 1, Plate 1, Plate 4, etc.). Additionally, the plates should follow immediately after the first reference to them, rather than being grouped together at the end.

Map 1 should follow after the first reference to it on page 20. Likewise, Map 2 should follow directly after on page 31.

In his review of Volume II, Chapter IV, SOIL RESOURCES (Dr. Fernando de Mendonca) the Scientific Monitor stated that this report completed the analyses relevant to the stated objectives of the investigation. The investigation went a long way in identifying promising and economical applications of remotely sensed earth resources data in the field of agronomy. Technical details in the form of LANDSAT imaging illustrations, overlays, and maps were amply provided. In addition, the usefulness of LANDSAT imagery in other discipline areas of land use and demographic studies was explored. Unfortunately, the study is labeled as preliminary because of the absence of ground truth data.

The content deficiencies that should be corrected before the Final Report is submitted are:

- Page 141, Paragraph IV.2.4.3.6: This statement needs clarification.

- Page 145, Paragraph IV.2.5.3.4: This statement needs clarification.

- Page 149, Fig. IV.7: Only 4 area types are described in the Legend although 6 area types are discussed in the accompanying text.

- Page 150, Fig. IV.8: No reference is made to this Fig. in the text.

- Page 151, Paragraph IV.2.6.3.2: This statement needs clarification.

- Page 155, Paragraph IV.2.7.2.3: There is a discussion of the Parana River but it is not designated in Fig. IV.9.

- Page 161, Paragraph IV.2.8.2.5: This statement needs clarification.

- Page 177, line 16: Refernece to Fig. IV.20 should be Fig. IV.21.

- Page 179, Section IV.3.2.2.1 Legend: It is unfortunate that the terms "cerrado", "cerradao", etc. were not defined earlier in the text.

Will you kindly consider incorporating these comments into your draft before submitting eight (8) copies of the Final Report to:

Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Scientific Investigation Support
Code 902.6

Sincerely,

James C Broderick

James C. Broderick
LANDSAT Technical Monitor


MAPA GEOLÓGICO DO PRÉ-CAMBRIANO DA REGIÃO AMAZÔNICA
COLÔMBIA
VENEZUELA
GUYANA
SURINAM
GUIANA FRANCESA
OCEANO ATLANTICO
EQUADOR
PERU
BOLIVIA
CONVENÇÕES
F Rochas Fanerozóicas
B Intrusivas Básicas (Diabásios e Gabros)
S Rochas da Cobertura Sedimentar Dobrada (Arenitos, Arcósios, Folhelhos, Conglomerados, Calcários, Dolomitos, Tufos etc.)
V Rochas Vulcanicas (Andesitos, Riolitos, Dacitos, Ignimbritos, Queratófiros, Brechas e Tufos)
G Rochas Graníticas (Granitos, Granodioritos, Adamelitos, Dioritos, Granófiros, etc.)
M Rochas Metasedimentares (Xistos, Quartzitos, Itabiritos, Filitos, Anfibolitos, etc.)
Complexo Cristalino (Gnaisses, Migmatitos, Anfibolitos, Granulitos, Granitos anatéticos, Metabasitos, Metavulcânicos, etc.)
Contatos
Lineamentos
Falhas
Índices Geocronológicos
1 - > 2200 m.a.
2 - 2000 ± 200 m.a.
3 - 1600 ± 100 m.a.
4 - 1300 ± 100 m.a.
5 - 1000 ± 100 m.a.
6 - 550 ± 100 m.a.
GILBERTO AMARAL
50 0 100 200 300 400 500 km
1973
MAPA DE LOCALIZAÇÃO