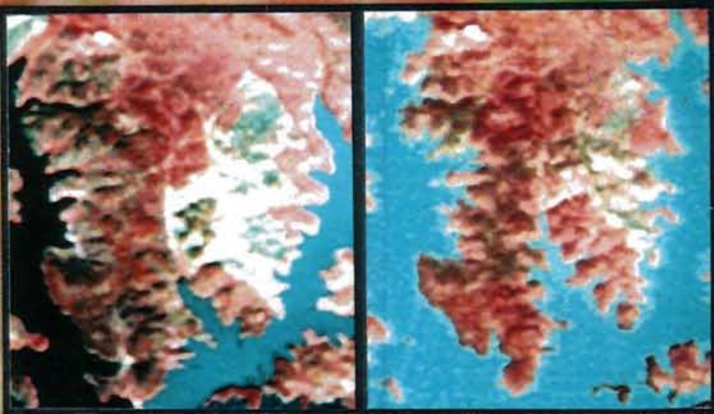
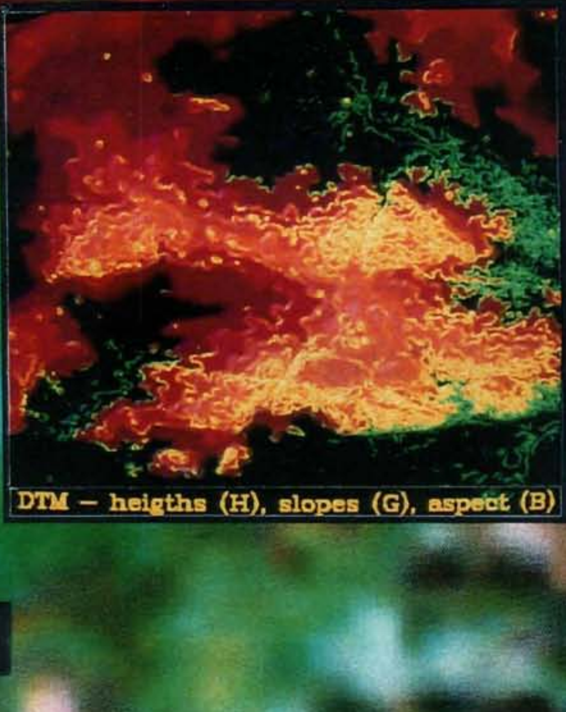
# NATO SCIENTIFIC AFFAIRS DIVISION



# SATCART



PO-833

# PO - 833 - SATCART

# UPGRADING NATIONAL TECHNOLOGY ON REMOTE SENSING AND IMAGE PROCESSING APPLIED TO THE PROSPECTION OF NATURAL RESOURCES AND CARTOGRAPHY

## Final Report

1988 - 1992

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Deputy Project Director - Doutor José Manuel Rebordão

RESEARCH SPONSORED BY THE NATO SCIENCE FOR STABILITY PROGRAMME

# Po-SATCART - Final Report

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[*] *A video of the SATCART activities and achievements is available on request from Dr. José Manuel N. V. Rebordão, INETI, Aerospace Laboratory, Estrada do Paço do Lumiar, 1699 Lisboa Codex, Portugal. Tel. 351-1-716.51.81, Fax. 351-1-716.30.48.*

# 1 - Introduction

Satellite remote sensing cannot by itself produce most of the maps people are used to. Our main assumption within the SATCART project was that remote sensing could reduce considerably the amount of field work, costs and labor, to produce land use cartography using radiometric or textural clues.

Past Portuguese experience has revealed two different attitudes concerning the relationship between remote sensing and cartography:

1. The information that remote sensing can provide to the user lays mainly on the strong pictorial character of satellite images, thus lacking rigor and cartographic content;

2. The information content of satellite images is so high that users should redefine their needs and be willing to use different kinds of geographic data representations.

Both attitudes are essentially correct and the extreme character they reveal arises from the net separation that still exists in Portugal between users and producers, and between remote sensing and cartography.

These attitudes trigger each other. Past experience has shown that acceptable cartographic precision can be introduced in satellite images provided that some precautions are taken in order to eliminate many kinds of pictorial "noise". The users should correctly understand available methodologies, their limitations and possible solutions. Users should be strongly involved with the system. It was - and still is - our belief that high resolution remote sensed images still lack efficient digital image processing techniques for information extraction and representation. We also think that many user's problems that had no answer with small resolution data can be solved with new sensors, and that old photo-interpretation methods can be applied to satellite images, much in the same way as in aerial photography.

It has been shown that human photo-interpreters are most sensitive to shape, context and color. Shape and context are concepts developed within mathematical morphology and texture analysis. We feel that research should continue, not only to improve knowledge in these fields but also to make them operational in the context of user's defined problems.

In a more general framework, remote sensing includes aerial photography. Within this project, aerial photography should provide two kinds of inputs to the processing and production system:

1. Digitized aerial photography can be manipulated in much the same way as any kind of digital satellite data;

2. Stereoscopic aerial photography can be analyzed with digital stereo plotters, using photo-interpretation techniques, and the output integrated in the local GIS, providing ground truthing to automatic classifiers, and introducing cartographic basis into complementary satellite data.

These possibilities of the whole system would allow for multi-resolution products where global structure and some level of detail would be provided by satellite data and finer detail by aerial photography.

It was an important goal of the project to build models accepting data of different resolution on equal footing, not only in what concerns the digital processing but also in whatever relates to feeding and handling the local geographical information database and tools.

Getting useful and cartographic information from remote sensed data supposes capabilities in:

1. Understanding the nature of the user's problem, evaluating the elasticity or rigidity of his specifications, evaluating how far the existing software might handle the problem, needs changes or redesign, and iterate the problem and methodology with the user.

2. Evaluating whether the user can access existing equipment and software to get the results he needs in a suitable format or if the complete resources of the system and processing chain should be used instead.

3. Merging pertinent cartographic information into image data.

4. Definition of a certain number of product formats each one being associated to a production file, an evaluation file, cost structure and actualization characteristics.

5. Design and development of image processing and graphical software. In the current status of image processing software for remote sensed images, this capability must be developed mainly in shape analysis, mathematical morphology, texture modeling, 2-D representation, restoration models, common models for image sensed by different sensors at different resolution (e.g. satellite data and digitized aerial photography).

6. Structuring processed information in a local geographical information system for internal use or transfer.

7. Ground-truthing of image data by radiometric measurement and access to a variety of data producers and institutions.

The project intended to create interfaces between all its components. This means that image processing should be integrated in the "production chain", should receive and integrate data and rules from cartography and generate output to the local GIS. Cartography should accept output data from the image processors, complete the editing or the merging with final data before sending it to the drawing equipment. The local GIS should be consistent remote sensing techniques, structuring objects derived from classification.

The different components would conduct scientific research in the fields still lacking operational methodologies for image analysis and representation:

1. In Digital Image Processing (DIP), research activity would be carried on automatic classifiers (multi-spectral, textural and multi-temporal, and expert systems supported classification), image restoration, shape analysis, texture analysis and image modeling;

2. In cartography, research activity would be carried out on classification trees (consistent at different scales, according to physical or use criteria);

3. In GIS, research activity would be carried out on the coupling between GIS and the digital image processing environment. Usually GIS stand from the side of the user of geographical data only, but the capabilities it incorporates make it a very valuable tool for image manipulations.

# 2 - Objectives of the Project

## 2.1 - General Objectives

The SATCART project was considered an essential item for the integration of knowledge and know-how stemming from the fields of remote sensing, data handling and cartography. Its accomplishment should ensure that the main objectives of the two private firms and the public laboratory would be achieved in the shape of a "consortium" leading to the setting up of an enterprise at a later step.

For this autonomous production unit to be born and for the integration of different fields to be possible, it would be necessary

1. to arrive at the completion of product's engineering,

2. to develop research and development activities in the fields covered by the project and in their interfaces,

3. to build a complete production process to control the flux of information from the inputs to the desired products, and

4. to acquire already existent know-how in the fields covered by the project, by consistent training of scientists and technicians in the pertinent subdomains.

The industrial outcomes of this project should be developed in the context of solutions to users' defined problems; in most instances, a final formatted and reported cartographic product would have to be developed. The "capacity to develop final products" in the domain of remote sensing applied to cartography, should emerge in parallel. The research and development activities of the project are considered critical, because it was recognized that many of the tools needed to obtain useful cartographic information from remote sensing data by automatic procedures still need improvement, mainly in the interfaces between the various domains and in the coupling of tools.

This project would be developed in a multi-institutional context, sharing existing or to be acquired, human, technical and infrastructure resources. In a three years time all these complementary resources should be fully integrated, physically and logically.

## 2.2 - Specific Objectives

The SATCART project identified a variety of objectives related to five major areas:

### 2.2.1 - Research and Development

This project aims at upgrading the Portuguese capabilities in the field of remote sensing applied to cartography of land cover. This has to be done with a full support from geographical information systems to preserve and handle processed data. This goal was to be achieved for a variety of fields of application, from agriculture to geology, from geography to regional planning.

Past needs have partially been fulfilled by conventional techniques. New sensors have non exploited potential that research should identify and transform into useful information.

For these final goals to be achieved, development should take place in the different domains involved and in their interfaces. At the onset of the project, it was expected that the fields of image analysis, representation and modeling and the interfaces between digital image processing, geographic information systems, cartography and expert systems, and data fusion would have to be considerably strengthened. Acquiring such capabilities was vital for the project to build new products and participate in the updating of thematic cartography in Portugal.

### 2.2.2 - Industrial Outputs

Information has to be handled by a variety of processing systems, to create final products from raw data and build and test production methodologies:

- Products
  - Land cover maps
  - Services
    - Image data
    - GIS covers
- Production processes

The control of the production process was the major industrial objective. An organized, optimized network for information handling and land cover map production should be built. The interfaces between the different building blocks (digital image processing, cartography, geographical information system) should be carefully designed. The products to be developed within this project were twofold; land cover maps in paper or film support; additionally, users should be able, in certain circumstances, to access directly to a fraction the resources of the system, to the image data base - to examine images personally and make some manipulation - and to the local GIS to analyze the data already processed. These outputs would be developed as a sequence of solutions to users' problems in the form of application projects of more reduced scope.

The project would thus be forced to acquire basic technologies in image processing, software management and test, product specification, image representation and storing, interfaces between image processing, cartography, data bases, atmospheric degradation and restoration, to mention just a few.

## 2.2.3 - Cooperation

The transfer of pieces of knowledge of different nature between private firms of software engineering and cartography, the University and a public laboratory, was one of the most important tasks of this project.

Multi-disciplinarity was known in advance to be difficult to achieve but the partners had already been working together for some time and had engendered a team work philosophy.

The active collaboration of international organizations was also to be looked for, although it could be anticipated that the strong commercial interest prevailing into this field of activity in Europe would create problems not easy to solve. NATO consultants had a very important role in the interface between the project and French institutions.

## 2.2.4 - Training

Training was an important and essential objective of this project, for it was clear that human resources in remote sensing were scarce in Portugal, either in the digital manipulation of image data or in the applications of remote sensing to the different domains (agriculture, forestry, geology, planning, etc.); the situation was similar as far as geographical information systems technology is concerned.

The program leaders were all involved in lecturing at the University of Lisbon and at the Technical University of Lisbon. Apart from acting at this high level education, the proponents of this project have started a technicians course for young people under the auspices of the E.E.C and around 50 people applied for the course which had a duration of 12 months. Within the SATCART level, training was to be considered at three levels:

**Project Team:** The members of the project team should attend workshops and conferences in their domains of activity. This kind of training should be of a practical and methodological character within institutions that develop similar activities. Some basic theoretical training could be given in Portugal.

**National Education System:** "Licenciatura" and Master thesis could be accomplished within the project. It was also envisaged to begin Ph.D. thesis, either in Portugal or abroad.

**Users:** Both the hardware configuration that will be put in place and the profile of the project team would allow a regular training of real or potential future users of remote sensing from the central or regional administration. The system included an easy to use digital image processor that could be accessed by trainees for visualization and some manipulation of image data.

## 2.2.5 - Users' interface

The user of remote sensing based cartographic products comes typically from the fields of agriculture, geology, planning and forestry. He does not have a particular background in computer science, or in remote sensing or in either of the related tools. Beyond his particular field, he is generally aware of conventional data produced in conventional form. Most of his first needs are conventional, in the sense that he is looking essentially for a different methodology to produce a pre-defined type of information in a specific format.

Nevertheless, not all the information the user is looking for is directly visible on remote sensing data. Sometimes it has an intrinsic use character and must be translated into physical terms. The user knows "how" to look at the images but is seldom clear in explaining in detail the nature of the photo-interpretation process he chooses.

The interface with the user is thus a methodological exercise. That implies the capability of the system to grasp the main conceptions, vocabulary and methods from the user's domain or, at least, their pertinent component to the image processing task.

The team incorporated some individuals that have been assigned this interfacing task. They did not have have a special background on computer science or on data processing but were fully aware of the capabilities of the system. They iterated with the user his set of specifications, looked for ancillary data, and evaluated and assessed their use.

# 3 - Realization of the Project

## 3.1 - Organization: the SATCART Consortium

The PO-SATCART project was executed by the National Laboratory of Engineering and Industrial Technology (LNETI, now INETI) and two private companies, EID and Geometral. The first milestone of the project was to establish the SATCART Consortium, in February 1988, coordinated and directed by LNETI. The consortium should provide a minimum and flexible structure in which all the members should participate in the main decisions of the project, and would provide the experience needed to decide whether or not the consortium should be transformed into a company by the end of the project. The consortium set the framework for the management control of the project, by quantifying labor, project costs and schedules.

The Project Director of the PO-SATCART project was also the President of the Consortium. The *Scientific Director* of the project (from LNETI), with scientific and technical responsibility, handled the daily life of the project, reported, and prepared proposals for approval of the Consortium. The *Financial Director* of the Consortium (from EID) held the financial management and reported to the Consortium. Geometral provided the *Marketing Director* of the Consortium, whose task was to identify application projects to be contracted and solved by the project team to test methodologies, and make the assessment of the potential market of remote sensing products and services, in order to prepare the fundamental decision to transform the consortium into a company.

The Project Director and the Scientific Director were nevertheless influential in the identification of projects, in a variety of demonstrations and contacts within the governmental organizations and, in general, in all the contacts where top-level contacts or the scientific complexity of the discussions should overcome traditional marketing practices - which do not work for high technology.

The Administration of the Consortium received monthly reports from the Scientific Director, updating the status of the different activities and application projects, including all the marketing contacts, staff problems, and problems hampering the activity of the project, to be solved at the level of each company. The Administration held formal meetings each 6 months, to aprove SFS reports and discuss how to proceed, although informal contacts between the representatives from the three partners were frequent. Institutional (ownership) changes at Geometral introduced strong uncertainties as to the future at the end of the project.

## 3.2 - Location

The project was approved by NATO in November 1987. Procurements were performed in the first semester of 1988 and the installation of the most important items took place in April 1989.

Until April 1989 the project had interfaced the image processor of LNETI to a VAX-750 computer belonging to EID, at EID headquarters, about 25 Km away. It was a complex period, because the members of the team had been gathered at LNETI, where some space was available, and the constant displacements put a considerable stress on all the members, both on the youngest and on the director. Very often, needed human resources were at the other site, with many negative consequences.

In the meantime, Geometral had decided to change their headquarters from Benfica to Alfragide, and about 50 $m^2$ were allocated to the project in April 1989: 20 $m^2$ for the computer systems and 30 $m^2$ to the team.

Both sites had unpleasant accesses, and the daily life and visibility of the project were seriously affected. The very reduced space allocated to the project by Geometral led inevitably to the separation between the engineering and direction sites, (at Geometral and LNETI, respectively) and too many unsolvable problems stemmed from this separation.

## 3.3 - Procurements

The first activity of the project was to elaborate a call for proposals to purchase the most important pieces of equipment: computer system, analytical stereo-plotter, digitizer, radiometer and GIS. NATO rules were followed. About 30 companies from NATO countries were invited to the tender, and competition was intense. NATO consultants had a very important role to help specify the architecture of the overall system and guided the most important choices.

The procurement process was led by the Opperations Director of EID, and reductions of about 40% (!) in the most expensive items (computer system and stereo-plotter) were achieved in 1987 after difficult but successfull discussions. Hardware and software capabilities were much higher than antecipated at the onset of the project. The complete procedure was hampered by the fact the a high performance digital image processor already existed, that should be integrated or interfaced with the equipments or software to be purchased.

The compatibility between all the equipments was not easy to achieve and implement, because some suppliers - or their representatives in Portugal - had some problems to supply the most appropriate drivers. This affected the high resolution video-digitizer, and significatively delayed the project activities related to aerial photography analysis.

A second procurement phase took place in 1990, for smaller equipments or to upgrade the previous system. Similar criteria were followed by the Opperations Director of the Consortium.

The list of equipments and software purchased within the SFS-SATCART project is included in Annex 5.

## 3.4 - Team

The members of the consortium decided to gather an integrated team, with all the individuals being directed by the Scientific Director, who took decisions on all the training, scientific and technical details of the daily life of the project, including reports, presentations at conferences, papers and content of the visits organized by the marketing. The list of the collaborating individuals is included in an Annex.

The variety of scientific fields and technologies led to a certain specialization - a non-redundant team was fully operational at the end of the project. Nevertheless the presence of six engineers in a small space inevitably distributed some information, and a reasonable level of general knowledge was spread by all the individuals.

Most of the engineers started their activity on the project as thesis students (at "licenciatura" or master level). It was not easy to harmonize academic and production interests, although the most favorable psychological attitude of all the members was instrumental to the success of the technical and scientific objectives of this 3 years project.

In 1989, when the initial team was aggregated, the contacts created in the context of the SFS program made possible the beginning of Ph.D. activities in France and in the US, on image processing of remote sensing images and knowledge-based systems, respectively. Two assistants of LNETI, that had participated in the pre-SFS activities (1985-1987) were then sent for specialized training in 1989.

## 3.5 - Project structure

The project was originally divided into 2 sub-projects, dealing with general management activities (all levels) - Sub-Project I - and scientific and technological tasks - Sub-Project II, which was further divided into 11 Activitites: specific problems of remote sensing, geographical information systems, software engineering, scene understanding, digital cartography, digital image processing, graphism, data fusion, atmospheric models and image corrections, production engineering and technical support.

Technical activities were executed according to a variety of philosophies. As stated originally, the project would be executed under the form of application projects. It did happen that way, although each individual making a thesis was given more general purpose scientific objectives that should be used, directly or adapted, to application projects. On the other hand, after the mid-term review, some additional individuals from LNETI were associated to the project for very specific developments to accomplish initial milestones (in GIS and artifficial intelligence).

A minor re-definition of some activities and milestones took place in April 1989. The complete structure, including the division of activitites into tasks and the evaluation Milestones, is included in Annex.

## 3.6 - NATO scientific support

The project was supported by specialists designated by the SFS program. We can acknowledge valuable support on decisions concerning the hardware and software structure of the project, to establish some form of links with remote sensing companies and institutions from NATO countries, and to help identify critical areas where in-house priority developments should take place.

## 3.7 - Financial management

All the accounting and financial management of the project (and also of the Consortium) was performed by the project Financial Director, also the Financial Director of EID with experience on handling other SFS projects. Every 6 months financial data was included into SFS progress reports, although the project internally kept monthly records for manpower and purchasings.

## 3.8 - General activities (sub-Project I)

The general activities of the project had been integrated into the Sub-project I, and included the conception and design of the philosophy of the system, the specification and procurements of hardware and software, the training, the installation of equipments, marketing activities and project administration.

The VAX system was delivered in April 1989 and the image processor was installed in mid July 1989, after several cumbersome problems related to the inconsistency between the drive and version of the VMS operating system. The video digitizer Eikonix was successfully installed only on the second half of 1990, also due to problems related to the incompatibility between the camera driver and operating system. The ArcInfo Geographical Information System was installed by the end of July 1989, and several versions were delivered during the 3 years project. Most of the members of the team acquired a good expertise on the different modules of this GIS, which turned out to be the final production tool installed at SATCART.

The digital stereo plotter, from Zeiss, was delivered in the beginning of September 1989, after a training period at Zeiss headquarters, in Germany. After one year of operation, it was clear that the instrument should be operated by its own computer, and a VAX 3100 was ordered in the second half of 1990. This was the second purchasing period of the project, and the following items were specified and acquired: the hand-held radiometer, a 1.7 Gb magnetic disk, several software packages for image processing, and two HP workstations to install digital image processing capability at LNETI, for research purposes, given that this Laboratory had fully allocated its image processor to the SFS SATCART project.

During its lifetime, the project received requests to perform the land cover of the Bacia do Vouga and of the District of Setúbal, two projects of utmost importance to test the connection between environments and push the complete configuration into its limits. The consortium also signed a contract with the EEC to make some multi-temporal studies for crop surface estimations, in the context of the European agricultural statistics projects. The cartography of forest fires, that had been actively demonstrated by LNETI since 1985, was finally contracted by the Ministry of Agriculture, and was executed in 4 months, (beginning in April 1990), managing to identify most of the forest fires until the summer of 1989. A similar request was received one year later, and the same methodology was used with considerable improvements in the technical management.

Marketing has always been hampered by the difficulty to define a clear strategy for the potential company into which the consortium SATCART might transform itself, and because of institutional (ownership) changes in one of the members of the consortium (Geometral). Nevertheless, two proposals were presented to the EEC on agriculture statistics and remote sensing - an operational project for which the EEC launched an international call for proposals and in which we had already been collaborating with the Portuguese Agriculture Department - one of the proposals was accepted, being the main activity of the team in 1990 and 1991.

# 4 - Scientific and Technical Achievements (sub-Project II)

## 4.1 - Science and Technology

### 4.1.1 - Specific problems of remote sensing

1 - Generalization of ancillary data in accordance with remote sensing capabilities.
2 - Analysis of remote sensing classification trees
3 - Ground truth collecting with video registering, from helicopter platforms
4 - Development of calibration methodologies with a multi-spectral hand-held radiometer.
5 - Specific studies: analysis of mixtures
6 - Data base with phenological characteristics of species

This activity included a certain number well known (but unsolved, in general) problems of remote sensing of thematical nature: how to access and use available data, how to collect ground information, how to design the application taking the nature of the sensor into account, and how to deal with mixtures. The knowledge acquired in this activity supported different remote sensing application projects, and increased considerably our experience with data and our sensitivity to several aspects of remote sensing problems.

In particular, mentioned should be made to the relation between resolution, output scale and the level of generalization, not only of the geometrical features, but, above all, of the items to be included into the legend. This problem is systematically present in all remote sensing projects in Portugal, due to the complexity of the landscape or to the insufficiency of the sensor resolution. No formal activity was performed on this issue, that, together with classification trees, were always present and behind all the application projects.

The first driving force for this activity was an EEC agriculture project. Two points have been developed very carefully: stratification and manipulation of multi-temporal data of the same area. Stratification is extremely important in Portugal because of the presence of permanent cultures associated with annual crops. The stratification was handled by the GIS, after partial digitalization of some available land cover maps; different forms of stratification, including the use of the topographical model and multi-temporal analysis lead to the development of hierarchical classifiers, based on the satellite screen colors, or on color tendencies, information that had to be correlated to the phenological cycle of species, antropic factors and climatic effects.

A proposal was made in October 1989 to the EEC - through the Joint Research Center (JRC, Ispra) establishment - to create a technical group to study some specific problems of remote sensing in the context of the Mediterranean countries. That proposal was accepted, and four meetings took place in 1990 and 1991, joining experts from Greece, France, Spain, Portugal and the JRC. The activity of the group was focused on three main topics: 1. use of soil information to deal with remote sensing imagery; 2. identification of the distribution of permanent cultures; 3. landscape modeling, scene simulation and associations.

Scientific coordination and some preliminary experiments on mixtures were the portuguese contribution to this EEC expert group on agriculture and remote sensing. A correlation was established between satellite and aerial photographs of the same area; for a given position of trees, simulated images were prepared in order to study, under parametric conditions, the effect of shadows, tree canopies and soil background. Current INETI activities on image simulation and radiometric properties of mixtures began at that time.

Ground truth acquisition by video recording from an helicopter platform was experimented with positive results, although the technique should be improved - nevertheless no use was made of it on operational projects. Absolute calibration of images by radiometric measurements with the hand-held radiometer was not executed within the scope of the project, due to the late arrival of the radiometer.

The application projects executed during the PO-SATCART project are summarized in section 4.2. We manipulated SPOT and LANDSAT images covering about 80% of the area of Portugal, to produce thematic maps for a variety of purposes, doing classification and multi-temporal analysis or simple photo-interpretation. Most of the tools developed under the other activities were used, more than 30 maps were delivered to users that requested a variety of analysis.

### 4.1.2 - Geographic Information Systems (GIS)

1 - Study of GIS characteristics
2 - Rasterised GIS specification for a personal computer
3 - Rasterised GIS implementation in a personal computer
4 - Installation of the ArcInfo GIS in the VAX and training
5 - Specification and implementation of messages exchanges between the image environment and the GIS
6 - Transfer of available ancillary data, already in digital form, to the GIS
7 - Development of hierarchical classifiers based on the GIS
8 - Using the GIS to structure digital terrain models already developed.

GIS were virtually unknown in Portugal in 1987 - the situation did change considerably since then. The first goal of the project was, at the time, to analyze in-depth the characteristics of such tools, assess their application for a variety of spatial data manipulation and image analysis, and also as a production tool. We selected the ArcInfo GIS, the most widely distributed and performant GIS at the time.

The period up to the delivery of the ArcInfo was fully dedicated to the theoretical study of available GISs and of the forms of integration of GIS with raster data produced by the image environment. We realized also that one of the reasons of the delay of the introduction of the GIS technology in Portugal was the high price of most of the systems and, after an assessment of many potential applications, decided to specify and develop an experimental prototype of a GIS, handling data in the raster format for PC-MSDOS environment: the RAGIS (from RAsterised GIS) - described below. RAGIS would not need any special image hardware, and should be used as a second order classifier, fed by data obtained by classification of remote sensed data, data of digital terrain models and other ancillary information.

After installation of ArcInfo, the emphasis was put on optimization of its performance within the VAX and the development of suitable interfaces to and from the image processing environment. ArcInfo was also evaluated as a general tool to structure data and support and improve classifications. Much effort was dedicated to understand its commands, operationally and using the AML macro programming language to speed up development and operational projects. All these goals were accomplished and all the members of the team acquired a reasonable expertise on the most significant modules of the GIS. For operational projects, images and coverages flew constantly between the image and the GIS environments; software limits were identified, processing times assessed and parametrization of the GIS (from the point of view of the VAX/VMS operating system) considerably improved.

Some spatial data bases (map coverages and municipality boundaries) were constructed, in order to create masks from within the GIS side, to be exported to the image side to restrict image processing to within restricted areas; classified data, altimetric and slope coverages were manipulated as ArcInfo coverages. ArcInfo was also used to accomplish several types of spatial operations: cartographic generalization, relations between different coverages (temporal classifications, topographical information, digitized maps). The number of archive coverages slowly increased according to the needs and output of the application projects, although not structures as an archive, waiting for the transformation of the Consortium as an industrial company.

On the last phase of the project, the links between the image and GIS environments were improved, and GIS coverages were used to provide training sets to image classifiers, after an intensive development to handle directly graphical elements without the need of an intermediate raster format. The inverse transformation was also developed. The positive aspect of these developments was a deeper understanding of the structure of the auxiliary files of the image environment, and of the export files of the GIS, thus opening the way to future improvements.

At the end of the project, GIS operation had become banalised at the team level. This is an important issue, that the project tried to outspread at all the contacts to a variety of potential users or clients, by showing real coverages of Portugal and performing a variety of application on the screen.

### 4.1.2.1 - RAGIS

RAGIS was specified and developed for MSDOS environment, due to its price, graphical capabilities and available supporting hardware and software. The most difficult problem to solve, due to this target environment, was the very limited memory management system of such computers.

Two versions of RAGIS were developed: the first one was completely programmed in C, and allowed the revision of some of the functionalities and specifications. The second one was conceived with an object oriented approach - at the same time one of main difficulties in the analysis phase, because object-oriented philosophy was unknown to the team at that time. Fundamental classes together with their functionalities were defined and given the form of C++ objects. The objects included in the system are abstract images and pictures, independent of their representation format (vector, raster or whatever), that can be operated with logical, thematical, and cartographic operators. The system dealt only with rasher data.

RAGAS was made of three independent modules: the image processing module, in which all the functionalities are implemented; an in-house developed relational data base kernel to handle non-volatile information on the objects; a graphical interface module, complying with the windows philosophy and providing menus and mouse events to the user.

The development of RAGIS was mainly a methodological exercise, because its development had to be stopped well in advance the conclusion of a testable prototype. On the other hand, it was becoming clear, as software development went on, that lower cost GIS were being developed for PCs environments, with superior capabilities to RAGIS. Its specification was nevertheless extremely important. It was also the first time, at LNETI, in 1988, that an object-oriented language was being used for applications, and the knowledge acquired by the three engineers in charge of the development was most useful for their future work.

## 4.1.3 - Software Engineering

1 - Insertion of new commands within the image software environment
2 - Graphical data base for satellite and maps coverages.
3 - Data base for ground control points
4 - Specification and implementation of transfer formats to external environments
5 - Logical integration of all the image equipments and tools within an unique environment

The main goal of this activity was to integrate whatever tool might be needed for operational projects, to simplify procedures and ease the learning phase of technicians. That goal was fully achieved, although some specificities of the Portuguese cartography precluded, for instance, the construction of the data base for control points.

The construction of new commands for the image processing environment was given higher priority, because of its complexity and operational need. Although the image processing system (Image processor M75 and S600 software system from International Imaging Systems, USA) is still one of the most complete and flexible systems available, still being used in most of the companies that began remote sensing activities in the 80's, real projects always need specific procedures, approaches or functionalities. It may be stated that, in most of the cases, the first phase of every project is to identify what tools are missing, make tradeoffs and do the development. At the end of the project, there was a considerable expertise in the creation of new commands (in FORTRAN and in C) or in the introduction of improvements in existing commands.

Image processing modules fully developed within the project - such as the digital terrain models - were also integrated. The same applies to masking modules, data translators from some scanners and the generation of image formats that were used at other locations with different environments. The masking module was supported by graphical databases, structured under ArcInfo, with municipal and NUTS (1,2 and 3) boundaries, and 1:25,000 (and derived) map coverages.

Macro files, from within the VMS environment, were widely used to execute batch processes combining image processing, GIS and other pieces of developed software. They were easily built and tested, and very complex procedures were executed at the most appropriate times to unburden the computer system resources. The capability to build these files was general, from engineers to technicians.

The analytical stereo plotter (Planicomp P1, from Zeiss) was also included in the SATCART environment, through DXF (AutoCad) and ASCII files accepted by the ArcInfo, data flowing easily in both ways. This instrument was of utmost importance to build high scale altimetric data to construct digital terrain models within the project.

### 4.1.4 - Scene understanding

1 - Design of the architecture of the control of resolution module.
2 - Design of the architecture of the region of interest module.
3 - Design of the modules evaluating primitives and managing perceptual groupings.
4 - Implementations, assessments and identification of artificial intelligence tools.

Once the GIS and image environments have been integrated, the problem of developing consistent strategies to make all the information interact and produce reliable classifications, should be solved. It was not within the scope of this project to solve it in its complete generality but the concept of some blocks have been elaborated. The purpose of this activity was to design and conceptualize some strategies based on the control of resolution, definition of the region of interest and on the evaluation of image primitives and output from perceptual grouping modules. We intended to grasp where artificial intelligence tools should be used and what problems might then be solved, in the specific context of remote sensed satellite and aerial photography images. It was taken for granted that some analytical tools - such as pyramids, trees, contours, Voronoi and Delaunay tessellations, developed within the project - were available and might be integrated according to the needs, at any time.

In the first phase of the project, the overall philosophy of the system was discussed, mainly its general manager, programming language, information preserving structures, geometric and algorithmic tools to be implemented, hypotheses generation and testing, conflict generation and handling and knowledge representation. A great deal of bibliographic analysis was performed.

Some preliminary work on the identification and processing of discrete patterns of points was also done. Such patterns may arise from intermediate processing, and can be handled using point processing tools, of which Voronoi diagrams is but one example. This problem is also related to scene simulation, in the sense that the position of trees or of individual plants can be modeled using statistical generators studied in the context of point and line processes. This approach began within the SATCART project and is still being improved within current projects in this area, at INETI.

In the second phase, two research proposals on these subjects were submitted, which somehow clarified and provided deeper specifications. One of them, in cooperation with the University, aimed at testing lower level procedures to be incorporated into such system, with design processing heuristics and image processing primitives, mainly on topology and shape driven polygon manipulations, as a powerful filtering technique to deal with typical classification results in remote sensing. An additional proposal was presented to the EEC to deal with the geometric part of the problem, but did not receive support.

Artificial intelligence tasks were clearly beyond the capabilities of the team and one of the engineers was sent to the MIT (USA) to complete a Ph.D. on knowledge-based systems applied to image and graphical data. Nevertheless, some AI programming languages (OPS5 and LISP) were studied, because control and inference mechanisms for knowledge manipulation can be easily implemented with them. The final choice for some preliminary implementations was C++, because of the availability of good development tools and convenient interface to C.

Scene analysis - in particular remote sensing scene analysis - is a pure research field, the development of which would obviously be very difficult within a project, such as SATCART, with a strong industrial focus. In such a project, real data must be processed. Reality is always very complex and does not comply with simple and well defined problems. Nevertheless, such is the goal of the scene analysis subdomain: to get meaningful information from complex images, using available information when available. In such context, although no results were obtained, two members of the team have elaborated about possible ways of handling such problems, and have become acquainted with the literature and the state-of-the-art in this field.

### 4.1.5 - Digital Cartography

1 - Software for digital stereo-plotters
2 - Specification of cartographic maps to be produced within this project
3 - Construction of Digital Terrain Models (DTM) from existing maps
4 - Methodology for identification and modeling of ground control points
5 - Construction of Digital Terrain Model from data output from the digital stereo-plotter

6 - Production of maps
7 - Development of digital ortophotographies

All the objectives of this activity have been achieved: maps (or numerical covers) were produced out of classified remote sensing images, at the most appropriate generalization level, digital terrain models were computed out of contour curves on paper maps or by interactive restitution of aerial photographs on an analytical device, and aerial photographs - that were transformed into digital files (rasterised) and corrected from all the geometric deformations - were ortho-corrected to eliminate perspective errors due to topographic effects, thus achieving one important milestone of the project.

Nevertheless, in order to fully integrate remote sensing data, some additional activities were also performed: the geometrical correction of satellite images, in order to build a cartographic reference into the data, and a variety of generalization procedures on classified remote sensed data, in order to select the level of geometrical detail that complies with the output scale of the map to be produced and with the resolution of the sensing instrument.

#### 4.1.5.1 - Digital Terrain Models

There are many applications of remotely sensed data in which terrain models are mandatory. For example: to understand the physiography of the site to correlate image characteristics with potential use and to perform stratification; to compensate, or at least identify, zones where shadows exist and to account for a variety of geometries of illumination and observation; to induce from known heights, aspects and slopes, which type of vegetation may be found, thus guiding the execution of specific classification algorithms. In fact, the addition of terrain information has been shown to improve classification accuracies of categories that exhibit unique terrain dependencies.

On a remote sensing facility context, digital terrain models (DTM) are usually standalone products. The emergence of computer graphics environments and the need to plan the occupation of the space lead many regional space managers to request such data irrespectively of any kind of satellite or aerial photography data with additional information.

Digital elevation data can be readily generated from digitization of contour maps by stereoscopy from a couple of aerial photographs or even from a pair of SPOT images. These procedures produce a set of points, distributed on a regularly or irregularly grid, that must be interpolated in a later step to generate continuous surfaces. Other terrain information, such as slope gradient and aspect can also be calculated from the original elevation data. Aspect is directly related to the exposure to the Sun and, irrespectively of geometrical considerations, is a very important feature to understand the distribution of certain types of cultures, namely permanent cultures.

In order to be useful in a remote sensing context, both digital terrain data and the satellite image must be georeferenced into the same system.

A number of approaches are available to remove or compensate the effects of shadows on satellite images, using the digital elevation data. Shadowed areas have lower mean and variance brightness with respect to sunlit areas. Reduction of the shadow effects prior to classification will reduces the intraclass radiometric variances and improves the classification.

The DTM was computed from a mathematical model of the surface which interpolates the elevation (z) of grid points (x,y) from a set of known points, acquired by manual digitization of height points and contour lines directly from maps, or by stereo-restitution methods using the Zeiss Planicomp-P1 instrument.

The elevation and slope are considered continuous functions at any point of the surface. The interpolation method is based on a triangular network of which the reference vertices are the digitized points. The Delaunay procedure was applied to generate the triangular mesh. The interpolation involves a piecewise complete bicubic approximation which is numerically obtained by using Zienkiewicz shape functions. Heights and tangent planes at the corners of the triangles are the parameters of these shape functions. The generated surface is smooth within the triangles and continuous from triangle to triangle. Slope and aspect are computed from the elevation data by considering the plane tangent to the surface at each point.

All this software was developed within the SATCART project. It is independent of the hardware and has already been ported to other computer environments. The programs have proved accurate for most situations. For high scale data, the accuracy of the height calculation was measured by the residual mean error of computed height points, measured on the same points by the operator in the Planicomp-P1 instrument. The derived height model was based on contour level data acquired also on the P1 instrument. For a 1:5,000 scale, the residual mean error was found to be 0.36 m, which is within the national cartographic standard for this scale. For smaller scales, slope, aspect and height were computed from 1:5,000 to 1:100,000 scale maps, integrated with remote sensed data, integrated with ArcInfo geographic information system, and translated to a format useful for ortophoto production.

Two complete examples of the integration of the DTM within the image environment are shown on the video. The topographic surface was "covered" by the satellite images, (a complete geometric inter-registration had taken place in advance), a path was constructed for the position of the observer, and a small animation with about 100 images constructed. The visual effects is clear, allowing the user to improve the understanding of the landscape under analysis. Terrain models have also been systematically used, when available, to guide stratification and classification within the context of operational projects.

#### 4.1.5.2 - The Planicomp P1 / Phocus analytical restitution system

Phocus is a photogrammetric and cartographic information system consisting of a comprehensive set of software components grouped into a environment that is superimposed on the operating system. The core of Phocus is a data base system for geometric and alphanumeric data. Data is collected and stored in structured form and can be processed and output according to specified selection criteria. Phocus is installed in the 3600 micro VAX running under the VMS operating system.

The Planicomp P1 analytical plotting system comprises the Phocus standard software and instrument-specific software. Within the P1, the mathematical relationships between photo coordinates and spatial coordinates are calculated by the integrated micro-processor.

The Planicomp P1 / Phocus system has the capability to acquire, process, store and output geometrical and alphanumeric data. The salient features are: orientation programs (interior, relative and absolute orientation), object data acquisition performed in accordance with the definitions of the object code table, editing functions, height measurement with automatic positioning in planimetry, photo coordinates measurement for aerotriangulation and Spot images restitution.

The Planicomp P1 / Phocus stereo restitution system was installed on September 1989. Two restitution operators, one editing operator and a system manager handled the system. The first important task was to optimize its performance and integrate it with the other resources of the system, allowing data to flow freely in both directions. As ArcInfo is a very powerful tool to prepare and plot maps, the data translator was developed.

There were many initial problems related to data transfer and communication with the main computer and with the HP-plotter, due to the incorrect parametrization of Phocus software in the main computer, input/output privileges, amount of data transference, or incorrect configurations.

The stereo restitution system was fully allocated to industrial production, under four main application domains and for a variety of (large) scales: aerial and terrestrial photogrammetric restitution, aerotriangulation and height (DTM) acquisition. Software was developed to improve specific features and ease the interface problems of specific applications.

### 4.1.5.3 - Digital ortho-images

Ortophotographs have long been recognized as supplements or alternatives to standard maps. Ortophotographs are usually produced by analog instruments, that achieve scale correction by adjusting the optical magnification, and direction correction by image rotation with Dove prisms. While these techniques produce ortophotographs of high quality, their applications are limited by the photographic film support.

The motivation to develop digital ortho-images was the need to georeference and geometrically correct high resolution digitized aerial photography: rectification techniques applied to the image remove tilt and relief displacement, lead to the digital ortophoto.

The terrain surface is defined by a grid of digital elevation values stored in raster format. A gray level - or a set of multispectral values - from the co-registered input image, is associated to each point. from the co-registered input image.

The two main sources of input data are a digitized aerial photograph and a digital terrain model (DTM). The raster file results from scanning the photograph to be rectified by an Eikonix digitizer. The DTM is previously computed with the following characteristics: a) it consists of a regular array of elevations referenced to the coordinate system used on the photograph (absolute orientation) b) is ordered from north to south in profiles ordered from west to east, c) the spacing of elevations along and between profiles is dependent on the output ortophoto scale and is a pre-defined value. Several other data files are required for ground coordinates of passpoints, photo coordinates of passpoints, camera calibration parameters, and photograph coordinates in the raster image system.

The input to the rectification process consists of camera calibration parameters, ground coordinates and photo coordinates of a least three passpoints of the rectified photograph. The exterior orientation of the photograph is solved using the familiar space resection equations. The six unknown orientation parameters ($X_0$, $Y_0$, $Z_0$, $\omega$, $\phi$, $\kappa$) are determined by the collinearity equations for the photograph passpoints. The coordinates (line and sample) of the fiducials in the raster image are previously determined on the image processing system. The photo coordinates are referenced to the camera fiducial coordinate system using a linear conformal transformation.

This technique maps the three dimensional object space into the two dimensional view plane. The object is first reoriented based on geometric transformation and then projected onto the horizontal plane. The major disadvantage is the need to interpolate gray levels in the horizontal plane. A fastest method is to convert the coordinates to integers by either truncation or routing. This method, which we did use, has the advantage of being extremely fast, but has two minor problems: multiple pixel assignments and pixel dropouts. Multiple pixel assignments occur when more than one input value maps into the same output grid cell. The dropouts occur when no input pixel maps close to an output grid cell. The resulting image contains black pixel-size gaps at these locations. The extent of a pixel dropout is a function of the transformations involved and the amount of relief in the original image. Pixel dropout is not a serious problem and can usually be ignored. One of the problems of the simple and fast nearest-neighbor method is the tendency to produce "blocky" images, but smoother images can be created by using a higher order interpolation scheme.

The program was satisfactory tested for many situations. Extreme vertical exaggeration may cause pixel dropouts, but this can be made much less noticeable by increasing the search window size. Tests were performed on two typical examples: a) aerial photograph of a mixed urban and rustic environment, b) terrestrial photograph of a building.

The accuracy of the rectification process was measured by computing the pixel coordinates of the passpoints appearing on the digital image and transforming them to their known positions. The passpoints locations in the ortophoto image were measured on the image display device and transformed to ground coordinates. The accuracy of the rectification was determined by comparing these measurements.

To industrialize this procedure, three problems remain to be solved: the correction of the distortion errors associated to the optics in the digitizing device; the identification of a suitable printing facility to produce ortho-images in paper for their final evaluation, and the construction, as automatic as possible, of all the cartographic information to be written in the border of the document.

#### 4.1.5.4 - Automatic Cartographic Generalization

One of the most active fields of SATCART was map production, thus making available in the usual paper format the results of classifications of remotely sensed data. The ArcInfo was the most important tool of the production chain, not only because of its output facilities but also because of the topological structure of the data that enabled the development of generalization procedures.

The job of map production has always been the responsibility of skilled technicians, who decided the type of information to represent and the graphical layout of the map, evaluating and solving superpositions and eliminating graphical features too small for the specified scale. The complete process is called generalization and few rules exist to automatically perform generalization. Among the subjective tasks, one of the most complex is certainly to represent information at a lower scale than the one available, or than the scale at which data has been collected. This is always the case in remote sensing.

In fact, due to the fixed resolution of the images acquired by the SPOT and LANDSAT systems, usual cartographic rules preclude the representation of information at scales higher than, say 1:50,000 - although in some cases, panchromatic SPOT derived information can be represented at higher scales. Nevertheless - and it did happen during the project - in many cases users request final data at the 1:100,000 scale, and the generalization problem has to be tackled. SPOT or LANDSAT information is partially lost when the output scale is 1:100,000 or smaller, but the availability of coverages at that scale for regional planning and the specifications of the users do create a technical problem and challenge.

Until 1991 the automatic generalization was a non-solved problem and commercial GIS did not handle such procedures - that were being investigated by some research institutes active in this area. The activity of the project was timely and effective.

Modern map production lines are adequate enough to allow for an almost completely automatic drafting of maps. SATCART built such a production line, but with unique characteristics, the most important of which is its automatic generalization feature. It has the ability to aggregate and eliminate information from the workspace in a way that spatial coherence and representability are always asserted, independently of the scale specified for the output of the data.

The robustness and effectiveness of the generalization procedure developed within the SATCART project was acknowledged, and its acceptance in the scientific and GIS communities was very acceptable.

## 4.1.6 - Digital Image Processing

1 - Methodologies for geometric pre-processing of image data
2 - Methodologies for radiometric pre-processing of image data
3 - Filtering and modeling with mathematical morphology techniques
4 - Classification methodologies
5 - Textural classifiers
6 - Contour extraction
7 - Pyramid manipulations
8 - Rasterization of maps of contours

### 4.1.6.1 - General

Many image processing software tools were developed and tested within the context of application projects, especially for radiometric filtering, noise reduction and classification procedures. Special reference is made to the development of mathematical morphology operators to decrease initial intraclass variance and post-classification noise, and filtering procedures that does not affect boundaries, by judicious exploration of the context of each pixel and decision relying on homogeneity criteria. Some of these tools were used systematically, others were very heavy, from the computational point of view, and could not, realistically, be applied over very large satellite scenes.

### 4.1.6.2 - Geometric correction of images

Before images can be merged with additional spatial data (morphologic terrain data, for example) or represented in a paper format, they must be rectified to a common coordinate system and placed in precise registration.

Within the project two different methods were considered. One can select a certain number of ground control points, identify them on the image and measure their cartographic coordinates on a map, set up a least squares model to correlate both sets of data, and apply that model to all the pixels of the image; in this case, it is important to build criteria that lead to the reduction of the number of the points for a final desired maximum error, and assess the quality of the representation of such structures on the maps in order to keep or discard them.

One can also build the mathematical model that relates the position and orientation of the remote sensing instrument on-board the spacecraft following a well defined orbit around the Earth, and the Earth itself. This is the kinematical model. It is also a parametric approach because some of the orientation angles of the instrument have to be estimated from, at least, three control points. This is the methodology followed by producers of data (such as SPOT), because the residual errors (smaller than 0.2 pixel) and the amount of work to collect ground control points are much smaller. Within the project it was only possible to study this approach from the geometric point of view and perform some simulations with LANDSAT data.

The non-parametrical approach was used in all the application projects. It became possible, within the SATCART project, to evaluate the importance of the quality of the selected points, the effects due to their number and distribution, the order of the mathematical polynomial used to relate both sets of data, the date of the paper map used to get cartographic coordinates and the reliability of the control point identification. At the end of the project, root mean square errors below one pixel could be routinely guaranteed. The price paid for that error was the time needed to geometrically correct one complete SPOT (60 x 60 Km) or LANDSAT scene (180 x 180 Km): about two working days.

### 4.1.6.3 - Classification methodologies

A strong emphasis was given, throughout the SATCART project, to remote sensing multi-temporal analysis, with different data sets covering the same area at different times. Due to the complexity of Portuguese landscape and to the low resolution of the available sensors, most situations correspond to mixtures, and the practical result is that the spectral signature of structures - at each resolution level - does not allow the separation between structures: there is no one-to-one correspondence between objects and measured radiometric signatures.

The situation is vastly improved with multi-temporal data, and it can be stated that the temporal variation pattern, for each band, is more characteristic of the objects.

Within the SATCART project, a lot of attention was given to the temporal variation of some radiometric indexes, namely those in close correlation with the screen colors, when three band images are displayed. Visual colors may be classified according to their hue, saturation and intensity. Hue depends directly on the relative weights of the three main components of a color. It was realized that, when hue identification and hue temporal variations were clear, the interpretation of the objects was much more certain. Hue analysis mimics photo-interpretation and easily incorporated into automatic algorithms.

Closely related to these temporal variation patterns is the idea of hierarchical classifiers, in which the classification at each level depends on the previous classifications. Once again the procedure was implemented automatically, through logical and arithmetic operations on images, following the equivalent logic on the classification items.

Although the complete procedure can be very complex, each classification can be made very simple, and, in fact, simple parallelepipedic classifiers were used instead of the much more elaborated statistical classifiers, that do depend on the spectral purity of data, a condition that can hardly be met with mixtures.

The Vouga and the EEC / Action 4 projects were implemented with such classification philosophy, with very acceptable results.

### 4.1.6.4 - Pyramids and trees

Pyramids are special structures for multi-resolution image representation. As the name suggest, each level of the pyramid has a resolution half of the level beneath. If a scene contains a variety of objects with different resolutions, it can be expected that some will disappear at lower resolutions, although their location can always be traced back if suitable vertical links are implemented.

These vertical links are very simple for usual pyramids. Within SATCART, not only these data structures were implemented from scratch, but a special way of establishing vertical paths was implemented. Basically, the idea was to discard the regular geometric inheritance and build up parents and sons relationships based on radiometric uniformities. In such a way, all the neighbors that belong to the same region - and that have basically the same gray level - can be fully represented by their immediate top-parent. This philosophy is applied bottom-up on the pyramid, thus leading to a new segmentation procedure, and creating a variety of paths throughout all the resolution levels of the image.

The tree organization of pyramids was developed and tested on typical remote sensing images, mainly SPOT panchromatic, 10 meter resolution. The amount of computing time and memory needs would preclude, in any case, its systematic application on running projects, and only a limited amount of tuning and tree organizations were actually tested.

Multi-resolution is one of the important current area of activity at INETI, and one of the physicists was sent to the University of Toulouse to develop wavelet multi-resolution methodologies on remote sensing data.

### 4.1.6.5 - Textural Analysis (raster approach)

Landscape complexity and low resolution lead inevitably to textured scenes. In some cases, the emergence of a texture is a positive sign because it enables identification, at a suitable generalization level. With commercial remote sensing sensors, this is usually the case with forest pixels at 10 or 20 meter resolution. In most of the cases, texture is, once again, related to mixture situations, and textured areas cannot be dealt with in the same way as more homogeneous regions, from the point of view of the classification procedures. To know in advance where texture areas are and to discriminate between different textures, is still a non-solved general problem of remote sensing.

Within SATCART, emphasis was given to a special type of stochastic models usually know as ARMA or ARIMA (autoregressive moving average or autoregressive integrated moving average). These models are widely used on signal processing (one dimension), but hardly used at two dimensions. The reasons are its mathematical complexity and computing time.

ARMA textural analysis was developed and applied to digitized aerial photography and SPOT panchromatic data, in which texture segmentation is an important goal. In fact, the higher the scale, the greater is the importance of variations between textures. The results of the supervised texture classifier are extremely interesting, although only for two texture classes at a time, which inevitably leads to a hierarchical, multi-step approach.

#### 4.1.6.6 - Textural Analysis (vectorial approach)

In a vectorial approach, textural analysis, or texture-based segmentation can be formulated as a sequence of operations over elementary (generally small sized) polygons whose categorical meaning is well known. The actions to be performed are of the gathering, or aggregating, type.

Texture patterns eventually show up as clusters of polygons with common features such as geometric attributes, gray-level, and spatial interrelationships, normally against a background. A textural classifier implemented under these premises should try to establish a category hierarchy in the first place, as to allow for a convenient objects-background local decomposition. The rest of the procedure should then be of geometric nature, measuring polygon geometric properties along with topological information about the spatial positioning of the various objects present.

SATCART developed a complex, recursive, texture analysis procedure within the GIS environment. It relies on a hierarchy table in which each class is assigned a relative order of relevance. Making use of the DBMS features of the GIS, it queries over the database to find geometric information about the polygons belonging to two of the classes present in the hierarchy table. After finding geometrically homologous polygons, it tries to generalize information, which it will do, if the neighborhood relationships between the isolated objects and the local background favor it.

This rather unusual form of looking at texture analysis gave rather good results, especially associated with the generalization procedure developed by SATCART. As a matter of fact, conveying a smaller scale of representation involves generalization not only of graphical nature but also of thematical nature. The latter has imbedded, actually, the flavor of texture analysis, as generalizing themes is the same as creating "dominant" themes which, in turn, reflect in a spatial aggregation/gathering of polygons with common properties.

This development was deemed necessary because of the special requirements of the Vouga project (see section 4.2.1).

#### 4.1.6.7 - Automatic Vectorization

Line information is normally entered into a vectorial editor by means of digitizing it in a digitizing table. The operator knows what he must capture, and selects the desired information from the paper map or film document. Some documents however are graphically simple and automatic procedures can be used.

In the framework of the digitization of a huge amount of simple graphical data, SATCART developed a production chain for a much quicker and self-consistent way of entering data. Main virtues of this procedure are integration of different equipment philosophies, reduction of labor work, and faster processing for massive collections of documents.

This development was driven by the needs of an agriculture statistics project for the EEC, where about 550 small colored hand-drawn maps would be provided with ground truth data, to be automatically converted to a GIS coverage for further manipulations. SATCART was thus led to use a commercial scanner to digitize the data and to create a new data translator for the scanned binary images.

The input documents (A4 transparencies with black lines to be digitized - field contours - and red lines to be ignored - strata contours) were scanned through a red filter, with a geometric resolution of 400 dpi and dynamical resolution of 1 bit, and automatically binarized. A thinning procedure, developed by SATCART, was then applied to transform thick binary lines into one pixel width lines, thus enabling the vectorization of data. The vectorization was also in-house developed, tracks the contour of each polygon, and produces a symbolic description of the arcs, that was subsequently converted to a format compatible with ArcInfo for additional processing. The complete procedure also guarantees that the cover is complete and topologically correct.

One of the most important milestones of the project was thus achieved, although SATCART does not claim to have solved the vectorization problem for large scale and complex maps, which is still a research topic and is delaying the widespread use of GIS, official digitized maps lacking.

## 4.1.7 - Graphism

1 - Operations on coverages
2 - Operations on image representations
3 - Operations on linear structures

### 4.1.7.1 - General

In the past, manipulations of graphical structures was done within computer graphics environments, more recently win GIS; most image processing systems hardly incorporated tools to manipulate graphical objects. This is the reason why it took sometime to create interfaces between both fields: it was not only a technical problem, it was also a cultural problem of the remote sensing community.

When SATCART began, the area of Graphism was given a higher priority because of the representation and GIS issues. As the project developed, it was clearly that useful work on digital terrain modeling had to rely on sophisticated graphical objects, and that some competence should be created in that the newborn field of Computational Geometry.

Still later, but already very near the completion of the project, it was clear that such tools, applied to manipulations on the two-dimensional plane, could also be extremely important for any multi-dimensional (metrical) feature space, and a bibliographic survey and study of the state-of-the-art was performed by team members of INETI - this area is still an active area at INETI.

### 4.1.7.2 - Representations

One of the most important issues regarding image processing environments is transparent communication between each of their components. The representation schemes employed are critical, as they determine the way the data is handled, and reflects the intrinsic nature of a specific process. Examples are the vector and raster environments, the former specifically assigned to coordinate handling procedures such as those performed in a GIS, and the latter present in every image processing action. The need to implement procedures under hybrid environments, as is the case of SATCART, makes the representation issues particularly important.

Aware of this fact, SATCART developed several representation conversion procedures, so that equipments and software packages of different types could work together in a project execution environment. Among others are: i) Vector to raster conversion, responsible for building up images from digitized data collected in a CAD environment; this procedure allowed for the construction of a rather precise model of the ground-truth of a specific area, and could be used in remote sensing classification tasks as an auxiliary tool. ii) Raster to vector conversion: this made the direct execution of maps from segmented images possible, after classification of remote sensed data.

Conversion procedures were tackled in a variety of ways, given the diversity of the data formats present in our computing system. All the software was made portable. Work was to be executed in a hybrid environment, where both raster and vector processing could be performed on the VAX, on PCs or on a graphics workstation. SATCART attained a good level of data transparency (or fusion), and most of the software could be developed in an almost device-independent way.

Mention is also made to the conversion between formats to represent graphical data. If GIS can be used to store ground-truth data to support future statistical classifiers on raster images, graphical structures have to be made compatible. These conversions from and to ArcInfo were also developed, driven by a EEC agriculture statistics project.

Two additional important representations have already been referred to at earlier sections of this report: multi-resolution pyramids associated to vertical linked trees, and irregular triangular networks - and associated Voronoi tessellations and diagrams - to represent the topographic surface, or any other distribution of points in any multidimensional metric space. SATCART work on conversions do include such complex representations.

### 4.1.7.3 - Topology based analysis

The inter-relationships between the various polygons resulting from segmentation are of the utmost importance when image analysis tasks are to be performed. Most of the times, a formal description of the scene is called for, and the appropriate tools have thus to be implemented.

Graph and Formal Language Theories provide a good and self-consistent framework for developing a Picture Description Language (PDL). Such a language is a most valuable tool for syntactic pattern recognition purposes, allowing a high level of interaction with the scene. Updates can be made effective with simple sentences, and a more appropriate knowledge representation is possible. It relies, however, rather heavily on the computational environment, and works best if helped by a graph that can keep track of all the topological relationships between the objects (polygons) in the scene, as well as update the scene based on the same topological relationships. That tool is given the name of Region Adjacency Graph (RAG).

SATCART developed a RAG tool to use for the topological description of the scene resulting from a classification procedure. Each segment (region) is adjacent to other segments (if any), and a web structure is created in the form of a graph, to keep track of all the relationships between segments. The computational implementation of the RAG contemplates the updating, deletion and rebuilding operations that one expects from such a tool. This makes it possible to act over the scene at a high level, and semantically-based decisions can be taken painlessly.

The RAG is a most valuable tool in every image analysis environment, and is the basis of several semantic and syntactic applications. SATCART plans to use it in the near future to interface with a knowledge-base system, to build a syntactically-oriented, logic-based, integrated image analysis system.

## 4.1.8 - Data Fusion

1 - Merging non processed satellite data and digitized aerial photography
2 - Merging processed satellite data and digital stereo-plotter processed output
3 - Merging digitized data (satellite or aerial photography) and altimetric data.
4 - Merging satellite data from different sensors and satellites

Operational projects depend on data availability and, in most of the cases, analysis of a site or region, relies on a variety of data, supplied from many sources in many formats, resolutions, deformations, nature, etc. Only in a very limited All the differences between different data sets have to be overcome within a common geometric and radiometric framework.

Data fusion between data of different nature has been achieved by SATCART in the following cases:

- digitized photography and topographical models produced by the analytical restitution system;

A molecule forced by electromagnetic fields act either as an absorber, when the exact amount of energy needed to reach an excited state strikes it, or an emitter. Particles submitted to electromagnetic fields may react by scattering that radiation.

The discrete nature of permitted electronic states, makes molecules only sensitive to precise amounts of energy, or frequency, as given by the Planck equation. Therefore, at certain discrete frequencies, molecules are forced to change their electronic molecular states, which correspond to absorption if higher electronic states are reached and to emission in the opposite case. Molecule composition and geometry impose the electronic bounding forces, thus defining the energy levels for molecular transitions. That's why different molecules show different absorption spectrums. Absorption of energy increases the internal energy of a molecule.

The regions of the electromagnetic spectrum where gas absorption is negligible and surface observation is allowed, are called atmospheric windows. Particles submitted to radiation may interact by scattering. The particles absorb the incoming energy and then re-emit that energy in all directions at the same wavelength (elastic scattering) or at slightly different wavelengths (inelastic scattering).

In order to accomplish the atmospheric correction procedure, the "Simulation of the Satellite Signal in the Solar Spectrum", (5S) software (University of Lille, France) was used: gaseous absorption bands are described as Voight bands instead of a myriad of discrete peaks, and multi-scattering effects are considered over homogeneous or heterogeneous ground.

The images from the Earth Observation satellites, LANDSAT and SPOT, are mainly affected by atmosphere scattering affects, due to the presence of aerosols, which can be clearly localized (clouds, fog, smog) or spread all over the image (haze, stratus clouds). In that case, images will have an hazy appearance, with loss of sharpness, decrease in histogram amplitudes, rise in global medium values.

The problem of atmospheric correction for scattering effects can be solved by two entirely different methods: filtering or calibration. In the filtering method the atmospheric correction is treated as a restoration procedure and two dimensional digital signal processing is applied. In the calibration method, the atmosphere correction amounts to estimate real radiance values from image data.

A calibration method was developed for LANDSAT and SPOT images. An image calibration procedure is not just an atmospheric correction tool. Before atmospheric correction becomes possible, the image values must be converted to real reflectance (or energy) values, the radiometric calibration. For this step to be possible, up-to-date sensor calibration data must be known, as well as the satellite positioning in orbit and viewing angles. Using site meteorological data (pressure, temperature and humidity profiles) or standard atmospheric data, ground reflectance characteristics and satellite navigation data, an atmosphere corrected image may be derived.

The final objective of an absolute calibration procedure may not be only the atmospheric correction of images but the direct comparison between images taken by different sensors or even by different satellites. After correction, satellite images reduce to matrices of real reflectance values, in spite of specific spectral windows, thus allowing the comparison between different spectral information (multi-sensor analysis) or different instants (multi-temporal analysis).

### 4.1.10 - Production Engineering

1 - Analysis of processing times and identification of pertinent micro-tasks
2 - Analysis of the patterns of use of equipments
3 - Construction of set of rules to document software code
4 - Construction of pertinent "work protocols"
5 - Construction of "cost schedules" for the different tasks related to products

Cost assessment of remotely sensed based products, either digital or analog, was considered an important task of SATCART. The objective evaluation of the time needed to obtain the products and their cost, either in personnel or consumption of hardware resources, had to be performed, or at least drafted, in order to compare quantitatively this technology with past technologies, and be competitive at the world market. These were the general requirements for this activity.

The Vouga project, concluded in December 1989, was the first project to profit from all the equipments and environments at SATCART. A certain work division was settled between both, and the identification of tasks for a complete complex project was accomplished. Other projects have shown that the real tasks of a project do fit directly into such list, which must be updated regularly. This project was entirely handled by the engineering team.

The cartography of forest fires, complete by July 1990, was handled by two engineers and two technicians - the latter actually perform all the systematic procedures within the image and the GIS environment.

At the completion of the SATCART project, there is a feeling that some of the most important issues of this problem have been tackled, but no further actions were taken, in the expectation of the transformation of the Consortium into a company.

We now know what is the profile of the technicians needed, what they can accomplish and their main problems and limitations to handle this technology. We have also become aware of their timing and efficiency. Nevertheless, we are not going to build quantitative measures or provide production engineering procedures: there is still no production engineer in the group, and whatever document we might produce would be a very poor academic exercise, without actual consequences for the future SATCART company.

### 4.1.11 - Technical Support

1 - Support activities to digital image processing
2 - Support activities to cartography

The goal of these activities was to prepare a minimum technical staff to handle routine image processing and cartography jobs, with operational knowledge of the hardware and software tools available, in order to accomplish production tasks. In 1990, a significant part of routine tasks should already be handled by non-engineers.

In 1990, in the context of a project to identify forest fires in the center and north of Portugal, it was possible to train two technicians to handle time consuming tasks such as:

- image environment: magnetic bands management, identification of ground control points and geometrical correction of images, and interactive classification of some themes (in the case of the running project, boundaries of old fires);
- GIS environment: digitalization of maps, use of the plotting system to produce final cartographic documents;
- global activities: hard copy production at a given scale, archiving of magnetic bands and films, filling of support data bases, etc.

This project was indeed an excellent exercise to train technicians in image and GIS manipulations.

As far as the analytical stereo plotter environment is concerned, the system was completely handled by two technicians, under control of an engineer.

Nevertheless, these technicians are not under control of the Project Director, their activity to SATCART has been reduced since July 1990, and their training unfortunately stopped.

## 4.2 - Application Projects

### 4.2.1 - Land Use of the Hydrographic Basin of the Vouga River with Satellite Images

The goal of this is project was to produce land cover maps of the complete hidrographic basin of the Vouga river, at the scale of 1:100,000, to evaluate how water was being consumed at the agriculture level, through the identification and rerpesentation of irrigated and non-irrigated crops and cultures..

This request was made by COBA, a consultancy private company, in charge of a complete study of the basin for the Ministry of the Environment.

Remote sensing studies had not been identified in advance, and the funding available to purchase satellite images was scarce. SATCART had to select the minimum set of images covering the complete site (about 400,000 ha). Multi-temporal analysis was thus excluded in advance. Three LANDSAT-TM quarter scenes were selected - two of which along the same track; they had been captured in September 1988 and we were not expecting significant radiometric differences between both sets.

A geo-referenced mosaic was produced after geometric correction of images with ground control points selected from 1:100,000 maps. The limits of the basin, previously digitized at the same scale, were then used to mask the image. Contour lines were also digitized from paper maps. The idea was to introduce additional constrains on the classification using elevations, to reduce uncertainties using simple agricole common-sense rules. In fact, no ground truth was available, beyond a general knowledge of the site, although significative samples of aerial photographs have been collected, to support photo-interpretation.

Radiometric preprocessing on the TM bands 2, 3, 4 and 5 - and computation of additional features (such as hue, saturation and intensity, for sets of three bands) made photo-interpretation possible. After the analysis of the complete site, a hierarchical classifier was implemented using a parallelepipedic decision rule. The final classes and limiting values of the relevant features are listed below:

| | | |
|---|---|---|
| **Water** | tm4 | 0 - 10 |
| **Wetland** | tm4 | 11 - 45 |
| **Forest** | int (5,4,2) | 1 - 11 |
| **Irrigated crops** | hue (5,4,2 | 24 - 180 |
| **Non-irrigated crops** | int (4,3,2)<br>hue (4,3,2) | 1 - 24; 127 - 255<br>1 - 169 |
| **Others** | int (4,3,2)<br>hue (4,3,2) | 25 - 126<br>171 - 255 |

The final classified image was then exported to the GIS environment and, as results should be represented at the scale of 1:100,000, the need was felt to implement an efficient generalization algorithm, to discard polygons smaller than 25 ha and aggregate small fields into clusters of polygons with a resultant thematic dominance.

This development of the generalization methodology was already referred to at section 4.1.5.4, and was the most rich, motivating, dynamic and interesting period of the SATURATE project. It must also be stated that it was the first application using the newly integrated computer, GIs and image processing system. All the scientific team participated into the development and execution of the project, and no technicians had been allocated to the project yet. For the first time, we were doing an exercise at big scale, with huge sets of data, and identifying, by ourselves, all the human specificity's of the generalization procedure. GIS files were huge, with thousands of polygons, smaller data sets had to be used instead of the original one. Nevertheless, after splitting, border problems appeared, and had to be overcome interactively.

After generalization and editing, we produced a variety of 1:100,000 documents satisfying all the cartographical conventions, and including additional information such as toponymia, and the network of rivers and roads: maps showing the (enhanced) LANDSAT scene, colored classified maps, and vectorial classification maps. A variety of statistics (at the map or basin level) were also produced. Some examples are included on the video and on the accompanying pictures.

### 4.2.2 - Satellite Multi-Temporal Study (agriculture statistics)

Within the context of the EEC Agriculture Project, Action 4, European rapid estimates of acreages and yields ground surveys, led by the Joint Research Center, Ispra establishment, SATCART was awarded a project to evaluate and test multi-temporal methodologies in order to prepare acreage statistics. The main goal was to evaluate how additional satellite data might eventually compensate such reduction in field labour, by optimizing the correlation between multi-temporal classification and ground-truth data, for the most appropriate legend.

A test site was selected in Portugal for the purpose of this project: it was a 40 x 40 Km square, centered near the village of Portel, in the South Alentejo - a very productive crop producing area in Portugal. The Ministry of Agriculture, through the General Directorate of Planning and Agriculture (Agricole Statistics Service) participated in the project, by executing the field campaign on 15 square segments of 49 ha. This field campaign, among other objectives, should produce information to guide the multi-temporal approach.

SATCART requested five SPOT scenes during the 1989 / 1990 campaign to evaluate automatically land use in the Portel site. Four scenes were received, but unfortunately, due to climatic reasons, only three were actually used: October 1989, January and April 1990. In fact, the Autumn of 1989 had been extremely dry in Portugal: many fields (planted before the rain) were affected by the excess of water, farmers decided to bare some fields again with spring crops or crop with shorter phenological cycle, and, in general, an usual land management did affect the multi-temporal heuristics we had been preparing for the project.

All the scenes were geo-referenced, thus becoming superposable. A digital terrain model was produced, after interactive digitalization of contour lines, from the 1:100,000 scale topographic maps.

No stratification had been performed when the field segments had been randomly selected, but we wanted to stratify based on topography, and restrict the possibilities of the classifier by using geometric data such as slope and exposition to the sun, which should be very important for permanent cultures, vineyards in particular. Additional data was also considered: urban perimeters, water bodies, sites of special vineyard production and finely divided land. Two strata were built, one with high potentiality for crop production - the target goal of the Agriculture Project - and the other with very low potential for crop growing (about 37% of the area of the Portel site).

Classification was hierarchical, based on a parallelepipedic decision rule acting on vegetation indexes computed from raw data. Each image date was classified independently. Two different vegetation indexes were constructed, aiming at identifying the intensity of photosynthetic activity, which can be related to the phenological condition of the crops. Thresholds were set visually, by interactively applying them to the images. Six interim classes were identified: bare soil with some vegetation, main water bodies, bare soil, green vegetation, forest and vivid vegetation.

The three independent classifications were them combined, according to a logic supported by realistic phenological cycles. Tri-temporal classification led to the final six classes: annual winter crops, annual spring crops, natural pastures, agro-forestry and forestry, water bodies and natural pastures. The tri-temporal aggregation was driven by ground truth data collected within 15 segments, through a systematic analysis of the confusion matrix between ground truth and tri-temporal classification.

The final results were quite surprising: on the one hand, total area of the six final classes for all the 15 segments is equal to the corresponding area obtained from field analysis; the Pearson correlation coefficient was 0.99! On the other hand, cartographic criteria, showed that only 64 % of the pixels were correctly classified - this is a normal value for most of the remote sensing applications. These results do show the potentiality of remote sensing to produce acreage statistics, whereas field boundaries are hardly reproduced with usual automatic classification techniques.

### 4.2.3 - Land Use of the District of Setúbal with Landsat Images

SATCART was requested to update existing land use cartography of five municipalities of the district of Setúbal, in order to evaluate global vegetation changes, for regional planning purposes.

A single LANDSAT-TM floating scene of July 1988 covered all the area of interest (about 500,000 ha). After geo-referencing and radiometric pre-processing, the scene was photo-interpreted, with panchromatic aerial photographs (scale 1:15,000) guiding the interpretation.

It was known in advance that complex agro-forestry systems and permanent cultures cover most of the area of interest. Without experience on remote sensing mixture handling - this is still an important research problem for Mediterranean countries - the analysis was performed by interactive photo-interpretation on the bands 5, 4 and 2 of the TM image. Some statistical significant doubts and ambiguities were solved by in-place field campaigns.

The following fifteen classes were identified and included into the land use legend: non-irrigated crops, irrigated crops, orchards, mixed agriculture areas, agro-forestry areas, forest, social area, social area with agriculture activities, artificially covered land, sands, dunes, wetlands, waters, other non-specified land.

Polygon boundaries were sketched directly on the land cover map to update. No software was available to do it on the screen, and it was considered important to profit from previous cartographic representations specially where there were no changes to monitor. Such contours were later manually digitized in order to introduce some cartographic information and prepare the output of the final maps. Five 1:100,000 maps were produced this way.

Some examples of this application are included in the video. Some photographs of the final maps are also included into the report.

### 4.2.4 - Dynamics of the Wetland Vegetation of the Tagus (Tejo) Estuary

Estuary ecosystems have a very high potential of biological productivity that subject them to important and continuous modifications. The estuary of Tagus (Tejo) is the larger Portuguese estuary. It is a very dynamic ecosystem, and updated data on its condition should be collected and kept.

The main objectives of this application were to update the cartography of the Tagus intertidal zone and to evaluate its evolution since 1980, using satellite images, digital image processing and geographic information system techniques, and to make an overview of the wetland vegetation of the estuary in view of the evaluation of its potential habitat passerine communities.

Previous data of the Tagus estuary intertidal zone is contained in eight thematic maps at the scale of 1:25,000, compiled by the Botanical Department of the Faculty of Sciences of Lisbon; ground truth data was collected in 1978.

These maps were digitized and structured as ArcInfo covers. Paper distortion correction was needed duestretching and shrinking of the base media. Final corrected covers were joint analysed with a SPOT geo-referenced multispectral satellite image of1986, using 1:25,000 topographical maps.

Image classification was based on ground truth data from 42 vegetation transects, performed in 1990 in different areas of the salt-marshes. Information from these transects, sketched on non-geo-referenced aerial photographs, was correlated to the image through a very complex procedure, and supported a supervised classification, with a minimum distance decision rule, in a hierarchical process throughout a variety of masking and relaxation operations.

The correlation between the classes represented in 1980 and the remote sensing legend was not straightforward, and for some themes an even wider discrimination seemed possible. Nine classes were identified - more than the five classes of the previous evaluation - although the important discrimination between *Spartina maritima* and *Scirpus sp* has not been achieved.

This work stressed the need to define operational methodologies to continue the follow-up of this estuary, otherwise it will be extremely difficult to have a self-consistent view of its long term evolution, inhibiting the rational utilization of wetland vegetation as agent for water pollution reduction and control.

Figures with relevant results are included for illustration.

### 4.2.5 - Cartography of the Intertidal Zones of Portuguese Rivers and Estuaries

Estuarine systems are highly sensitive biological and ecological areas. The study of the time evolution of botanical species inside estuarine intertidal areas can be used to control water quality and pollution recovery. Those who experienced on-site estuarine sampling and measurement, know how difficult it is to walk on those areas and the long time it takes. Yet, remote sensing (satellite or aerial) images can be used for low resolution and high frequency survey of estuarine areas, thus allowing immediate control of the influence of man on those critical areas.

A private company (Tabaqueira, SA) asked the SATCART team, at the very first beginning of his activity, immediately after the acceptance of the SATCART project, to study and represent on maps the intertidal area of the Ria Formosa - a very large estuary, in Algarve - and of four rivers: Mondego (center), Tejo (Lisbon), Sado (Setúbal) and Guadiana (Algarve). The knowledge of the extent and of the main land use of those areas was important for Tabaqueira, to support decisions related to the selection of new sites for acquaculture in Portugal.

Intertidal areas can be defined as the emerged areas in low-tide which are submerged under high-tide conditions. Therefore, it would seem appropriate to subtract the low-tide image from the high-tide image to find intertidal regions. This approach presents some drawbacks: high cost (two satellite images per estuary at very precise timing - minimum low or maximum high tides), need for inter-registration of images and incomplete intertidal area definition (salterns are dropped down as they are only periodically submerged). Nevertheless, it was tested for the estuary of Sado, with which all the preliminary experiences were performed.

SPOT images were used. The steering capability of the HRV Earth Observation Instrument of SPOT made the programming of the data-taken possible, and minimum low-tide scenes could thus be imaged. Nevertheless, the complete data-taken took far more time than expected, due to difficulties of SPOT programming and bad atmospheric conditions.

After many independent experiences, a thematic index methodology was selected to classify automatically estuarine intertidal areas.

Five thematic classes were considered: salterns, wetland, wetland sediments, wetland vegetation and marsh areas. The identification of these classes was made possible by the use of the three SPOT spectral bands and of additional spectral features, such as the hue, saturation and intensity. The complete set of features was used to construct thematic indexes (basically these indexes are ratios between linear combinations of features, far less sensitive than individual features to variations related to context).

Four indexes were defined, tested and empirically fit to enable class extraction by simple segmentation. These indexes were made specific to water, sand, salterns and high moist content areas.

As an example, the water index was defined as ($a$.XS1-XS3)/XS3: XS1 and XS3 have opposite variations with the water content, and $a$ allows some tuning for the correct discrimination between water and wetland vegetation (XS1-XS3 does mix water and vegetation in wetlands). The division by XS3 increases water signal due to the low reflectivity of water in XS3 band.

A supervised hierarchical classifier was used using a simple parallelepipedic decision rule. Some post-classification mode filtering was needed to reduce classification noise and made the representation clearer and free from very small details.

For each river, a 1:50,000 scale vectorial map was produced on a transparent sheet, to allow superposition to the standard 1:50,000 topographic maps. In addition, a significant set of photographs of the original image, classification details and interface to the ocean were also delivered.

This application was developed within the framework of the NATO-SFS program but still without the integrated system the SFS funding made possible. No GIS was available, and all the interfaces of the image processing system (at EID) to the cartographic equipment (at Geometral) had to be fully developed by the project team. It can be stated that the preliminary maps we produced of the SADO intertidal area were the first example of cartographic products, made automatically from remote sensed data: they had a scale, complied to the most important cartographic rules and could be laid down on top of maps of the same site. This application was also the driver for all the work done by SATURATE on representations of two-dimensional structures, already developed in section 4.1.7.2.

The video and the accompanying pictures - basically over the Tejo estuary - follow, and do illustrate this application of the SATCART project.

### 4.2.6 - Forest Fires Cartography

The traditional photo-interpretation (based on aerial photographs) and field surveys techniques provide the best results in high resolution forest fire mapping when time, efficiency and costs are not important, or when the sites to be covered are small enough.

When forest fires are to be yearly monitored for an entire country, satellite images provide a good and cost-effective alternative.

This application had already been presented to the Ministry of Agriculture in 1986 by LNETI, with many demonstrations showing clearly that the technique was adequate. At that time, no statistical information existed concerning the area of forest destroyed by fires, although it was currently stated that, between 1974 and 1989 Portugal had lost about 1/3 of its forest.

Only by the end of 1989 have we managed to overcome the last resistance of the General Directorate of Forestry, and have been requested to make the first coverage of the center and north of Portugal (about 1,500,000 ha) and represent all the forest fires on paper maps, at the scale of 1:100,000.

The project was conducted from April to July 1990, and was carried out by one engineer and one technician. In this project two LANDSAT-TM and five SPOT-XS images, dated October 1989, were used. Twenty nine map sheets were produced (national IGC grid, scale 1:100,000) showing fire contours and fire areas; a dBASE statistics file (containing map sheet number, fire identification, area per fire, fire percentage in county and fire area in county) was also supplied.

After a quick photo-interpretation of the images, it was clear that no time was available to develop an automatic procedure coping with the variety of situations that were visible on the images. Fires from 1989 and fires from the previous year - or even earlier - had very different radiometric characteristics; many differences also existed between SPOT and LANDSAT data, due to resolution and different spectral bands and radiometric resolution.

An interactive procedure was thus selected, after geometric correction of all the seven complete images using ground control points. The operator interactively designed the polygon circumscribing the forest fire, and the last part of the procedure was automatic: data was filtered, raster data was converted to vectorial and exported to the GIS, a data base was filled and maps were produced.

Given that this exercise was pioneer in 1990, many doubts were identified. Two operational teams were sent to the sites to confirm (or not) the interpretation of the satellite image. About 200 on-site confirmations were made, for a total of 3026 forest fire polygons.

The video and the accompanying pictures illustrate this application of the SATCART project. It was repeated for the fires of 1990 and 1991, for the complete country. The procedure was updated and made completely operational, being currently executed by technicians alone.

### 4.2.7 - Military Satellite Photo-interpretation (PAIESAT project)

Ever since SPOT was launched, one of the important applications of its 10 meter resolution panchromatic images was intelligence. The commercial venture of SPOT and the no restriction commitment of France concerning the continuity and availability of data, were very much discussed at the time, because the implications for national security were obvious, and in many countries people was not prepared to understand that anyone, at least in theory, might have access to intelligence information.

In this context, SATCART was approached by the General Chief of Staff in order to undertake a training action for military photo-interpreters on satellite imagery and on the most important characteristics and semantics of digital image processing environments, given that additional information can be obtained from images with series of suitable digital manipulations. This was the PAIESAT project: Program of Acquisition of Strategic Information from Satellites.

A series of lectures (about 20) were organized by the SATCART team for the four officials that had been designated, from the Air Force, Navy and Army. This team had then the opportunity, for six months, to manipulate most of the computing and image processing resources of SATCART, from the manipulation of magnetic CCT with raw data, to more complex manipulations to clean, improve contrast or transform the data.

This training action was finalized by a real exercise: the General Chief of Staff defined a mission, SATCART ordered the data, and the military team did all the manipulation, interpretation and produced the intelligence report, without civilian interference. At the same time, a second military team did an on-site inspection and reported. Both reports were compared and this (classified) exercise was considered successful.

A second mission was later assigned, but no images have ever become available. More recently, the advantages of this training action were felt at the European level, and some of these officials have been designated as Portuguese members of international organizations preparing to act as an European satellite intelligence agency.

## 4.2.8 - Figures

The video enclosed is part of this report and illustrates how SATCART was requested to make studies and produce cartographic maps out of satellite data, and covered the complete area of Portugal, with the exception of the Atlantic islands of Madeira and Açores. The technology that was developed to produce some of the video sequences was described in section 4.1.

On the following pages the application projects requested to SATCART and described in sections 4.2.1 through 4.2.6 are illustrated with representative photographs of the results.

# Land Use of the Hydrographic Basin of the Vouga River with Satellite Images (4.2.1)

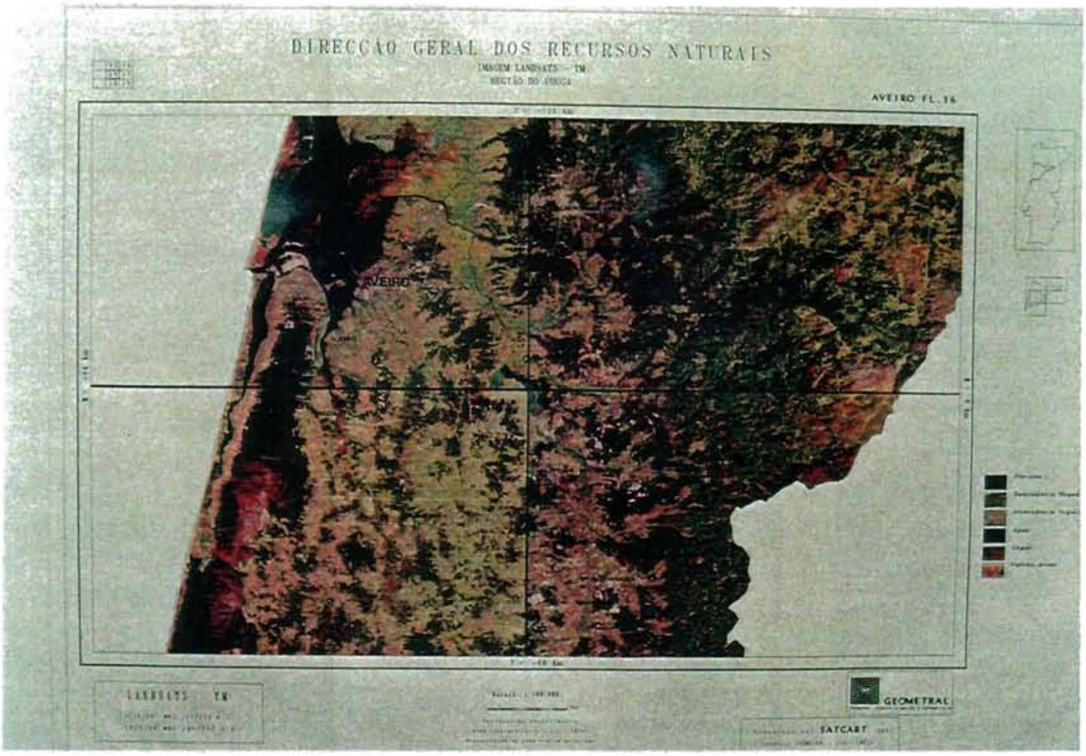


Fig. 1 - One of the five 1:100,000 maps with the Landsat data of the basin, with photointerpretation key.

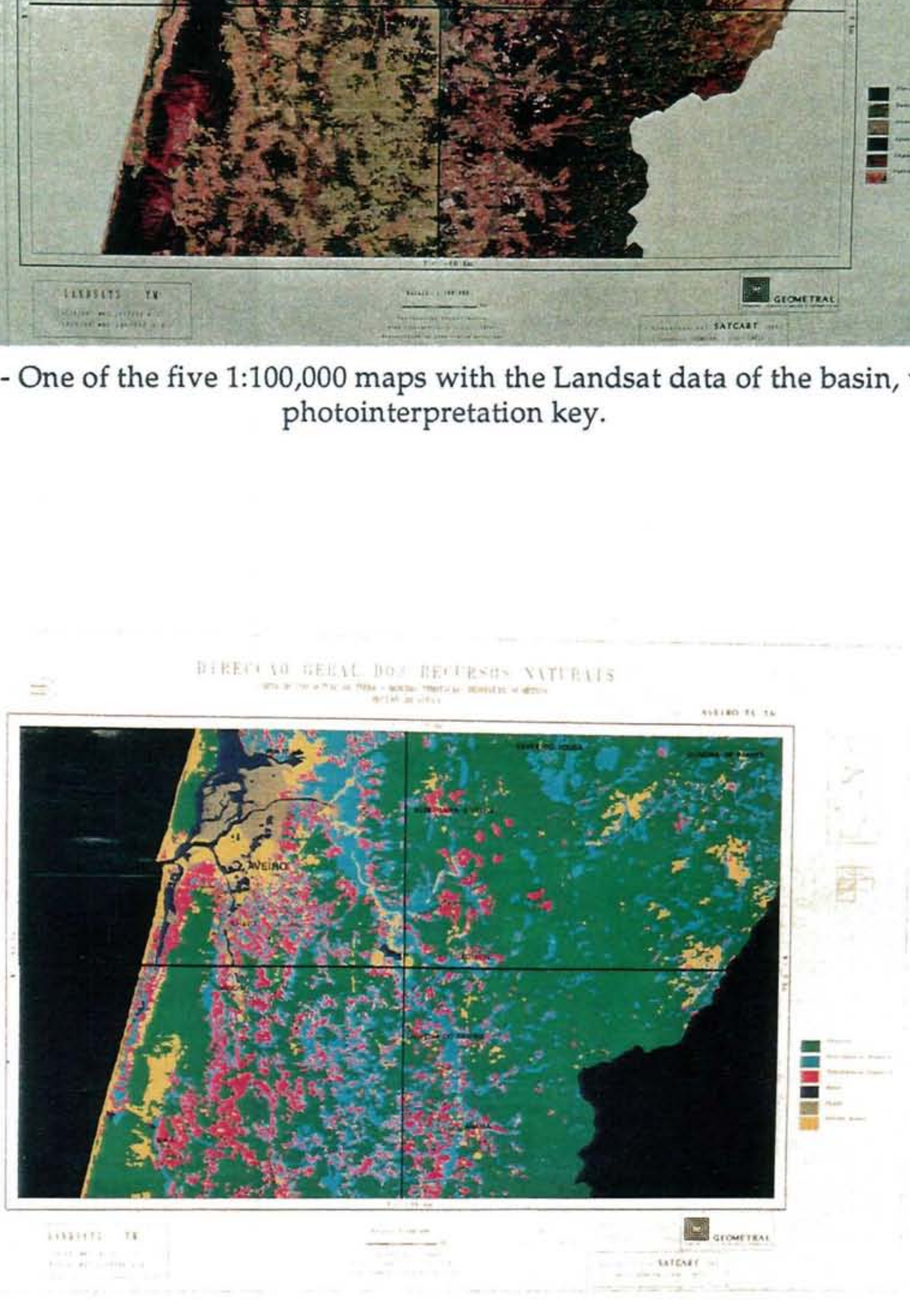


Fig. 2 - Classified data (5 classes).

# Land Use of the Hydrographic Basin of the Vouga River with Satellite Images (4.2.1)

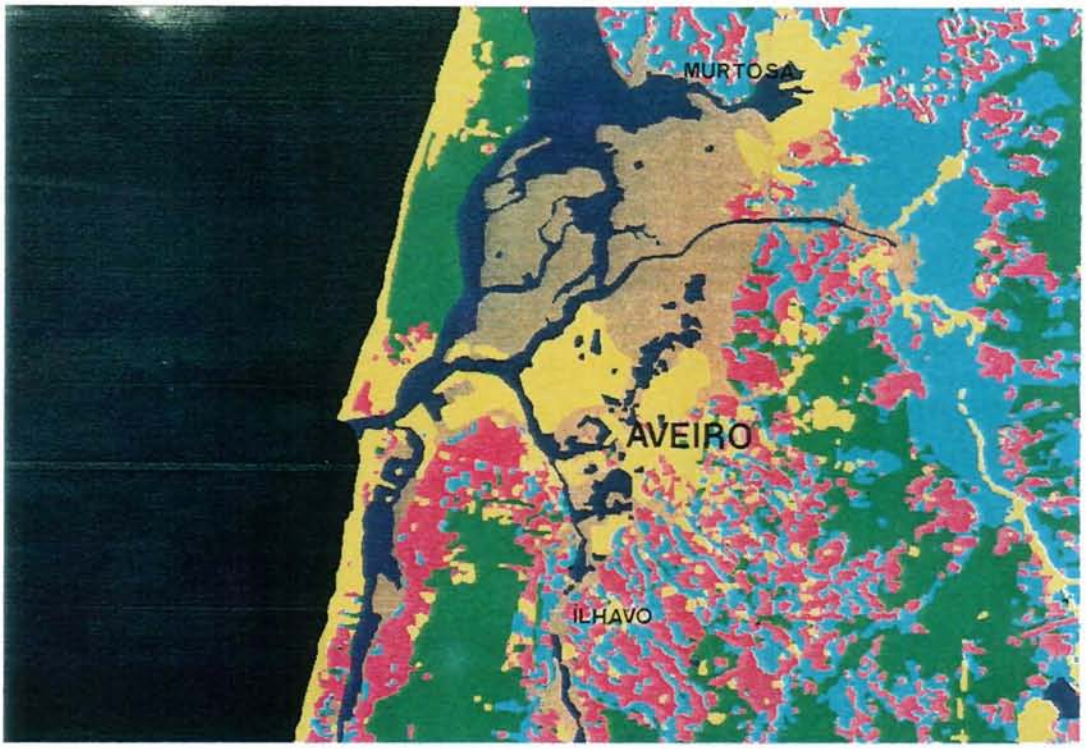


Fig. 3 - Detail of the classification (before generalization).

Fig. 4 - Final generalized contour map.

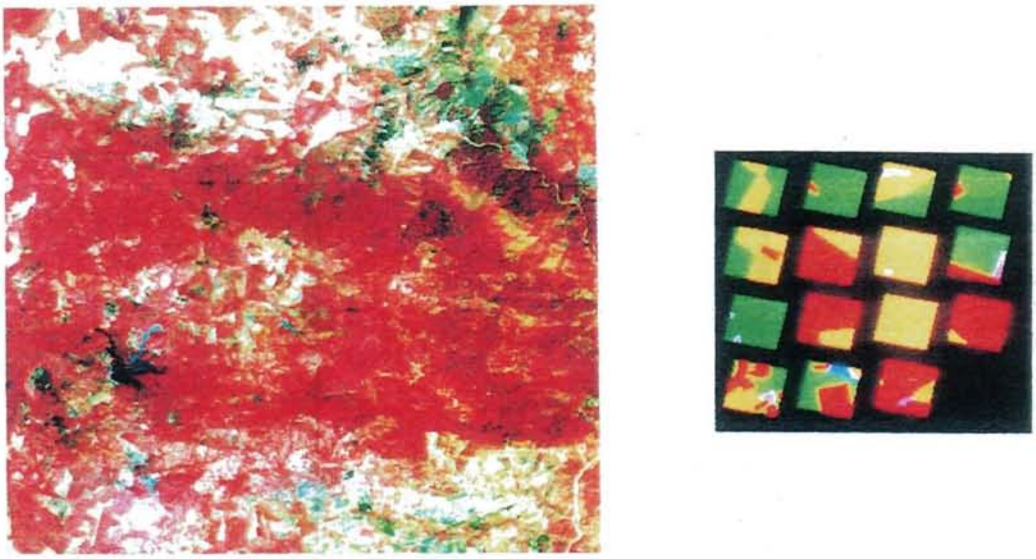
# Satellite Multi-temporal Study (Agriculture Statistics)
## (4.2.2)

# AGRICULTURE PROJECT

Action 4 - Multi-temporal study

European rapid estimates of acreages
and yields ground surveys in 1989 and 1990

Final report



Lisbon, July 1991

SATCART

Consórcio LNETI - EID - GEOMETRAL

Portugal

Fig. 5 - The 40 x 40 km SPOT image of the test area (Portel) and maps of the ground truth data collected by the field surveyors.

## Satellite Multi-temporal Study (Agriculture Statistics)
## (4.2.2)

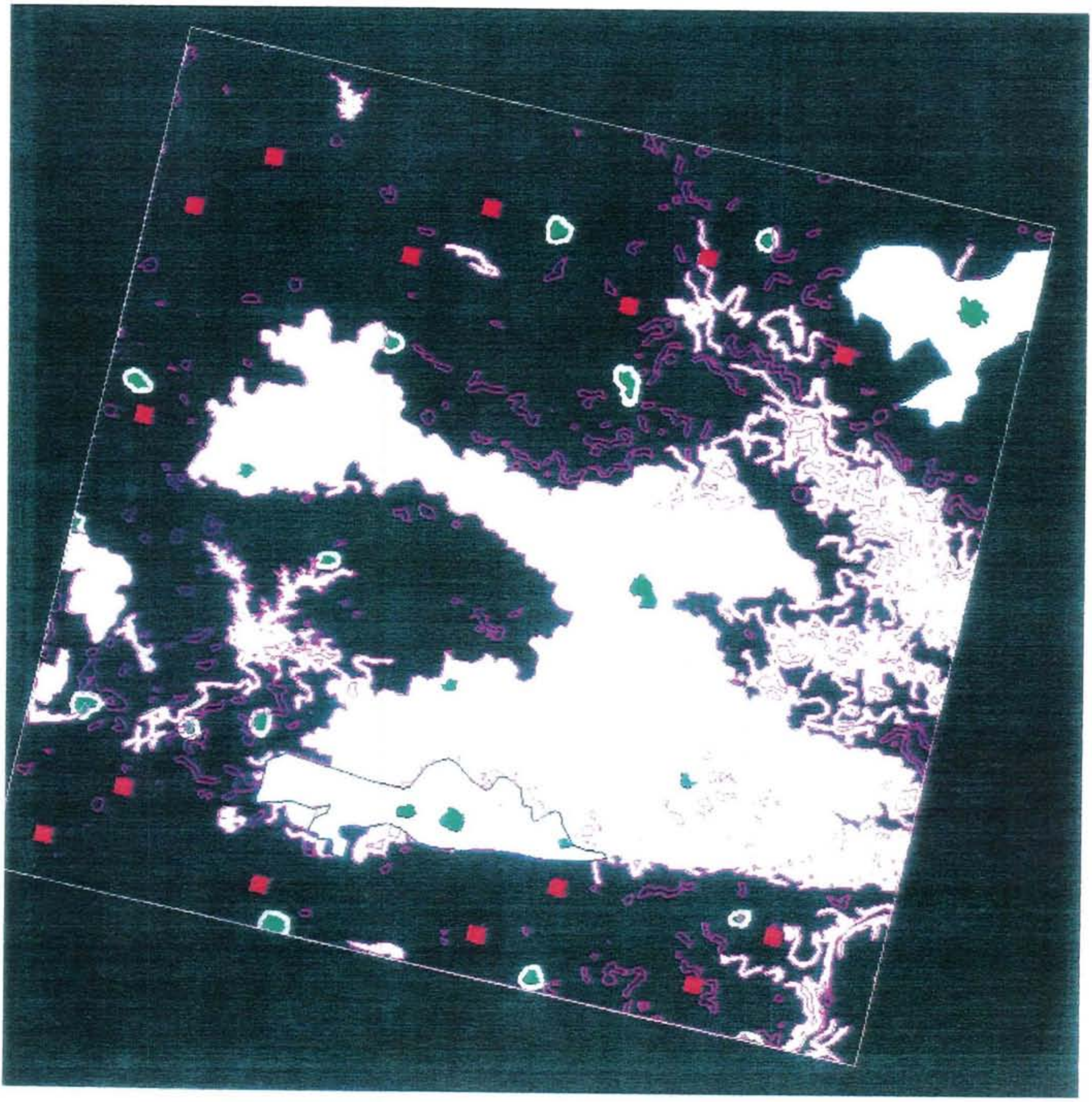


Fig. 6 - Stratification map, with area of higher elevation and slope, and water bodies (white), villages (green), segments (red). Classification was restricted to the black area.

# Satellite Multi-temporal Study (Agriculture Statistics)
(4.2.2)

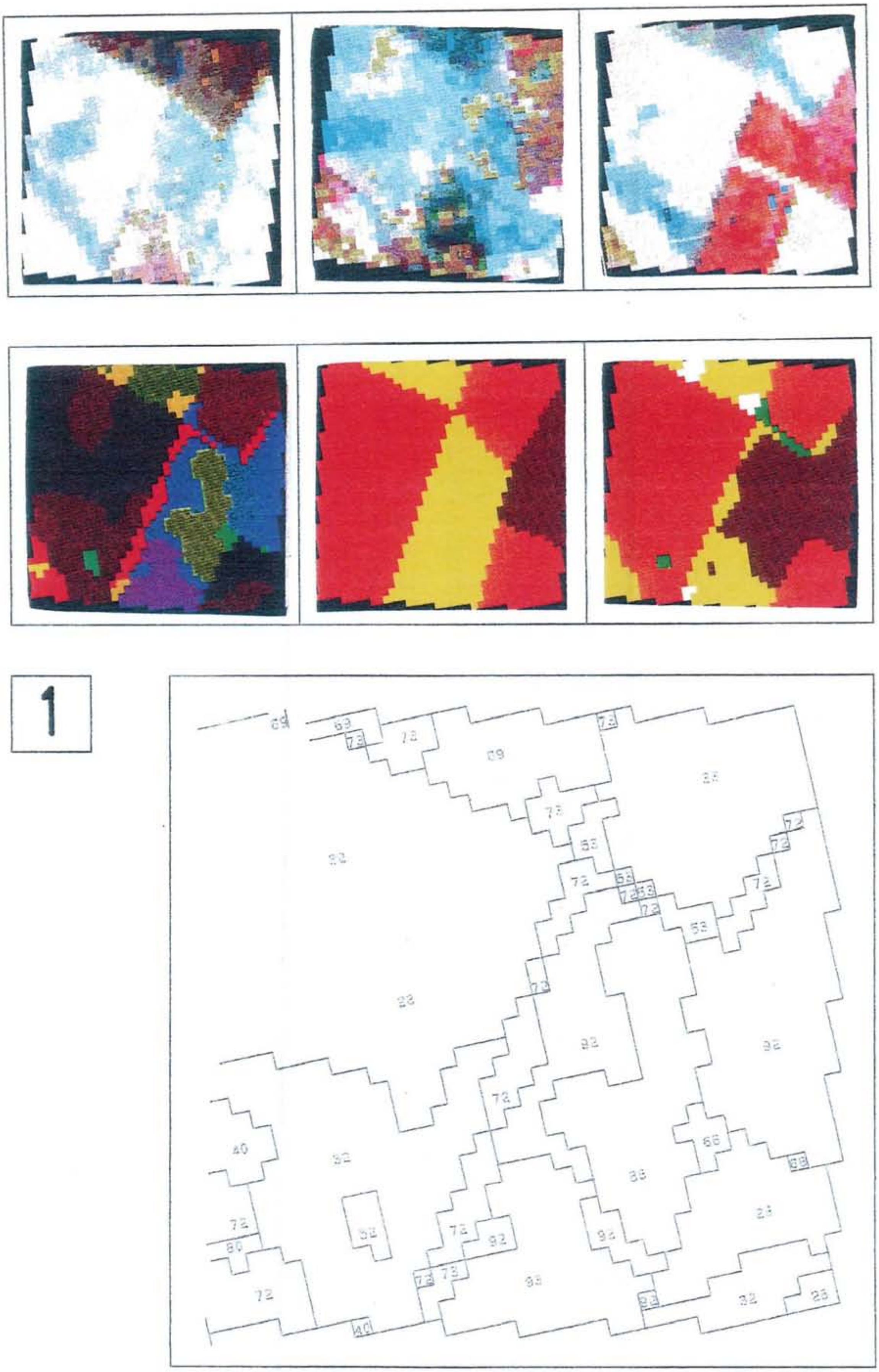


Fig. 7 - Analysis of segment no. 1. First row: SPOT data of November, January and April; 2nd row: tri-temporal classification (A), ground truth, final classification; bottom: the same as A, for class agregation purposes.

# Satellite Multi-temporal Study (Agriculture Statistics)
(4.2.2)

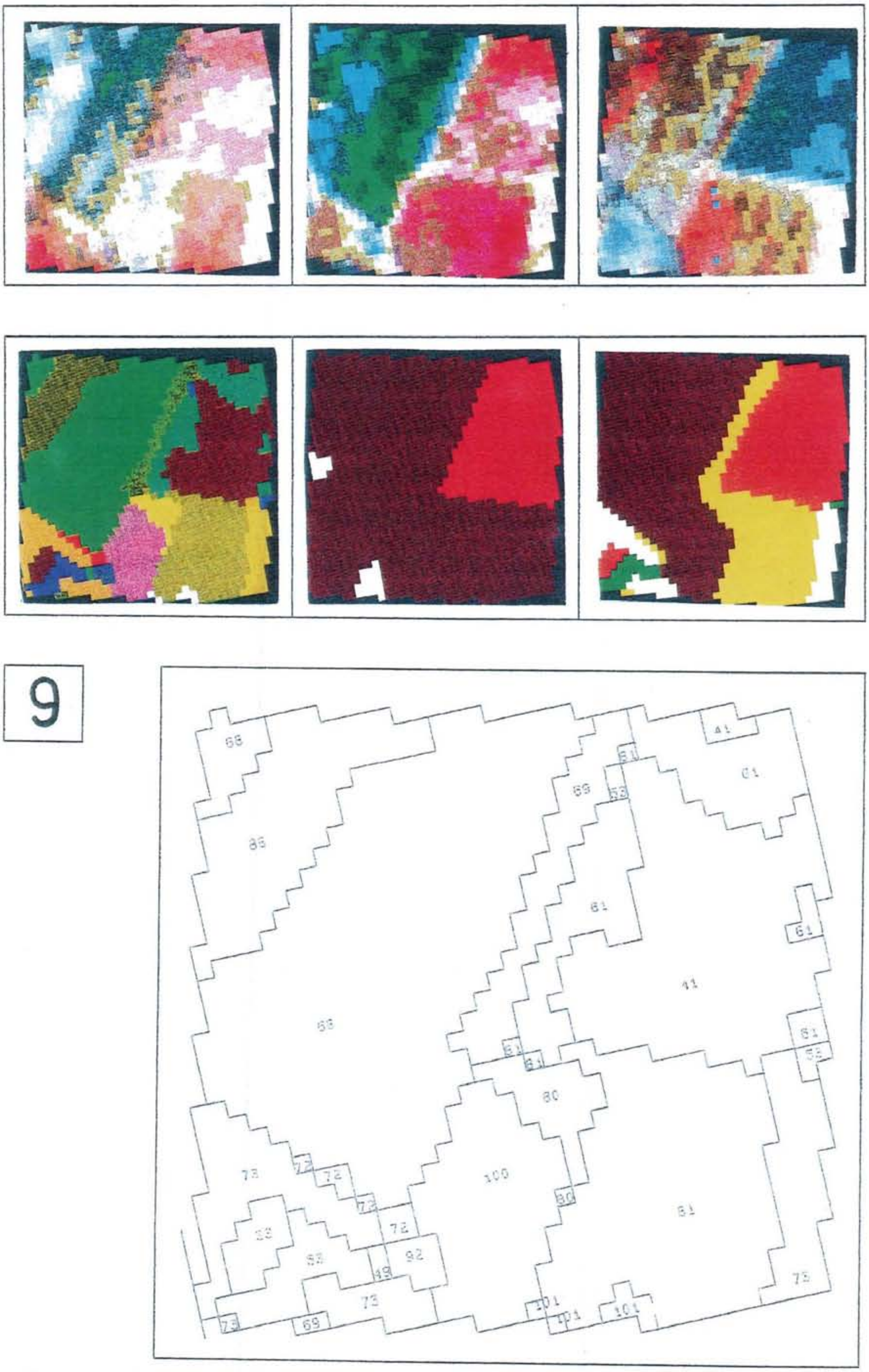


Fig. 8 - Analysis of segment no. 9. First row: SPOT data of November, January and April; 2nd row: tri-temporal classification (A), ground truth, final classification; bottom: the same as A, working plot for class agregation purposes.

# Land Use of the District of Setúbal with Landsat Images

## (4.2.3)

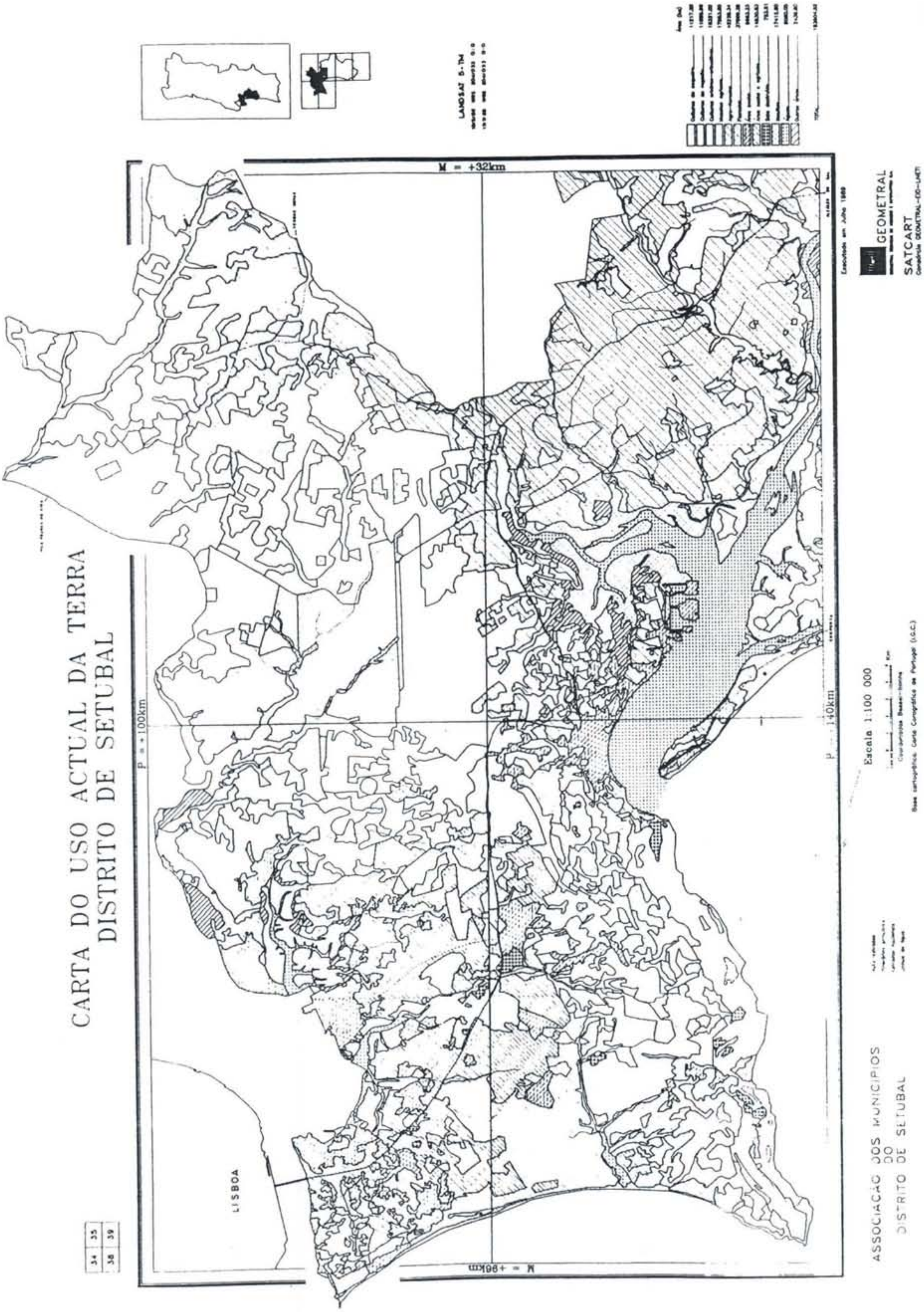


Fig. 9 - One typical map output of the project, at the scale of 1:100,000 (south of Lisbon).

# Dynamics of the Wetland Vegetation of the Tagus (Tejo) Estuary
(4.2.4)

Fig. 10 - Digitized map of the Tagus estuary intertidal zone (Ponta da Erva). Classes: dominance of several salt-marshes species (white), dominance of *Scirpus maritimus* (red), dominance of *Spartina stricta* (green), mud flats (stripes).

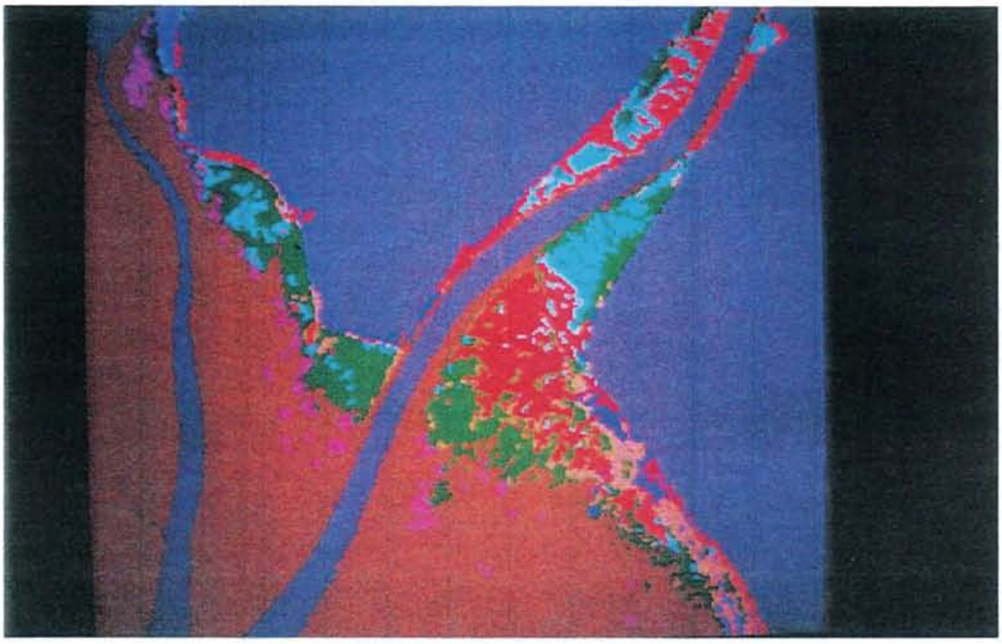


Fig. 11 - Classification of the Tagus estuary intertidal zone (Ponta da Erva), with 9 classes.

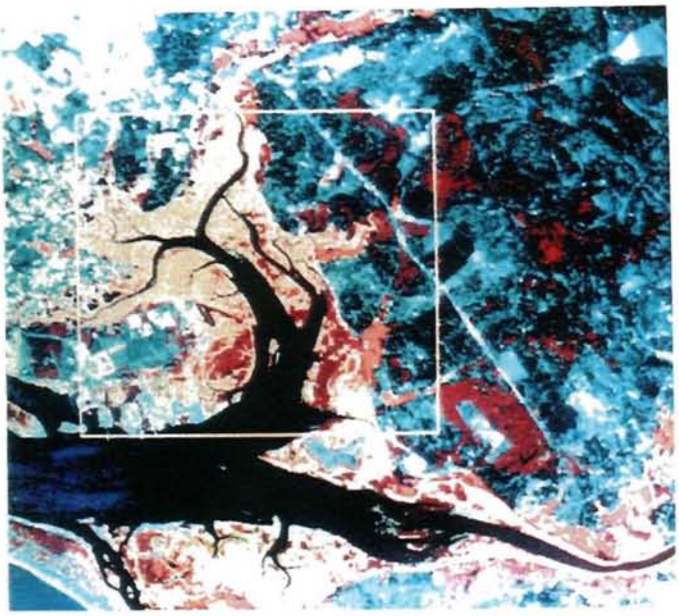


Fig. 12 - The estuary of Sado, identification of a 512 x 512 pixels area (preliminary work, 1987)

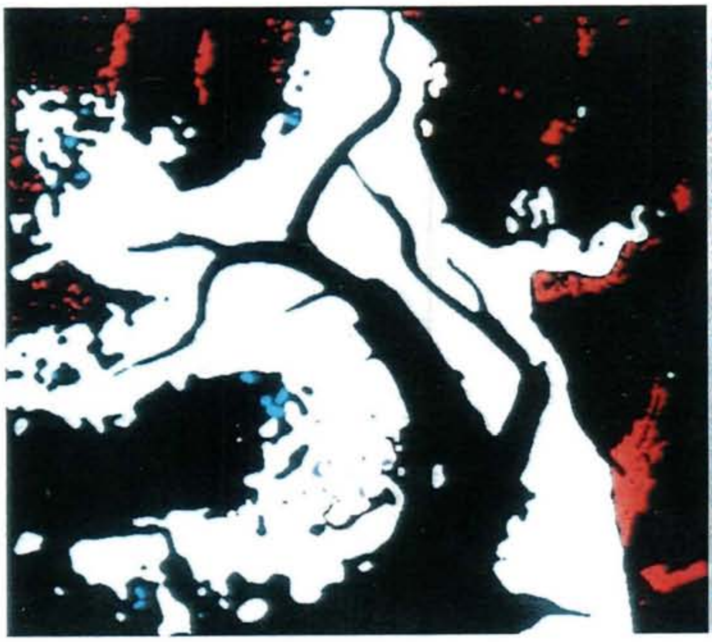


Fig. 13 - The estuary of Sado, classification (5 classes) (1987)

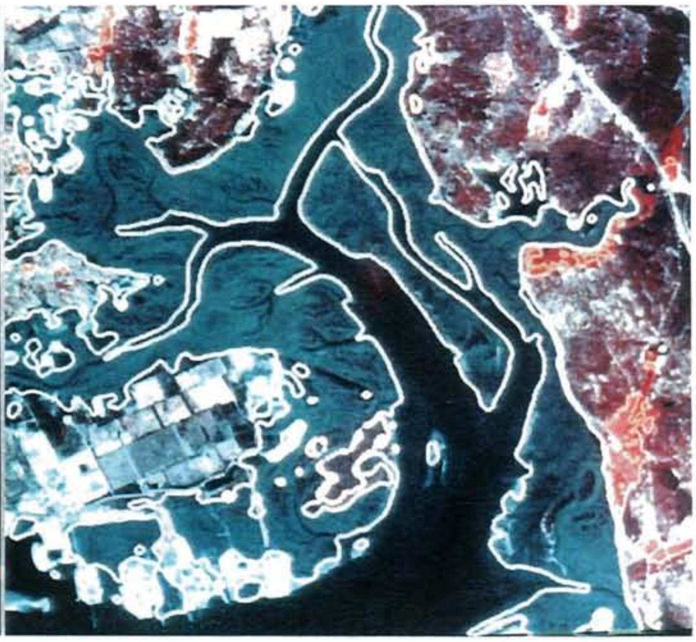


Fig. 14 - The estuary of Sado, classification superimposed on the original image (1987)

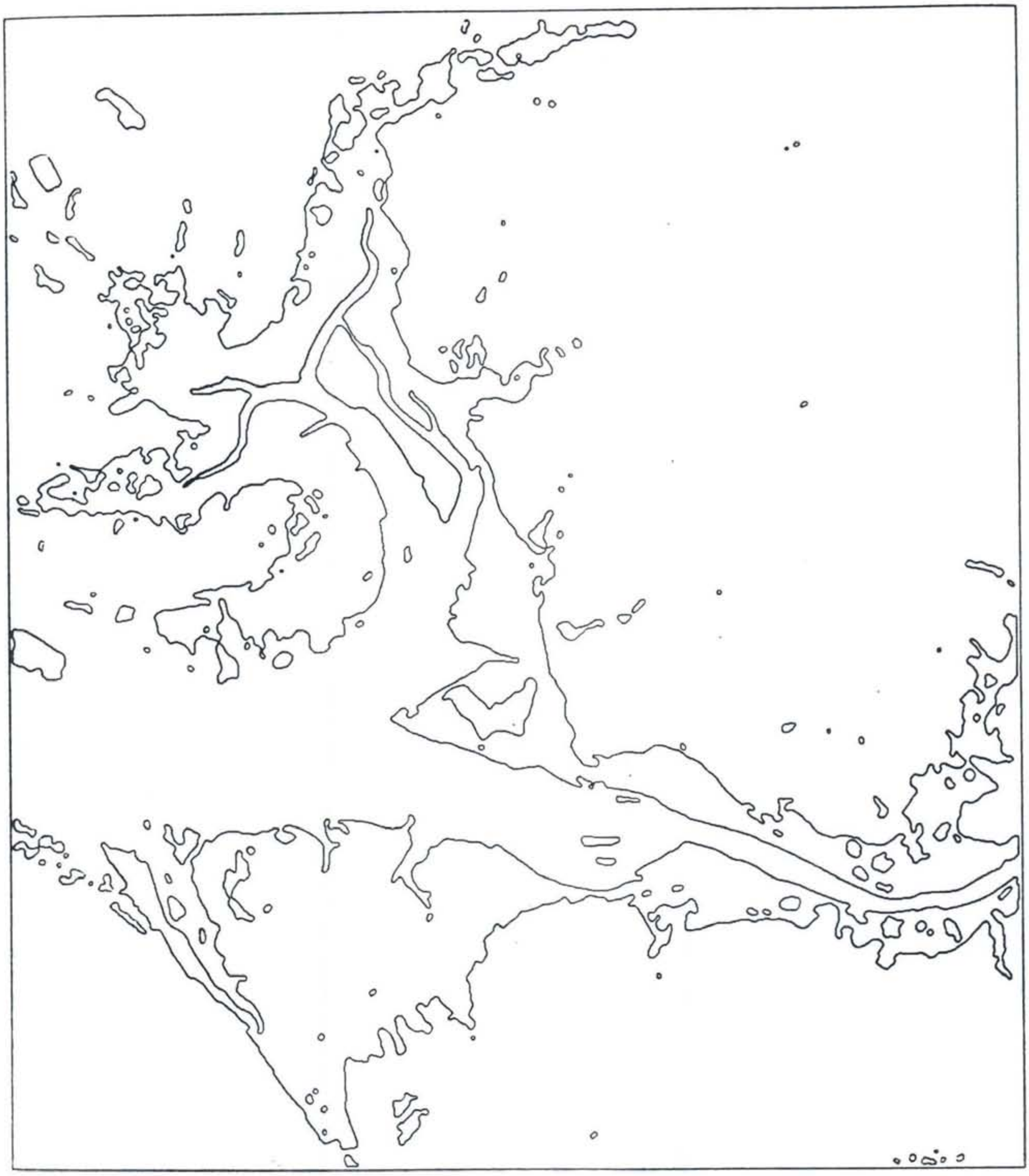


Fig. 15 - The estuary of Sado, first classification plot made automatically in Portugal, out of a satellite image and complying with cartographic standards (geometry, only) (1987).

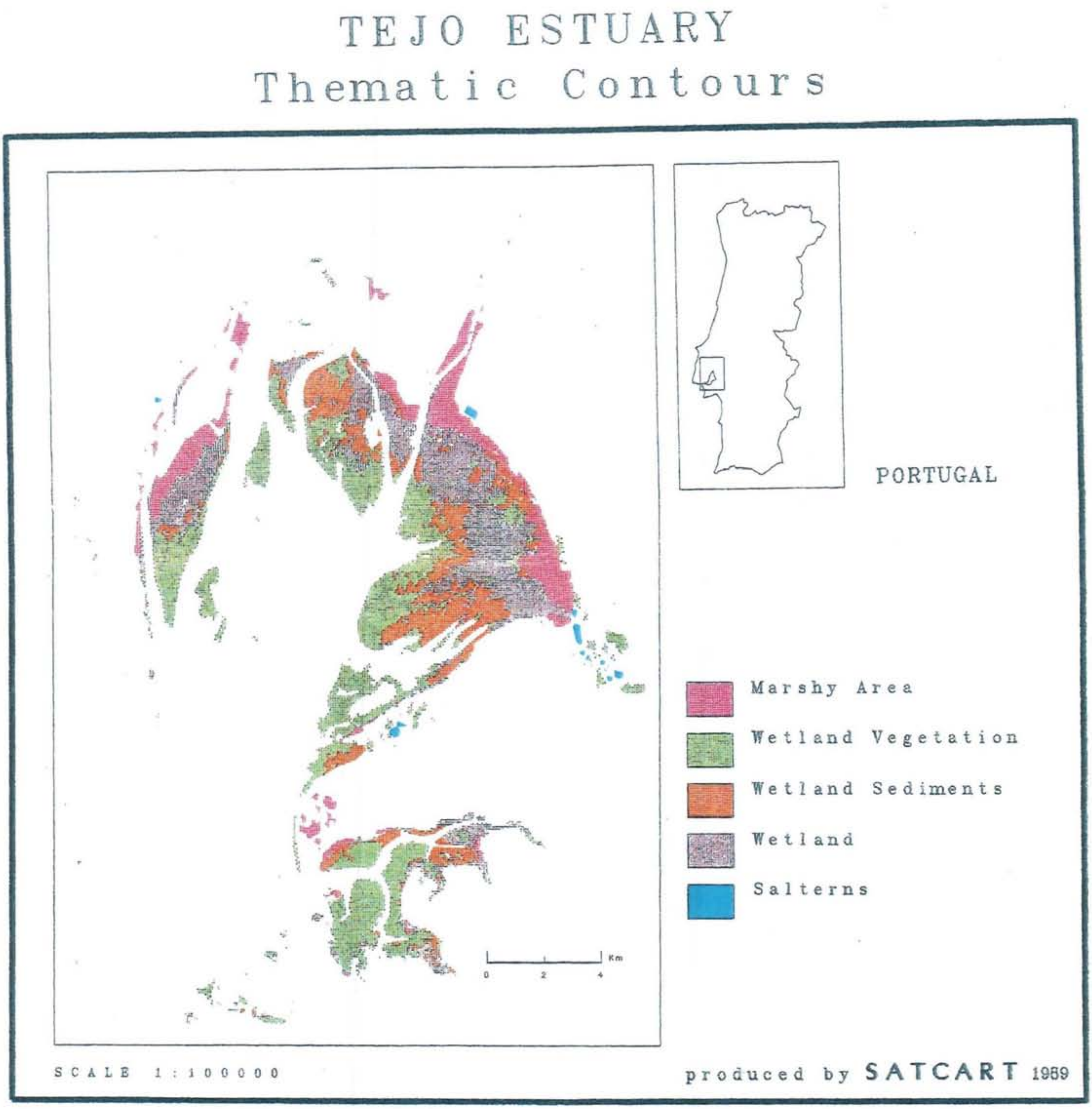


Fig. 16 - Thematic contours of the estuary of Tagus (Tejo), 1989.

# Forest Fires Cartography (4.2.6)

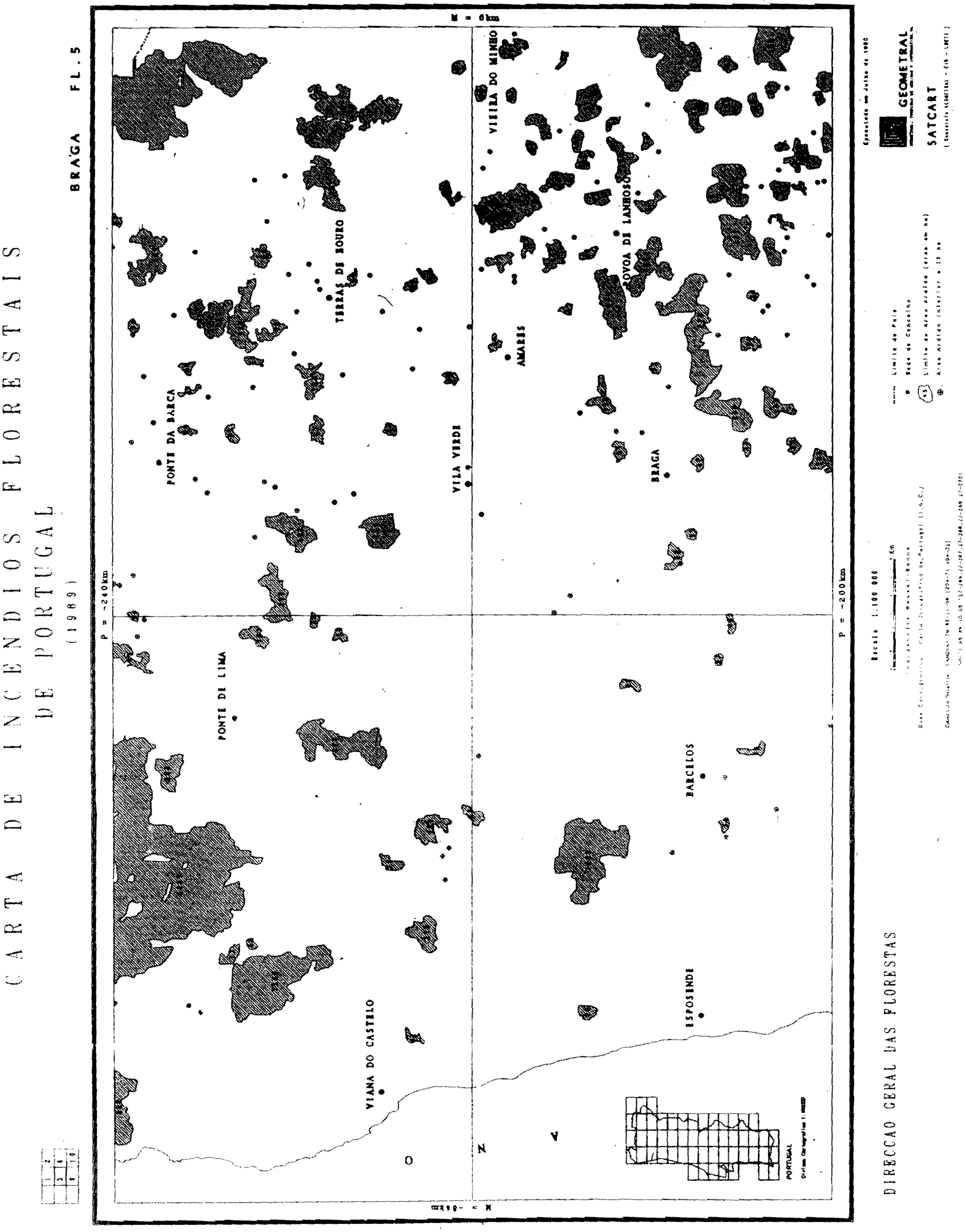


Fig. 17 - One typical map output of the project, at the scale of 1:100,000 (north of Portugal).

# 5 - The impact of SATCART in Portugal

## 5.1 - Accomplishment of initial objectives

We consider that the most important objectives of the SFS-SATCART project were achieved. In fact:

- Production lines for cartographical products made from remote sensed satellite data (maps or GIS covers) were developed and activated to solve a variety of application problems coming from different users and institutions;

- Image processing and GIS techniques and systems were integrated for map production and image analysis;

- High level training for the industrial and research staff was accomplished, with a philosophy of "on-job-training" for the former and academic thesis for the latter;

- A small, highly specialised non-redundant technical team, fully mastering the computer and cartographic systems, was trained and available at the end of the project, ready to restart activities within the context of an independent industrial company;

- Border scientific issues between remote sensing, cartography and GIS, on the one hand, and between image processing, computer graphics and computational geometry, on the other hand, were the phocus of the training activities and of the non-production tasks of the project;

- A number of valuable scientific and methodologic exercices were very satisfactorily solved on automatic generalization, texture analysis, automatic vectorization, data fusion, digital ortho-images, atmospheric compensation and multi-temporal classification;

- The interest and limitations of satellite remote sensing data in the Portuguese context of very complex landscapes were very significatively assessed, throughout the application projects that covered all the area of Portugal, with interactive or automatic techniques;

- SATCART managed to identify and make initial contacts with a variety of industrial and scientific institutions in Europe that, at the long term, might lead to cooperation in remote sensing and cartography.

All these objectives were achieved in the context of solutions to users' defined problems and requests, as specified in the project plan in 1986, with an integrated team coming from three institutions with completely different cultures - that the project has been able to comply with such differences is, by itself, a very positive outcome of this common activity between 1986 and 1991.

## 5.2 - Major errors

The complex technical activities carried out by SATCART during the first half of the project, although related to application projects, were executed by a team of young development engineers, that did manage to solve the problems. Nevertheless, during this very exciting phase, no experimented industrial engineers were made available to the project to simplify the procedures and produce the documentation, according to the usual sound rules of industry. The final result was a very strong dependency on some individuals and, in some cases, the complexity of the procedures inhibitted the potential execution of some tasks by unskilled technicians - which were not made available to the team during the development phase - or by outside engineers.

Although the philosophy underlying the project (to achieve the objectives in the context of solutions to users' defined problems and requests) looks sound and pragmatic for industry, in almost all the applications we had to undertake minimal solutions complying with specifications, and could not afford (for calendar reasons) the development of other methodologies that, in some cases, would certainly be much more effective and interesting from the scientific point of view. This approach was, in some cases, very frustrating, and might only have been compensated by a team profile comprising production and development engineers.

The very small dimensions of the team and its non-redundancy put an extreme stress on the Scientific Director, that was the only person aware of all the developments under way. The ridiculous amount of space made available by Geometral to the project inhibited his presence most of the time - because no technical working meetings could be arranged in such environment without disturbing all the remainding members of the team and the execution of the contracted application projects, that were given higher priority than research and development activities.

The initial project plan was defined in terms of technology developments and some milestones related to technologies and to some expected application projects. The former were defined in very general terms, making it difficult to define end points. It is now realised that most of the research & development tasks were too ambitious, especially for a team made out industrial engineers with different interests from their more scientific oriented colleagues from INETI. This fact has also disturbed the administrations of the industrial companies, used to products and not to medium term development, the importance of which for future applications was unclear for them.

The abovementioned problem might have been solved with additional students from the Universities, not administratively linked to the institutions. Once again, the exiguity of space at Geometral made the integration of further individuals impossible, thus excluding a valuably contribution to the scientific component of the project.

Unfortunately, companies do not know how to cope with less structured opportunities, and tended to think only in terms of the computer costs associated with such students.

The ambiguity of the end points of the project was not a problem by itself, given that one of the objectives of the project was the setting up of a new company, at a reasonable time after the end of the project. People was ready to cope with some initial uncertainties between the end of the project and the initial activities of such company.

Nevertheless this transition - that did not happen, due to the institutional changes, instabilities and lack of coherent medium term strategy of Geometral - was too long, accumulated non-solved problems became intolerable, and highly valuable engineers took personal decisions concerning their professional carrier and left. The same happened with the Scientific Director of the project, that monthly reported all the problems and difficulties due to postponed decisions. Nevertheless these individuals are still active in remote sensing in other companies or at INETI, and their SATCART experience and training must have been globally positive. No SATCART company was created in 1992 and it seems too late to create it now.

Finally, the idea of an integrated team under the leadership of the Scientific Director, that was crucial for the development of the project and integration and interface tasks, reached its limits on the last third of the project, with companies requesting additional tasks directly from their employes, without taking SATCART activities into consideration and without discussion such changes with the Director. This type of management created enormous stress at the team and at the management levels, with obvious consequences at the operational level.

## 5.3 - Major achievements

The first Portuguese maps made out of satellite data, produced automatically and complying with all the cartographical conventions, were produced by the SATCART team as early as 1987.

The complete and dual-sense integration between a remote sensing image analysis environment and a GIS environment was developed by SATCART, at a time when no commercial products with such integrated capabilities existed on the market.

Data fusion from a variety of sensors and sources was achieved by SATCART in phase with international developments.

# 6 - Conclusions

The activity of SATCART in the last period has been driven by the achievement of some developments in image processing (topologic analysis tools, automatic vectorisation, digital orto-images and satellite orbital models for geometric correction), by the conclusion of operational project for agriculture statistics, and by the preparation of important projects for agriculture inventories.

Scientific and technical objectives were achieved. Milestones have been overcome and, most important, knowledge was created on how to manage a complete production line for cartographic products and services, on how to identify and do scientific work on current problems of international research. At the beginning of the project, we were far behind many foreign scientific groups and industrial companies. At the project completion we felt to be "among equals", with much less extensive experience - measured by the number of activities - but confident on capabilities just developed.

A minimum, non-redundant team of critical dimension, has existed covering all the issues that have been developed during the project. Nevertheless, the value of each individual depended dramatically on the overall context and management skills. Those individuals should have been given tasks not conflicting the accumulated background until youngers might have been involved.

From the scientific point of view, a handful of important problems are still waiting for time and a positive environment. Many of those basic problems may have important operational consequences. Two examples follow: automatic altimetry and automatic vectorization. Nevertheless, the physical working conditions were, definitely, not compatible to any type of scientifical analysis, as has been stressed in all previous visits of the NATO / SFS management.

As the end of the project came closer, we have been under extreme pressure due to non-scientific and non-technical non-solved problems. The idea of a new company to inherit the know-how of the project had always been in the minds of the collaborating institutions, LNETI, EID and Geometral.

Nevertheless, the capability to transform this idea into reality has been developing too slowly, hampered by difficulties to identify the strategy, to divide the workshare, to keep the staff together and in-place, and to allocate individuals to tasks more suitable to their capabilities and professional or personal objectives.

The objective of creating an independent company was not achieved. Nevertheless, it is a pleasure to ackowledge that three members of the team are still working together in a small and independent industrial company devoted to remote sensing and geographical information systems (GEOGRAF), with national and international activities, and we believe that credit must be given to their training and projects executed within the SATCART project.

The technical challenges of the remote sensing projects gave rise to a new activity at INETI related to the simulation of images, either to evaluate the performance of future systems of Earth observation, or to analyse the influence of many variables on the images, thus guiding the choice of image processing methodologies. In fact, in any typical remote sensing project, exogenous information is always scarce and getting information out of images may have several solutions (the inverse problem is an ill-posed problem); we thus felt, at INETI, that a systematic evaluation of the effects of such variables on the images was needed through simulation. These simulation projects are running at INETI until 1996 and are supported by the EEC (Environment) and by the EUCLID program.

# 7 - Acknowledgments

This project was made possible by NATO, through the *Science for Stability* Programme.

Aknowledgements are also due to the following institutions:

| | |
|---|---|
| JNICT | Junta Nacional de Investigação Científica e Tecnológica |
| EMGFA | Estado Maior General das Forças Armadas |
| FLAD | Fundação Luso-Americana para o Desenvolvimento |
| DRARO | Direcção Regional de Agricultura Ribatejo e Oeste |
| CNROA | Centro Nacional de Reconhecimento e Ordenamento Agrário |
| MAPA-DGF | Ministério da Agricultura Pescas e Alimentação, Direcção Geral de Florestas |
| MAPA-DGPA | Ministério da Agricultura Pescas e Alimentação, Direcção Geral de Planeamento e Agricultura |
| TABAQUEIRA, EP | |
| INIP | Instituto Nacional de Investigação das Pescas |
| CNIG | Centro Nacional de Informação Geográfica |
| CEE-JRC | Comunidade Económica Europeia - Joint Research Center |
| SCE | Serviços Cartográficos do Exército |
| IGC | Instituto Geográfico Cadastral |
| AER | Atmospheric Environmental Research, Cambridge, USA |
| SCOT CONSEIL | Toulouse, França |
| CNES | Centre National d'Études Spatiales, Toulouse, França |

We are also grateful to many individuals - managers, scientists, engineers and technicians - portuguese or foreigners, who helped with their contributions, experience, discussions and challenges.

# Annexes

# A.1 - Structure of the project

## A.1.1 - Sub-project I: General Activities

**A. Conception and philosophy of the system**
1. Image hardware subsystem
2. Cartographic subsystem
3. Software tools
4. User's interface
5. Information flux

**B. Specification and procurements of the hardware and software**
1. Hardware specification and procurement
2. Software specification and procurement

**C. Training programming**
1. Contacts and choice of training institutions
2. Training profile definition

**D. Installation of equipments**

**E. Marketing**
1. Contacts with potential users
2. Demonstration activities
3. Release of publicity documents

**F. Project Administration**

## A.1.2 - Sub-project II - Scientific and Technical Activities

**A. Specific Problems of Remote Sensing**
1. Generalization of ancillary data in accordance with remote sensing capabilities
2. Analysis of remote sensing classification trees
3. Ground truth collecting with video registration from helicopter platforms
4. Development of calibration methodologies with a multi-spectral hand-held radiometer
5. Specific studies: analysis of mixtures
6. Data base with phenological characteristics of species

**B. Geographical Information Systems (GIS)**

1. Study of GIS characteristics
2. Rasterised GIS specification for a personal computer
3. Rasterised GIS implementation in a personal computer
4. Installation of the ArcInfo GIS in the VAX and training
5. Specification and implementation of messages exchanges between the image environment and the GIS
6. Transfer of available ancillary data, already in digital form, to the GIS
7. Development of hierarchical classifiers based on the GIS
8. Using the GIS to structure digital terrain models already developed

**C. Software Engineering and Production**

1. Insertion of new commands within the image software environment
2. Graphical data base for satellite and maps coverages
3. Data base for ground control points
4. Specification and implementation of transfer formats to external environment
5. Logical integration of all the image equipments and tools within and unique environment

**D. Scene Understanding**

1. Design of the architecture of the control of resolution module
2. Design of the architecture of the region of interest module
3. Design of the modules evaluating primitives and managing perceptual groupings
4. Implementations, assessments and identification of artificial intelligence tools

**E. Digital Cartography**

1. Software for digital stereo-plotters
2. Specification of cartographic maps to be produced within this project
3. Construction of Digital Terrain Models from existing maps
4. Methodology for identification and modeling of ground control points
5. Construction of Digital Terrain Model from data output from the digital stereo-plotter
6. Production of maps
7. Development of digital ortophotographs

**F. Digital Image Processing**

1. Methodologies for geometric pre-processing of image data
2. Methodologies for radiometric and atmospheric pre-processing of image data
3. Filtering and modeling with mathematical morphology techniques
4. Classification methodologies
5. Textural classifiers
6. Contour extraction
7. Pyramid manipulations
8. Rasterisation of maps of contours
9. Testing the capabilities of neural networks to geometrical classification
10. Applications

**G. Graphism**
1. Operations on coverages
2. Operations on image representations
3. Operations on linear structures; closing incomplete contours
4. Feature extraction from N-dimensional clusters

**H. Data fusion**
1. Merging non processed satellite data and digitized aerial photography
2. Merging processed satellite data and processed output from the digital stereo-plotter
3. Merging digitized data (satellite or aerial photography) and altimetric data
4. Merging satellite data from different sensors and satellites

**J. Atmospheric Models and Image Correction**

1. Study of available atmospheric models and assessment of meteorological data
2. Study of atmospheric degradation of satellite imagery
3. Absolute calibration of images
4. Inter-calibration of multi-temporal images

**K. Production Engineering**
1. Analysis of processing times and identification of pertinent micro - tasks
2. Analysis of the patterns of use of equipments
3. Construction of set of rules to document software code
4. Construction of pertinent "work protocols"
5. Construction of "cost schedules" for the different tasks related to products

**L. Technical support**
1. Support activities to digital image processing
2. Support activities to cartography

## A.1.3 - Milestones

N1 - Installation of all the equipments (July, 1989)
N2 - Rasterised GIS for a PC environment (October, 1989)
N3 - Image processing micro-tasks - costs and timings (October, 1989) - discarded
N4 - Maps production chain (December, 1989)
N5 - Integration of the GIS and image processing environments (January, 1990)
N6 - Hierarchical multi-temporal classification using the Digital Terrain model and information stored on the GIS data base (January, 1990)
N7 - Fusion of satellite and digitized aerial photography data (June, 1990) - discarded
N8 - Construction of digital ortophotographs (October, 1990)
N9 - Raster digitalization of contours drawn in maps without further symbolic information (November, 1990)
N10 - Final report (December, 1990)

M0 - Setting system philosophy and organization
M2 - Digital terrain model from existing cartography, in a test zone
M3 - Forest fire identification operational system (June 1990)
M6 - Intertidal zone cartography and surface evaluation
M10 - System integration; maps production

# A.2 - Collaborators

## A.2.1 - Individuals

**LNETI**

Prof. Dr. J. Pinto Peixoto - President of the Remote Sensing program
Prof. Dr. F. Carvalho Rodrigues - Project Director

Doutor J. M. Rebordão - Scientific Director, Deputy Project Director
Dr$^{a}$. M. Conceição Proença (1)
Eng. Fernando Melo
Eng. Pedro Ferraz de Abreu (2)
Eng$^{a}$ M. Margarida Matos
Eng$^{a}$ Ana Gonçalves
Paulo Garcez (2)

**GEOMETRAL**

Sr. J. L. Bouça - President of Geometral
A. Silva e Castro - Marketing Director
Eng$^{a}$. Isabel Ferreira
Eng. João Catalão

**EID**

Cte Pires de Matos - President of EID
Alm. A. Sameiro
Dr. Rui Rodrigues - Financial Director
Dr. João Romana
Eng. Tomaz Pessanha
Dr$^{a}$. Rita Crespo

*Notes*

1. A Ph.D. was completed in Toulouse, France, with a grant from the French government, within the project.
2. Preparing a Ph.D. at the MIT, USA, with a grant from LNETI.

# A.2.2 - Institutions

1. FLAD, Fundação Luso-Americana para o Desenvolvimento
2. JNICT, Junta Nacional de Investigação Científica e Tecnológica
3. DRARO, Direcção Regional de Agricultura da Região Oeste
4. Tabaqueira, SA.
5. EMGFA, Estado Maior General das Forças Armadas
6. Ministério da Agricultura, Direcção Geral de Planeamento e Agricultura, Serviço de Estatísticas Agrícolas

# A.3 - Documents. Publications

## A.3.1 - Sub-project I: General Activities

I.B.1 - Final documents of the procurement for the mainframe computer, digital stereoplotter, video digitizer, image plotter, radiometer, optical disk, May, 1988.

I.B.2 - Analysis of the proposals and selection of vendors, September, 1988.

I.B.3 - Report of the visit of A. Silva e Castro and J. Martinho to Zeiss, in West Germany, September, 1988.

I.B.41- Proposals received from the vendors: Radiometer, Image digitiser, Image Plotter, Global Configuration, Optical Disk.

I.B.42- Proposals received from the vendors: Mainframe Computer, Digital Stereoplotter.

I.C.1 - J. Romana, Report on the Summer School of Space Physics, August 16 - September 3, 1988.

I.C.4 - I. Ferreira, Report on the course "Remote Sensing for Vegetation Monitoring", Joint Research Center, Ispra, April 10-14, 1989.

I.C.5 - J. Catalão, report on the training at Zeiss headquarters.

I.D.1 - Description of the hardware environment at SATCART, May 1989.

I.D.2 - Description of the software environment at SATCART, May 1989.

I.E.1 - Marketing Strategy of the SATCART consortium, February, 1988.

I.E.2 - Contract of the Consortium SATCART, January, 1988.

I.E.3 - Catalog of SATCART capabilities, November, 1988.

I.E.4 - The SATCART consortium, published in O Jornal, December 2, 1988.

I.E.5 - Remote Sensing and Agriculture Statistics, November, 1988

I.E.6 - Contract with the E.E.C. for agricultural forecasts.

I.E.7 - SATCART standard products, January 1990.

I.F.1 - Set of management forms, January, 1988.

## A.3.2 - Sub-project II: Scientific and Technical Activities

II.A.1 - First report to the FLAD, January 1988 (in Portuguese), Appendix 3.

II.A.2 - Second report to the FLAD, July 1988 (in Portuguese), Appendixes 1, 5.

II.A.3 - "Cartografia Temática de Estuários de Rios Portugueses", JNICT report, September 1988, (in Portuguese)

II.A.4 - "Cartografia Temática de Estuários de Rios Portugueses", TABAQUEIRA report, Abril de 1989.

II.A.5 - "Cartografia Temática de Estuários de Rios Portugueses", JNICT project, final report, December 1989.

II.A.6 - "Land use cartography of the hydrographical basin of the Vouga river (in Portuguese), final report, January 1990.

II.A.7 - "Land Use and GIS tools from TM over wide areas", by J. M. Rebordão, I. Ferreira, F. Melo, J. Catalão, Beltsville Remote Sensing Symposium, USA, May 16-18, 1990.

II.A.8 - J. M. Rebordão, F. Melo, I. Ferreira, J. Catalão, "Combining image and GIS environments for large scale inventories over wide areas", International Symposium 'The integration of photogrammetry and remote sensing into GIS: use and quality', Strasbourg, France, November 6- 9, 1990.

II.B.2.1 - J.M.Rebordão, M.M.Matos, "Formal specification of a Geographical Information System, I - the logical universe", internal report, February, 1989.

II.B.2.2 - J.M.Rebordão, M.M.Matos, "Formal specification of a Geographical Information System, I - the functional universe", internal report, February, 1989.

II.B.2.3 - M.M.Matos, J.M.Rebordão, "GIS specification - an example", presented at the 13rd Urban Data Management Symposium", Lisbon, May 29, 1989.

II.D.1.1 - J. M. Rebordão, "Artifficial Vision - another form of perception", presented to the symposium "Introduction to Neuroscience", Lisbon, April 20, 1989.

II.D.1.2 - "Monoscopic analysis of digitised aerial photographies", project proposal accepted by JNICT (July 1990), CAPS (IST) - SATCART.

II.D.1.3 - Project proposal submitted to the EEC (October 1990), J.R.C., Agriculture project, Action 4.

II.D.4.1 - A.Gonçalves, I.Ferreira, "Expert system developed in OPS-5 for rotation of cultures" (in Portuguese), internal report, October 1988.

II.E.1.1 - "The Planicomp-P1/Phocus system: overview of the activity of the past six months", J. Catalão, (in Portuguese), October 1990.

II.E.2.1 - First report to FLAD, January 1988 (in portuguese), Appendix 4.1.

II.E.3.1 - First report to FLAD, January 1988 (in Portuguese), Appendix 5.

II.E.3.2 - Second report to FLAD, July 1988 (in portuguese), Appendix 10.

II.E.3.3 - J. Catalão, J.M.Rebordão, "Merging and cutting of triangular irregular networks", technical report, June 1989.

II.F.1.1 - M.C.Proença, J.M.Rebordão, "Fusion of the panchromatic XS bands of SPOT", internal report, July 1988.

II.F.2.1 - J.Romana, I. Ferreira, "Identificação de superfícies de referência na folha 38B", internal report (in portuguese), May, 1988.

II.F.2.2 - J. M. Rebordão, "Look up table loadings for image processing with controlled knots", Computer Vision, Graphics and Image Processing, 47,189-202(1988).

II.F.4.1 - M.C.Proença, J.M.Rebordão, I.Ferreira, "Metodologias de pré e pós processamento em imagens SPOT - aplicações à classificação temática", FLAD second report, Appendix 4, February 1988.

II.F.4.2 - J.M.Rebordão, M.O.Pereira, M.C.Proença, T.C.Pereira, "Bi-temporal Analysis of SPOT data by photo- interpretation procedures", in FLAD first report, Appendix 6.2, January 1988.

II.F.4.3 - J.M.Rebordão, M.C.Proença, "Implementation of general decision tables in pipeline image processors", SPIE Proceedings 1062, SPIE's LO LASE'89, January 15, 1989.

II.F.5.2 - F.Melo, J. M. Rebordão, "Textures in satellite images and cartographical generalization", RecPad 90, Lisbon.

II.F.6.1 - F. Melo, "Representações de Informação Bidimensional em Aplicações da Detecção Remota", Tese de Licenciatura, Instituto Superior Técnico, LNETI, Outubro 1988.

II.F.10.1 - First report to the FLAD, January 1988 (in portuguese)

II.F.10.2 - Second report to the FLAD, July 1988 (in portuguese)

II.F.10.3 - "Cartografia Temática em zona intermarés de estuários e rios portugueses", report to JNICT, September, 1988 (in portuguese)

II.F.10.4 - "Cartografia Temática em zona intermarés de estuários e rios portugueses", Relatório TABAQUEIRA, April 1989.

II.F.10.5 - "Cartografia Temática em zona intermarés de estuários e rios portugueses", JNICT, final report, December 1989 (in portuguese).

II.F.10.6 - "SPOT thematical indexes applied to cartography of the intertidal area of the Tejo river", Photo- Interpretation 89-3,4.

II.G.1.1 - F. Melo, J. M. Rebordão, "Automatic cartographical generalization for Landsat derived thematical maps", ESRI, 1990 User conference, March 1990.

II.H.1.1 - M.C.Proença, J.M.Rebordão, "Fusion of the panchromatic XS bands of SPOT", internal report, July 1988 (II.F.1.1)

II.H.4.1 - J. Romana, Correcção Radiométrica de Imagens satélite, Faculdade de Ciências de Lisboa, Tese de Licenciatura, March 1990. (II.J.2).

II.J.1 - J. Romana, report of the Summer School of Space Physics, August 16 - September 3, 1988.

II.J.4.1 - J.Romana, I. Ferreira, "Identificação de superfícies de referência na folha 38B", internal report (in portuguese), May, 1988.

II.K.1.1 - "Tasks in a remote sensing project", February 1990.

II.K.4.1 - "The Planicomp - P1 / Phocus system: overview of the activity in the first six months", internal report (in Portuguese), October 1990. (II.E.1.1)

# A.4 - Thesis

1. Melo, "Representações de informação bidimensional em aplicações da Detecção Remota", Tese de Licenciatura, Instituto Superior Técnico, LNETI, October 1988.

2. L.N.Abreu, "Segmentação de imagens texturadas com base em modelos auto-regressivos", Master thesis, Instituto Superior Técnico, LNETI, November, 1988.

3. P. Ferraz de Abreu, "Artificial Intelligence & Graphics", Master thesis, MIT, USA, July 1989.

4. J. Romana, "Correcção Radiométrica de Imagens satélite", Faculdade de Ciências de Lisboa, Tese de Licenciatura, March 1990.

5. H. Ribeiro, "Modelação das órbitas dos satélites LANDSAT e SPOT - 1", Faculdade de Ciências de Lisboa, Estágio de Licenciatura, September 1990.

6. J. Almeida, "Modelação das órbitas dos satélites LANDSAT e SPOT - 2", Faculdade de Ciências de Lisboa, Estágio de Licenciatura, September 1990.

7. C. Catalão, "Modelos digitais de terreno e suas aplicações no contexto das aplicações da detecção remota", assistant thesis, Faculdade de Ciências, October 1990.

8. M. C. Proença, "La transformée en ondelettes appliquée au traitement d'images de télédétection", PhD, Toulouse University, October 1992.

9. M. Rita Crespo, "Cartografia do habitat potencial de passeriformes no Estuário do Tejo por processamento digital de imagens", Tese de Licenciatura, Faculdade de Ciências de Lisboa, July 1993.

10. P. Ferraz de Abreu, PhD thesis, MIT, USA (running)

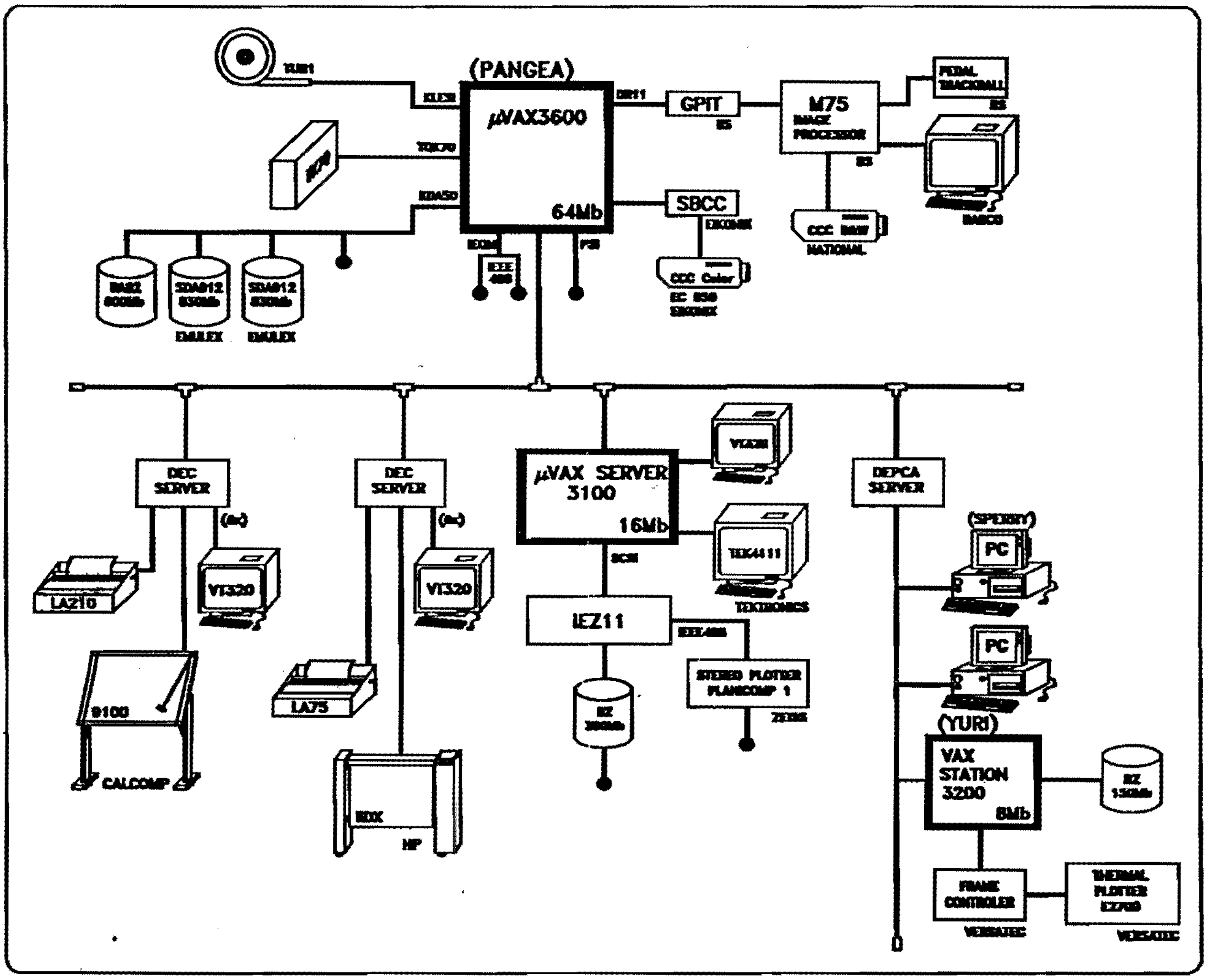
# A.5 - Equipments and software

The following items of equipment were purchased by the SATCART project *(smaller items are considered integrated at a system level and are not discriminated in this list - the inventory document discriminates them on an individual basis):*

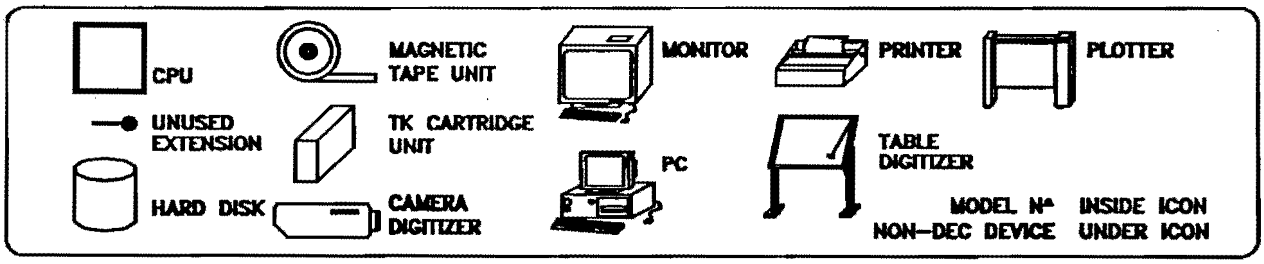
1. DEC Micro Vax 3600 computer system cluster, including a magnetic tape unit (TU-81), a terminal server, Ethernet node, multiplexers for terminals, 8 VT320 terminals; VMS, Fortran, C, ...
2. DEC Micro Vax 3200, including a RGB monitor;
3. DEC Vaxstation 3100;
4. HP polychromatic workstation;
5. HP color workstation;
6. Eikonix Digitizing Camera system, including a Vax controller, mechanical stand, illuminating box and chromatic filters;
7. HP Draftmaster Plotter;
8. Barringer handheld Radiometer, including tripod, filters and calibrating tools;
9. Zeiss analytical stereoplotter Planicomp P1 system, including a Tektronix terminal and operating and aplications software (Phocus, Bingo, ...);
10. EMULEX 2GByte hard disk subsystem;
11. Image processing and GIS software (Arc Info, S600/IIS, BUZZ&GEST).

The figures on the following pages illustrate the hardware and software architecture of the SATCART computer system.

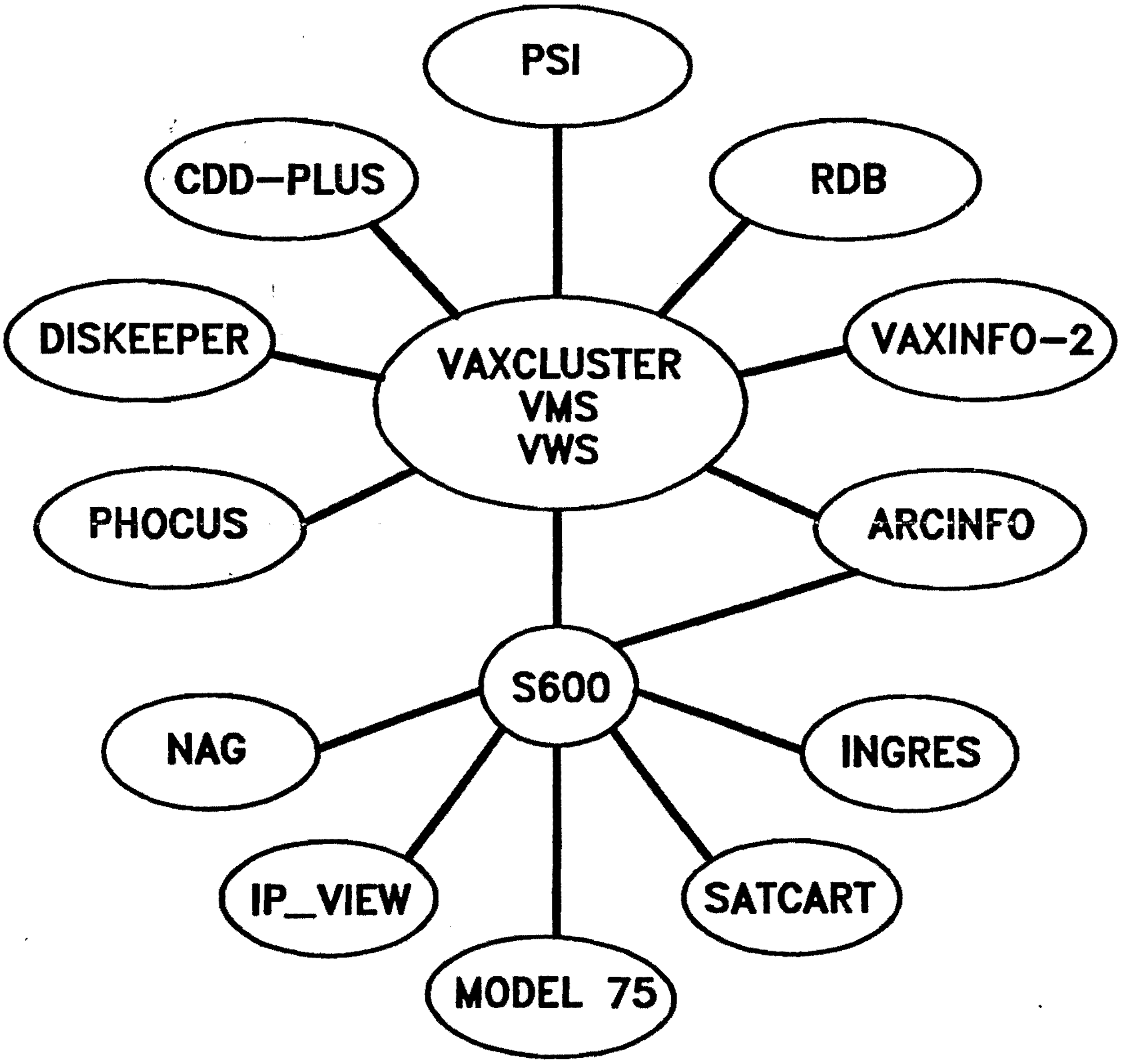
# SATCART HARDWARE CONFIGURATION



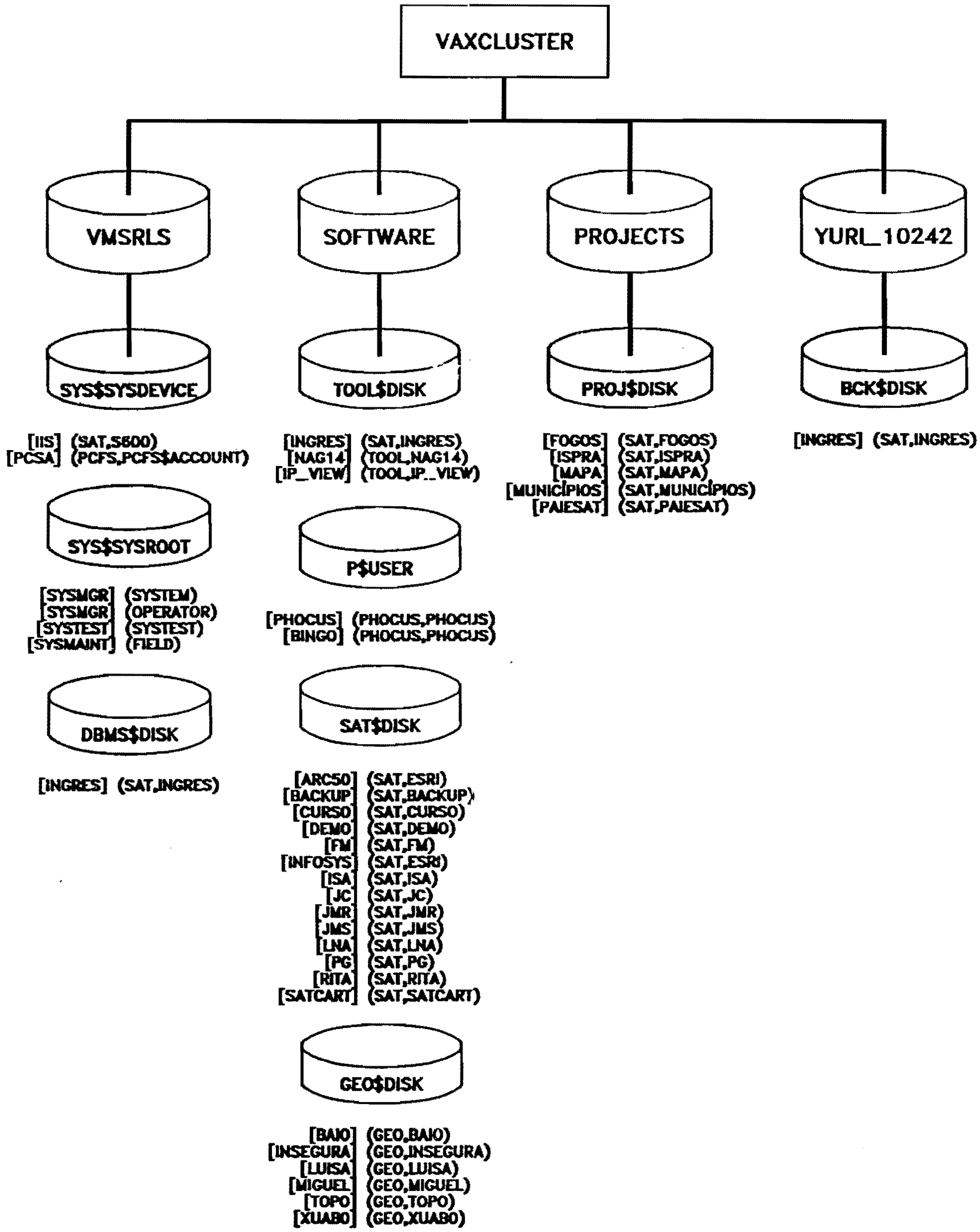
## LEGEND



# SATCART SOFTWARE ENVIRONMENT



# SATCART USER MANAGEMENT



# A.6 - Consultants and Experts

## A.6.1 - NATO's consultant

1. Dr. David Levy (CNES)
Period: 1987-1988

2. Dr. André Mangin (CNES, Scot Conseil, Eurostat)
Period: 1989 - 1990

## A.6.2 - Experts

1. Name: Dr. W. Bruce

Function: NATO special consultant
Date : July, 27-28, 1987
Goal : Discussion on the hardware configuration

2. Name: Dr. R. Kaplan

Function: Principal scientist at Atmospheric Environment Research, USA
Date: November, 9 - 13, 1987
Goal: Atmospheric models - fundamentals.

3. Name: Dr. R. Isaacs

Function: Senior scientist at Atmospheric Environment Research, (AER), USA
Date: December, 4 - 12, 1988
Goal: Data Fusion. Software for image standardization. Calibration of images in luminance. Simulation of the atmosphere with the LOWTRAN system. Very important discussions for the development of Activity (Atmospheric Models and Image Correction). Possibility of accessing the software used at AER.

# A.7 - Financial overview

In this Annex a financial overview of the SATCART project is provided, with summary tables on:

- Partners' expenses,
- Major equipment,
- Budget,
- Budget - breakdown,
- Cost per partner,
- Labour cost.

## A.7.1 - Partners' expenses *(k.BF)*

| Expenses | Partners | | | | Total | % |
|---|---|---|---|---|---|---|
| | NATO | INETI | EID | GEOMETRAL | | |
| **Equipment** | 29.122 | - | - | - | 29.122 | 23,0 |
| **Visits** | 1.167 | - | - | - | 1.167 | 1,0 |
| **Consultants** | 487 | - | - | - | 487 | 0,3 |
| **Other** | 222 | 10.582 | 5.693 | 3.768 | 20.265 | 16,0 |
| **Labour (Note)** | - | 31.332 | 22.554 | 21.796 | 75.682 | 59,7 |
| TOTAL | **30.998** | **41.914** | **28.247** | **25.564** | **126.723** | |
| % | *24,5* | *33* | *22,3* | *20,2* | *100* | *100,0* |

*NOTE: 1 Hour = BF 2.000*

## A.7.2 - Budget of major equipment and software *(see Annex A.5)*

| Equipment | *k.BF* |
|---|---|
| DEC MicroVax 3600 Computer system (including 2 VAXstations 3100, 3200, 2Gb disk subsystem) | 10.747 |
| HP UNIX workstations | 1.493 |
| ZEISS analytical stereoplotter P1 system | 10.192 |
| Eikonix digitizing camera system | 1.860 |
| Hand-held Barringer Radiometer | 898 |
| HP Draftmaster plotter | 398 |
| Software: image processing, GIS | 3.534 |
| TOTAL | **29.122** |

## A.7.3 - Budget

| | *k.BF* | % |
|---|---|---|
| **NATO** | 30.998 | *24* |
| **National** | 95.725 | *76* |
| **TOTAL** | **126.723** | ***100*** |

## A.7.4 - Budget breakdown

| | **Labour** | **Equipment, travel, etc.** | **Total** |
|---|---|---|---|
| **NATO** | - | 30.998 | 30.998 |
| **National** | 75.682 | 20.043 | 95.725 |
| **TOTAL** | **75.682** | **51.041** | **126.723** |
| | *60%* | *40%* | |

## A.7.5 - Costs per partner

| | *k.BF* | % |
|---|---|---|
| **NATO** | 30.998 | *24,5* |
| **INETI** | 41.914 | *33,0* |
| **EID** | 28.247 | *22,3* |
| **Geometral** | 25.564 | *20,2* |
| **TOTAL** | **126.723** | *100,0* |

## A.7.6 - Labour cost

| | *k.BF* | *Hours* | % |
|---|---|---|---|
| **INETI** | 31.332 | 15.666 | *41,4* |
| **EID** | 22.554 | 11.277 | *29,8* |
| **Geometral** | 21.796 | 10.898 | *28,8* |
| **TOTAL** | **75.682** | **37.841** | *100,0* |

# A.8 - The SATCART Consortium

## CAPÍTULO VI

### Disposições transitórias

### ARTIGO 30.º

### Actividade da Sociedade antes do registo definitivo

1 — O conselho de administração fica autorizado a exercer qualquer acto compreendido no objecto social da Sociedade ainda antes do seu registo definitivo.

2 — Qualquer dos membros do conselho de administração fica também desde já autorizado a levantar as quantias depositadas na Caixa Geral de Depósitos correspondentes às entradas dos sócios para o capital social, mesmo antes do registo definitivo da Sociedade, desde que tais levantamentos tenham como fim a aquisição de equipamento ou de quaisquer bens imóveis.

### ARTIGO 31.º

### Nomeação dos membros dos órgãos sociais

Para o triénio de 1989 a 1991 são desde já nomeados membros dos órgãos sociais os seguintes elementos:

*a*) Conselho de administração: presidente, Luiz Clemenceau de Azevedo Marques, arquitecto, casado pelo regime de separação absoluta de bens com Ana Maria Mendes de Azevedo Marques, residente na Quinta da Marinha, vilas 23 e 29, em Cascais; administrador-delegado, Dr. João Carlos de Sousa Caetano Serafim, casado com Paula Cristina Ferreira dos Santos Macedo Serafim no regime da comunhão de adquiridos, residente na Rua de Francisco Stromp, 5, 3.º, esquerdo, em Lisboa; vogal, Almir de Lima Machado, arquitecto, brasileiro, divorciado, residente na Avenida de Sernam Betida, 5706, apartamento 902, Rio de Janeiro, Brasil;

*b*) Fiscal único: efectivo, Maria do Carmo Henriques Neto, revisora oficial de contas n.º 593, residente na Rua do Professor Hernâni Cidade, 10, em Lisboa; suplente, José Manuel Carlos Monteiro, revisor oficial de contas n.º 592, residente na Avenida de D. Nuno Álvares Pereira, 2, 8.º, direito, no Cacém;

*c*) Mesa da assembleia geral: presidente, Dr. José Firmino Vieira de Meirelles Corte Real, advogado, solteiro, maior, residente na Rua de Fialho de Almeida, 17, 5.º, direito, em Lisboa; secretário, Dr. Pedro José de Almeida Semedo Antunes Pimenta, advogado, casado no regime de separação de bens com Ana de Barros Queiroz Teixeira e Silva, com escritório na Avenida Marginal, bloco B, 1.º, F, em Cascais.

*(Duas assinaturas ilegíveis.)* — A Notária, *Maria das Dores Canudo Cabaça.*

27.º Cartório Notarial de Lisboa, 16 de Fevereiro de 1989. — O Ajudante, *Manuel dos Santos Portela.* 4-0-3245

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## SATCART — CONSÓRCIO DE GEOMETRAL-EID-LNETI

### Introdução

O LNETI, a EID, S. A., e a GEOMETRAL, S. A., têm vindo a ser pioneiros em Portugal no desenvolvimento de tecnologias de processamento de imagens, de ambientes de *softwares* dedicados e cartografia com suporte digitalizado.

Para alcançar os objectivos propostos obtiveram o apoio da Tabaqueira, E. P., complementando com o apoio da Junta Nacional de Investigação Científica e Tecnológica para um estudo da zona intermarés em cinco estuários da costa portuguesa, da Fundação Luso-Americana para o Desenvolvimento e da Direcção Regional da Agricultura da Região Oeste, para a classificação automática de ocupação de solos e ainda a aprovação e apoio do projecto «Upgrading National Technology» por parte do programa «Science for Stability» da Organização do Tratado do Atlântico Norte.

No sentido de rentabilizar o esforço já efectuado e em curso de desenvolvimento e com vista a alargar as capacidades de intervenção nos mercados externos do LNETI, a EID, S. A., e a GEOMETRAL, S. A., decidiram agregar as suas vocações complementares num consórcio denominado SATCART — Consórcio de GEOMETRAL-EID-LNETI, como fase intercalar até à constituição de uma empresa especializada neste ramo de actividade.

Contrato de consórcio entre GEOMETRAL — Técnicas de Medição e Informática, S. A., com sede na Avenida do Conselheiro Barjona de Freitas, 10-A, Lisboa, EID — Empresa de Investigação e Desenvolvimento de Electrónica, S. A., com sede na Quinta dos Medronheiros, Lazarim, Monte da Caparica; LNETI — Laboratório Nacional de Engenharia e Tecnologia Industrial, com sede na Estrada do Paço do Lumiar, Lisboa, adiante designados como Membros, é celebrado um contrato de consórcio externo, nos termos das cláusulas seguintes:

### ARTIGO 1.º

### Denominação e localização

O consórcio designa-se por SATCART — Consórcio de GEOMETRAL-EID-LNETI e funcionará na Rua E, Quinta Grande, lote 62, em Alfragide, podendo, porém, o COF deliberar quando o entender, que passe a funcionar noutro local.

### ARTIGO 2.º

### Objecto

1 — O consórcio tem por objecto a execução de acções de investigação científica, desenvolvimento tecnológico e a prestação de serviços no domínio do processamento digital de imagens, tendo em vista a produção de cartografias de base e temáticas e a constituição ou carregamento de sistemas de informação geográfica, essenciais às actividades do ordenamento e da gestão integrada do território e seus múltiplos recursos, especialmente nas suas componentes social, económica e ambiental.

2 — As referidas acções vão orientar-se de uma forma imediata para as aplicações nos domínios da geologia e prospecção mineira, para os inventários agrícolas e estimas de produções, para a gestão dos recursos hídricos incluindo os oceânicos adjacentes e, bem assim, para os estudos conducentes à promoção da qualidade do ambiente em geral.

### ARTIGO 3.º

### Duração e extensão

1 — Sem prejuízo de se reportarem à data da assinatura deste contrato, a produção dos seus efeitos fica dependente do visto do Tribunal de Contas.

2 — A duração deste contrato é de três anos.

3 — Os Membros poderão acordar na extensão do objecto do consórcio, mediante a alteração deste contrato.

4 — O contrato poderá ser prorrogado ou resolvido a qualquer momento, por acordo dos Membros envolvidos.

### ARTIGO 4.º

### Participação

1 — As prestações de cada membro são, para os efeitos deste contrato, as seguintes:

GEOMETRAL — cartografia de base temática, sistemas de informação geográfica e desenho automático, bem como o *marketing* e comercialização.

EID — engenharia de *software*, inteligência artificial, representação gráfica, engenharia de produção e bases de dados, bem como a gestão administrativa e financeira.

LNETI — processamento digital de imagens, grafismo e sistemas de informação, bem como a direcção técnico-científica.

2 — A participação de cada Membro será função do investimento e do apoio devidamente quantificado, realizado por cada um.

O instrumento de avaliação desta participação será a contabilidade expressa na documentação aprovada pelos Membros do Consórcio.

### ARTIGO 5.º

### Exclusividade

É permitido ao LNETI o exercício, fora do Consórcio, de actividades objecto deste contrato, enquanto a sua natureza de instituto público e de serviço central do Ministério da Indústria e Energia o exigirem.

### ARTIGO 6.º

### Conselho de orientação e fiscalização

1 — O conselho de orientação e fiscalização (COF) é o órgão máximo do Consórcio.

2 — O COF é composto por um representante de cada um dos seus Membros.

3 — Ao COF compete orientar e fiscalizar a actividade do Consórcio e decidir as medidas que devem ser adoptadas, em caso de incumprimento das obrigações por parte de alguns dos Membros.

4 — Cada Membro deve indicar o seu representante no COF, com mandato de um ano, renovável, podendo, no entanto, cada representante ser pontualmente substituído, mediante carta dirigida ao chefe do Consórcio.

5 — O COF reunirá, por solicitação do chefe do Consórcio ou de um dos seus Membros, mediante convocatória escrita e com aviso mínimo de 48 horas, excepto em caso de manifesta urgência em que a convocação se pode processar telefonicamente.

6 — O COF designará os Membros da comissão consultiva.

7 — As deliberações do COF deverão ser tomadas por consenso.

### ARTIGO 7.°

### Chefe do consórcio

1 — O chefe do Consórcio é a EID — Empresa de Investigação e Desenvolvimento de Electrónica, S. A.

2 — Compete ao chefe do Consórcio cumprir todas as deliberações do COF e assegurar o cumprimento de todas as disposições legais e contratuais do Consórcio.

3 — Compete ainda ao chefe do Consórcio:

3.1 — A representação dos Membros do Consórcio perante os clientes e outros terceiros, nos termos das procurações que lhes sejam conferidas;

3.2 — A coordenação e a supervisão das actividades dos Membros;

3.3 — Assegurar a circulação pelos restantes Membros de todas as informações ou comunicações relevantes para as actividades do Consórcio;

3.4 — Assegurar, por todos os meios, o integral cumprimento das obrigações contratuais com terceiros, designadamente a preservação de aspectos de confidencialidade técnica;

3.5 — Receber as quantias ou valores que sejam devidas a Membros do Consórcio e providenciar pelos pagamentos que lhes sejam devidos, nos termos contratuais e segundo as modalidades de gestão a deliberar pelo COF;

3.6 — Convocar os representantes dos membros para reuniões do COF, quando julgue conveniente, ou quando tal lhe tenha sido solicitado por um dos Membros;

3.7 — Providenciar as instalações necessárias e convenientes para a boa execução dos objectivos do Consórcio;

3.8 — Assegurar que é salvaguardada a adequada vigilância a todas as instalações do Consórcio, para a boa e segura execução dos objectivos do contrato.

### ARTIGO 8.°

### Comissão consultiva e auxiliar

1 — A comissão consultiva e auxiliar é um órgão de consulta do COF e do chefe do Consórcio e auxiliar deste último.

2 — Os elementos da comissão consultiva e auxiliar, em número de três, serão nomeados pelo COF.

3 — Cabe à comissão consultiva elaborar propostas de actuação e, após a sua aprovação pelo COF, colaborar com o chefe do Consórcio na sua execução, designadamente nos domínios seguintes:

Planeamento e direcção científica e técnica;
Elaboração de relatórios de actividades;
Planeamento e coordenação de actividades de formação;
Definição dos instrumentos de avaliação financeira;
Elaboração dos relatórios de execução financeira;
Elaboração e implementação do plano de *marketing*;
Estabelecimento de contactos comerciais.

### ARTIGO 9.°

### Relações entre o chefe do consórcio e os membros

São obrigações dos Membros perante o chefe do Consórcio:

1) Dar assistência e cooperação ao chefe do Consórcio, sempre que necessário ou solicitado e empreender qualquer acção no âmbito dos objectivos do Consórcio;

2) Fornecer atempadamente ao chefe do Consórcio as informações necessárias à sua missão;

3) Enviar representantes habilitados a tomar parte em discussões técnicas, comerciais, financeiras ou de qualquer outra natureza, sempre que solicitadas pelo chefe do Consórcio;

4) Dar conhecimento ao chefe do Consórcio do andamento da concretização dos objectivos deste contrato.

### ARTIGO 10.°

### Encargos dos membros

1 — Os encargos que se refiram à prestação de um Membro para a execução dos contratos com os clientes serão integralmente suportados por esse Membro.

2 — Os encargos e custos referentes ao Consórcio, na sua globalidade, são suportados pelos seus membros de acordo com critérios a adoptar pelo COF.

3 — Cada um dos Membros do Consórcio obriga-se ao pagamento de uma taxa aos outros Membros pela utilização a seu proveito de equipamentos alocados ao Consórcio, pelos mesmos Membros ou por entidades externas ao Consórcio, de acordo com os critérios definidos pelo COF.

### ARTIGO 11.°

### Responsabilidade dos membros

1 — Cada Membro é responsável perante cada um dos restantes Membros pelo cumprimento das suas obrigações específicas e por aquelas que for deliberado que sejam individualmente assumidas perante terceiros, em representação ou no interesse do Consórcio.

2 — Esta regra não é afectada, mesmo em caso da responsabilidade solidária dos Membros perante terceiros.

3 — Cada Membro é responsável perante os outros Membros pelos prejuízos que advierem ao Consórcio pelo incumprimento das suas obrigações no âmbito do presente contrato de consórcio, perante terceiros que forem por si causados.

4 — Cada Membro, na prestação de serviços a terceiros, obriga-se a invocar a sua condição de consorciado sempre que aqueles tenham sido realizados no âmbito do Consórcio.

### ARTIGO 12.°

### Cedência da posição

1 — Nenhum Membro tem o direito de ceder, no todo ou em parte, os seus direitos e obrigações que lhe caibam no âmbito do presente contrato, sem acordo prévio dos outros Membros.

2 — A subcontratação por um dos membros de uma parte significativa das tarefas que lhe foram cometidas no âmbito do presente contrato, ou dos contratos celebrados com clientes, depende igualmente do consentimento dos outros Membros do Consórcio.

### ARTIGO 13.°

### Resolução do contrato

1 — No caso de um dos Membros ser dissolvido, por qualquer causa, ou de ser objecto de concordata, acordo de credores, gestão controlada ou declaração de falência ou de ter infringido o disposto no n.° 1 do artigo anterior, os outros Membros poderão resolver o contrato em relação a esse Membro e continuarão os trabalhos em curso, salvo se o conselho de orientação e fiscalização deliberar de outro modo.

2 — No caso de incumprimento, por parte de um Membro, das obrigações resultantes do presente contrato e do contrato celebrado com o cliente, os outros Membros, mediante deliberação do conselho de orientação e fiscalização, notificá-lo-ão das medidas a adoptar.

3 — Se o Membro faltoso não cumprir no prazo que lhe for fixado de acordo com o número anterior, os outros poderão resolver o contrato quanto a esse Membro, tomando simultaneamente as providências necessárias para anular, na medida do possível, as consequências do incumprimento.

4 — O disposto nos números anteriores entender-se-á sem prejuízo do direito dos outros Membros a serem indemnizados pelos prejuízos causados pelo Membro excluído.

### ARTIGO 14.°

### Lei aplicável e resolução de litígios

1 — Em tudo o que seja omisso no presente contrato, aplicar-se-á o disposto no Decreto-Lei n.° 231/81, de 28 de Julho.

2 — Todos os litígios emergentes do presente contrato que não possam ser amigavelmente resolvidos serão dirimidos por arbitragem, nos termos da Lei n.° 31/86, de 29 de Agosto, e do Decreto-Lei n.° 425/86, de 27 de Dezembro.

3 — A decisão arbitral será proferida no prazo máximo de seis meses a contar da nomeação do árbitro único ou do terceiro árbitro, de acordo com o diploma referido no número anterior. Este prazo poderá ser prorrogado, por acordo escrito das partes, até ao dobro da sua duração inicial.

4 — O tribunal arbitral decidirá segundo o direito e da sua decisão não haverá recurso.

### ARTIGO 15.°

### Alteração do contrato

O presente contrato só pode ser alterado por deliberação unânime dos Membros.

Quinta dos Medronheiros, Lazarim, 13 de Janeiro de 1988. — A Administração da GEOMETRAL, *(Assinatura ilegível.)* — A Administração da EID, *(Assinatura ilegível.)* — O Presidente do LNETI, *(Assinatura ilegível.)*

Homologo — O Ministro da Indústria e Energia, *Luís Fernando Mira Amaral.* 1-0-8600