RAS/86/036
Field Document 10
February 1993

# SPOT SATELLITE IMAGE TREATMENT AND VISUAL INTERPRETATION FOR FORESTRY AND LAND USE MAPPING

## *REPORT OF THE TRAINING COURSE ON REMOTE SENSING*

22 - 27 JULY 1990 NOUMEA, NEW CALEDONIA

Editors
Gilbert DAVID
Jens - Peter LILLESØ

SOUTH PACIFIC
FORESTRY DEVELOPMENT PROGRAMME

INSTITUT FRANCAIS DE RECHERCHE SCIENTIFIQUE
POUR LE DEVELOPMENT EN COOPERATION (ORSTOM)

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The conclusions and recommendations given in the report are those considered appropriate at the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages of the project.

The designations employed and the presentation of the material and maps in this document do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organisation of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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## FOREWORD

Remote sensing has, traditionally, involved the use of aerial photography techniques. The first real development of these techniques began during the First World War in the Near East and Europe, and during the Second World War in Europe, Asia and the Pacific. Black and white panchromatic aerial photography has been mostly used, particularly in developing countries. Colour aerial photography has also been used in the past few decades, but these have been restricted to special areas of interest because of the high costs involved.

The greatest advances in remote sensing technology began with the availability of satellite imagery data, following the launching of the first Earth observation satellite, LANDSAT 1 in 1972, followed by other satellites such as NOAA AVHRR, the Meteosat series, and more recently SPOT. There is no doubt that the use of satellite data has been, and will continue to be, greatly enhanced by the development of digital image processing techniques.

The use of satellite data has not only greatly improved the management of our fast-depleting natural resources, but has now become an integral management decision tool in most countries, including many developing countries. This has been especially so for countries with considerable forest resources.

Therefore, it was decided to organise a training course in remote sensing, with particular emphasis on the visual intepretation of satellite imagery, for the forestry and related sectors in the larger Project countries, ie Solomon Islands, Fiji and Vanuatu (Fiji was unable to send any participants). The course was funded by the South Pacific Forestry Development Programme (RAS/86/036), and organised by ORSTOM in Noumea, New Caledonia.

We are grateful to Dr. Gilbert David of ORSTOM for his untiring efforts in organising and running the course, and for being the principal editor of this report; to Mr. Jens-Peter Lilleso, Associate Professional Officer, RAS/86/036, for his equally untiring efforts and dedication in putting together the first draft of this report; and to the Office of Language Services, Prime Minister's Office, Republic of Vanuatu, for translating all the French lecture notes to English. Without their collective, selfless efforts, this report would not have been published.

We are confident that this report will be of use to all those interested in the application of remote sensing techniques in the more effective use and management of their natural resources.

(TANG, Hon Tat)
Project Coordinator

December 1992
Suva, FIJI.

# PART 1. REPORT OF TRAINING COURSE

# 1. REPORT OF TRAINING COURSE

*by P. Tranquillini,*
*FAO,*
*South Pacific Forest Development Programme*

*G. DAVID*
*ORSTOM, MISSION PORT VILA*

## 1. BACKGROUND

A Remote Sensing Training Course was originally scheduled to be held in Suva, Fiji, in February 1990 by the FAO South Pacific Forestry Development Programme in collaboration with ESCAP Regional Remote Sensing Programme (RAS/86/141) Suva and ORSTOM Mission in Port Vila. Since some of the participants were unable to attend, the course was postponed to July 1990, by which time RAS/86/141 had been terminated. However, ORSTOM. in Noumea agreed to arrange the training course at their Caledonian Image Treatment Laboratory, LATICAL (Laboratoire de Traitement d'Image Calédonien) and provide suitable facilities, technical equipment and expertise, and lectures by the staff, on a contract fee basis.

## 2. PRE-COURSE FIELD TRIP

At the suggestion of the technical organisation in ORSTOM Noumea, a two-day field trip was organised before the course on 12 and 13 July 1990. For logistic reasons, the pre-course trip was organised only for Vanuatu in the areas covered by the satellite scene to be analysed at the course (North Efate). This exercise provided a preliminary overall knowledge of the territory which proved to be very useful for the supervised image treatment in the laboratory, since it would not have been possible to check again the classification obtained in the field.

## 3. THE TRAINING COURSE

### 3.1 ORGANISATION

The training course on remote sensing was held in the LATICAL laboratory at the ORSTOM Centre, Noumea, New Caledonia from 22 to 27 July 1990, under the sponsorship of FAO RAS/86/036 SPFDP which organised the course with the technical cooperation of ORSTOM Mission Port Vila and ORSTOM Centre Noumea.

The course was originally directed at staff of Forestry and other Departments of Fiji, Solomon Islands and Vanuatu. Five participants from two countries, Solomon Islands (2) and Vanuatu (3), attended the course (see Annex 1). The Fiji Forestry Department declined to send any participants since their remote sensing staff was scheduled to attend a RS course in Japan in October 1990 under the sponsorship of the Japan International Corporation Agency (JICA). The FAO Project sponsored four participants (two each from Vanuatu and Solomon Islands).

The theme of the course was on satellite image treatment and visual interpretation for forestry and land use mapping. The work was done on two SPOT satellite scenes. The objective of the course was to introduce to the participants the capabilities of satellite imagery treatment and classification, to develop techniques and skill in visual interpretation of satellite imagery and to help produce a land-use map.

Mr. William Bour, Head of LATICAL Noumea served as the principal resource person for the training. He supervised all the lecture and laboratory sessions. All the LATICAL staff (Messrs. D. Lille, F. Albert, P. Nosmas) and Mr. G. David from ORSTOM Port Vila provided lectures.

## 3.2 PROGRAMME

The programme consisted of lectures, classroom work, laboratory work and a field demonstration trip (see Annex 2). The schedule was spread over 5 working days (Monday 23 to Friday 27). The distribution of the different activities was:

| | | |
|---|---|---|
| Lectures | 1.5 days | 30% of total time |
| Practical work | 2.5 days | 50% of total time |
| Field demonstration | 1 day | 20% of total time |
| Total | 5 days | |

Fourteen lectures covered :

* basic principles of RS technologies and the existing diversity of satellites and sensors;
* spectral signature, digital image analysis and automatic classification;
* ecology, geomorphology and climatology for visual interpretation and mapping.

The practical work in the laboratory and in the classroom was dedicated to the image computer classification and to the drawing of the land-use map. The SPOT image for Vanuatu was provided by ORSTOM while the FAO Project purchased the SPOT image for Solomon Islands (since none was available in the ORSTOM library).

## 3.3 REGISTRATION

Arrival of the participants on Sunday 22 July.
After the registration in ORSTOM, a leisure trip was organised in the afternoon to Koghi Mountain, a recreational reserve close to the city, where the participants had the opportunity to familiarise themselves with the New Caledonian natural environment.

## 3.4 OPENING SESSION

The training course was formally opened by Dr. Jean Fages, Director of ORSTOM Centre Noumea, Mr. Tang Hon Tat, FAO RAS/86/036 Project Coordinator and Mr. William Bour, Head of LATICAL Noumea.

Dr. Fages welcomed the participants and the coordinators and thanked FAO for sponsoring the course. He briefly described the role and the activities of ORSTOM and LATICAL and underlined that this was the first RS seminar ever held in Noumea. He informed of the forthcoming International Workshop "Pix-îles 90", 19-24 November 1990 in Noumea, organised by ORSTOM and IFREMER and invited the participants to attend the meeting.

Thanking ORSTOM Noumea and Port Vila, Mr. Tang indicated the importance of RS in forestry. The high-resolution SPOT imagery is now permitting the compilation of inventories and land-use surveys, especially for those countries that cannot afford to have updated aerial photographs. He pointed out that there are only two foresters among the participants, reflecting an integrated approach to land-use and planning.

Mr. William Bour described the history of LATICAL Image Treatment Laboratory and briefly introduced the staff, the equipment and the activities carried out. He outlined the structure of the course and its objectives.

## 3.5 LECTURE AND LABORATORY SESSIONS

This section briefly summarises the topics covered during the daily sessions.The classroom was equipped with slide projector and white board for lectures and drawing tables where people could work on their maps. The image treatment laboratory facilities are described in Annex 3.

Monday 23 July:

- **Opening session.**
- **Introduction to the principles of Remote Sensing** and description of the different satellite systems and scanners, with particular emphasis on LandSat, SPOT 1 and SPOT 2. Description of the production of electromagnetic radiation (EMR).
- **Overview of SPOT satellite.**
- **Lecture on digital image analysis and processing.**
- **Lecture in visual interpretation and mapping units**, related to the Melanesian environment.

**Laboratory session.** The afternoon was dedicated to work on the two scenes for Solomon Islands and Vanuatu. After a demonstration on the enhancement of the raw picture, a print-out on VERSATEC was distributed to the participants for a first definition of landscape units by visual interpretation.

Tuesday 24 July:

- **Lecture on image geometric correction.** Intrinsic errors of the satellite, extrinsic errors, correction methods, SPOT products in respect of the level of correction performed.
- **Lecture on image colouring in Remote Sensing.** Definition of colour, systems of repre-sentation of colours, decomposition, codes for computer, yellow-magenta-cyan (YMC) system, additive synthesis and subtractive analysis, transfer functions, look-up table (LUT).
- **Lecture on spectral signature of vegetation.** What it is, response of vegetation, parameters, vegetation index, bi-dimensional histogram.
- **Forestry and land-use in Southern New Caledonia. Lecture** on an ongoing remote sensing project carried out by LATICAL for the New Caledonia Territory Administration. Digital Elevation Model (DEM) image registration, vegetation types, field checks, statistical analysis. The lecture served as an introduction to the field demonstration.

**Laboratory session.** During the afternoon in the laboratory, starting of the supervised classification. Study of the bi-dimensional histogram and modification with the mouse of the computer. The participants elaborated the images on the screen, according to their field knowledge, to improve the capacity of identification and to enable the successive automatic classification.

Wednesday 25 July:

A cluster of **lectures** on geography and ecology on the Melanesian Islands environment applied to the visual interpretation in RS.

- **Climate as a main factor for vegetation, erosion and modification of the landscape.**
- **Energy flow and water cycle.**
- **Geomorphology and pedology as environmental factors for vegetation mapping.**Geomorphological units, drainage lines, rock weathering, transportation processes and flows.

**Laboratory session.** In the afternoon, introduction to the automatic classification of the image. After the inputs from the participants, the image was reprocessed. Output of this statistical procedure was a tentative classification, to be later checked in the as a post-course activity. Improvement of the units defined and description of the interpretation.

Thursday 26 July:

**Demonstration field trip to Yaté Road area.** It was a practical demonstration to the trainees on how ground-truthing is done. LATICAL had an order from the Southern Province of New Caledonia, to perform a land use/suitability analysis for crop and reforestation planning in the dry wildlands of the southern part of the Territory. The analysis on SPOT image gave a vegetation type and cover map. Then, through the digitising of the topographic map contour lines, a slope and aspect model was performed, and then a tridimensional Digital Elevation Model (DEM) showing a landscape vision of the environment.

The collective field trip helped to finalise the vegetation map, through detection of reliable "training zones" and automatic classification of the image back in the laboratory. The training zones previously defined were checked in the field with the vegetation index map and the last automatic classification performed. To exactly know the position, a geostationary satellite positioning device (GPS) was used.

Friday 27 July:

**Laboratory session.** End of the land-use mapping exercise in the classroom. Definition and description of the units. Key of interpretation according to technical characters, units and elements, colouring, shape, etc.

- **Lecture on strategic planning for operational RS projects.** Definition of the thematics and needs, job strategy, accuracy, planning the work, RS processing, final products, costs, statistics.
- **Lecture in relief mapping.** Introduction to the Digital Elevation Model, how to use it.
- **Final overview on application of satellite data,** with special emphasis on the South Pacific and ORSTOM research in the region.
- **Closing ceremony.**

### 3.6 CLOSING OF THE TRAINING COURSE

The training course was officially closed at 16.00 on Friday, 27 July 1990 in the ORSTOM Centre Noumea by Dr. Jean Fages, Director of ORSTOM Centre and Mr. William Bour, Head of LATICAL. The five participants, the LATICAL staff, Mr. G.David from ORSTOM Port Vila and Mr. P.Tranquillini on behalf of the FAO South Pacific Forestry Development Programme attended the farewell ceremony hosted by Mr. M. Fromaget, ORSTOM Information Officer.

## 4. SECOND PHASE - POST-COURSE ACTIVITIES

One of the objectives of the training course was to conduct a land-use mapping exercise and a field check supervised by FAO and ORSTOM coordinators in both of the countries. The two coordinators prepared a short guide to help the trainees to complete the visual interpretation of their Spot image (Annex 4). The guide was sent to each trainee in the beginning of August.

The field programmes were carried out from 20 to 24 August 1990 in North Efate, Vanuatu and from 25 August to 2 September in Guadalcanal, Solomon Islands. A report was submitted by the participants upon completion of their exercises.

## 5. RECOMMENDATIONS

During the last session of the course, a questionnaire (see Annex 4) was distributed among the participants, with the aim to collect some background information from them and their evaluation of the workshop. The general comments were very positive, and all the participants felt the course had enhanced their professional knowledge. Through the analysis of all the answers (see Annex 5) and also through discussions with the participants, the following main points emerged:

*1. One week was too short for the broad scope of themes discussed in the lessons.*

*2. More time should have been devoted to the computer work.*

*3. Advance information, e.g.*

- *agenda of the course sent out before the course, to enable participants to prepare themselves;*
- *outlines of the lectures, to help people follow the subjects more effectively;*
- *instructions and handouts for the laboratory work.*

*4. Need for a follow-up after the completion of the course, in form of a field exercise.*

*5. More information on RS courses, publications, notes, etc. from FAO to the countries.*

*6.. Implementation of national sub-programmes and exercises in RS for the South Pacific countries.*

APPENDIX 1.

# PARTICIPANTS AND RESOURCE PEOPLE

## Participants

| SOLOMON ISLANDS | Address |
| --- | --- |
| Mr. Ed Edrei Dolaiano<br>Principal Forestry Officer<br>Forestry Division | Ministry of Natural Resources<br>P.O. Box G 24<br>Honiara, Solomon Islands |
| Mr. Fuata Isimeli Mosese<br>Senior Surveyor<br>Photogrammetry Section<br>Survey and Mapping Division | Ministry of Agriculture and Lands<br>P.O. Box G 13<br>Honiara, Solomon Islands |

**VANUATU**

| | |
| --- | --- |
| Mr. Aru Joel Mathias<br>Forest Utilisation Officer<br>Department of Forestry | Department of Forestry<br>Private Mail Bag 064<br>Port Vila, Vanuatu |
| Mr. Mackenzie Vagaha<br>Root Crops Officer<br>Department of Agriculture,<br>Livestock and Horticulture | Department of Agriculture,<br>Livestock and Horticulture<br>Private Mail Bag 004<br>Santo, Vanuatu |
| Mr. Pierre-François Calame (*)<br>Junior Agronomist, agronomy section<br>Department of Agriculture,<br>Livestock and Horticulture | Department of Agriculture,<br>Livestock and Horticulture<br>Tagabe station<br>Private Mail Bag<br>Port Vila, Vanuatu |

(*) not funded by FAO RAS/86/036 SPFDP

## Resource Persons

| | |
| --- | --- |
| Mr. Frédéric Albert<br>Computer Engineer<br>Image Processing Specialist | LATICAL<br>ORSTOM Centre<br>B.P. A 5 Noumea CEDEX<br>Nouvelle-Calédonie |
| Mr. William Bour<br>Head of LATICAL | LATICAL<br>ORSTOM Centre<br>B.P. A 5 Noumea CEDEX<br>Nouvelle-Calédonie |

Mr. Gilbert David
Geographer
ORSTOM Coordinator

ORSTOM Mission de Port-Vila
B.P. 076
Port Vila, Vanuatu

Mr. Didier Lille
Computer Engineer
RS Specialist

LATICAL
ORSTOM Centre
B.P. A 5 Noumea CEDEX
Nouvelle-Calédonie

Mr. Patrick Nosmas
Computer Engineer

LATICAL
ORSTOM Centre
B.P. A 5 Noumea CEDEX
Nouvelle-Calédonie

Mr. Paolo Tranquillini
Associate Professional Officer
FAO Coordinator

FAO South Pacific Forestry
Development Programme
Private Mail Bag 010
Port Vila, Vanuatu

APPENDIX 2.

## REMOTE SENSING TRAINING COURSE
## AGENDA

ORSTOM - LATICAL
NOUMEA, NEW CALEDONIA
(22-27 JULY 1990)

SUNDAY 22

| | |
|---|---|
| 08:30 | Registration of participants: Tontouta Airport |
| 09:00 | Transit to ORSTOM |
| 11:00 - 17:00 | Field trip: KOGHI Mountain |

MONDAY 23

| | |
|---|---|
| 08:00 - 08:30 | Opening Session<br>Welcome address by Dr. J. Fages, Director of ORSTOM<br>Message by Mr. TANG HON TAT |
| 08:30 - 09:00 | Presentation of LATICAL and Training Courses objectives:<br>**W. BOUR** |
| 09:00 - 09:30 | TEA BREAK |
| 09:30 - 10:00 | Principles of remote sensing :<br>**D. LILLE** |
| 10:00 - 10:30 | The SPOT satellite system, an overview :<br>**D. LILLE** |
| 10:30 - 11:00 | Introduction to image processing:<br>**F. ALBERT** |
| 11:00 - 11:30 | Elements of satellite imagery, visual interpretation and mapping<br>**G. DAVID** |
| 11:30 - 12:00 | Discussion |
| 12:00 - 14:00 | FREE TIME FOR LUNCH |
| 14:00 - 17:00 | Practical work.Visual interpretation of VERSATEC prints from SOLOMON Islands and VANUATU.<br>* CCT data reading,<br>* Enhancement of the images,<br>* Printing,<br>* Visual interpretation: definition of landscape units. |

TUESDAY 24

| | |
|---|---|
| 08:00 - 08:30 | Geometric corrections:<br>**F. ALBERT** |
| 08:30 - 09:00 | The colour in remote sensing:<br>**D. LILLE** |
| 09:00 - 09:30 | TEA BREAK |

| | |
|---|---|
| 09:30 - 10:00 | Spectral signatures of vegetation :<br>**P. NOSMAS** |
| 10:00 - 10:30 | Remote sensing application: Forestry and land use in the South of New Caledonia:<br>**P. NOSMAS** |
| 10:30 - 12:00 | Practical work Visual interpretation (continued), Visual interpretation Identification of training sets. |
| 12:00 - 14:00 | FREE TIME FOR LUNCH |
| 14:00 - 17:00 | Practical work Supervised classification: initiation |

WEDNESDAY 25

| | |
|---|---|
| 08:00 - 08:30 | Environmental factors relevant to vegetation mapping,geomorphology and pedology:<br>**G. DAVID** |
| 08:30 - 09:00 | Climate and vegetation in Melanesia:<br>**G. DAVID** |
| 09:00 - 09:30 | Energy flow and material cycles in tropical forests:<br>**G. DAVID** |
| 09:30 - 10:00 | TEA BREAK |
| 10:00 - 12:00<br>and<br>14:00 - 17:00 | Practical work:<br>supervised classification on Efate<br>and on Guadalcanal images. |

THURSDAY 27

| | |
|---|---|
| 09:00 - 17:00 | Field trip: Yate Road, introduction to ground truthing |

FRIDAY 27

| | |
|---|---|
| 08:00 - 09:30 | Practical work: Preparation of thematic maps |
| 09:30 - 10:00 | TEA BREAK |
| 10:00 - 12:00 | Preparation of thematic maps (continued) |
| 12:00 - 14:00 | FREE TIME FOR LUNCH |
| 14:00 - 14:30 | Assessing a remote sensing project:<br>**F. ALBERT** |
| 14:30 - 15:00 | Relief mapping: Digital Elevation Model:<br>**D. LILLE** |
| 15:00 - 15:30 | Applications of satellite data for land and sea surveys, an overview: **W. BOUR** |
| 15:30 - 16:00 | Closing ceremony |
| 16:00 - 18:00 | F A R E W E L L   C O C K T A I L |

APPENDIX 3.

## L.A.T.I.C.A.L

Caledonian Image Treatment Laboratory
(Laboratoire de Traitement d'Image Calédonien)

The LATICAL Image Treatment Laboratory was set up 2 years ago, within the premises of ORSTOM Centre.

The staff of the laboratory is: the Head, Mr. Bour, fisheries biologist, plus 3 computer engineers.

The equipment is:

- a SUN 3/160C Computer Station, 3 terminals, 500Mb hard-disk
- an ISIS Monitor, high resolution (3,000x3,000 pixel)
- a TEKTRONICS 4696 Colour Printer
- a VERSATEC Printer, A0 posters capability, electrostatic 4-colour printer
- a BENSON 6361 Digitiser
- an AKAI Optic Disk Reader

The total cost of the equipment is about 1,000,000 F Francs (180,000 US$).

LATICAL has been working in close contact with the ORSTOM research units and with the New Caledonia Territory Administration. The main fields of activity are reef productivity studies and vegetation mapping.

APPENDIX 4.

# NOTES FOR THE FIELD-CHECKS AND FOR THE PREPARATION OF THE REPORT

**WHEN** The field-checks will be held in:

| | | | |
|---|---|---|---|
| VANUATU | 20 - 24 | August | Gilbert, Paolo |
| SOLOMON ISLANDS | 27 - 30 | August | Gilbert |

**WHAT TO DO** Before that date, you should:

- **finish** the general visual interpretation of the maps.
- **focus** on some aspects of your field of work (gardens, coconut intercropping, forest types, geomorphological features, etc.) to be verified on the ground and then considered in your report.

## STEP ONE: FINISH THE VISUAL INTERPRETATION

A. Go more in **detail** with the differentiation, if possible.
B. Give a **number** to every type of unit.
C. Description of the **colour** and **texture** of every area:
Colour: hue, tone, brightness.
Texture: size, shape, granularity, linearity, order, contrast.
D. Give an **interpretation** of what you think it is (forest, coconuts, pastures, etc.) You can get help from the existing maps (topo, land-use, vegetation, soil maps, etc.) and from the air-photos.

Follow the attached Table 1 as an example. Try to prepare a similar one.

## STEP TWO: DRAW THE UNITS ON TRACING PAPER

A. **Overlay** the tracing paper report to your interpretation and draw the boundaries (using **black** pencil).
B. **Colour** every type of unit corresponding to a number.

## STEP THREE: AUTOMATIC CLASSIFICATION MAP

A. First write a **list** of "what you **expect** to distinguish from the automatic classification. This is a tentative list and it will help you to check if really the image gives you all the information that you wish to get.
B. You should **focus on your field of work** (agriculture, survey, forestry) and prepare a detailed list of features that it would be interesting for you to identify.

This list will be the basis for the field-check. As an example, see Table 2.

Table I

TENTATIVE VEGETATIVE AND LAND USE SCHEME

Prepared for visual analysis of Landsat-MSS color composite imagery at scale 1: 250 000 in Papua New Guinea

| CLASSIFICATION LEVEL | | |
|---|---|---|
| 1 | 2 | 3 |
| 1. URBAN LAND | . City/towns<br>. Transporation<br>. Open Mining | |
| 2. AGRICULTURAL LAND | . Permanent<br><br><br><br><br><br>. Arable land | . Coffee<br>. Coconut<br>. Oil Palm<br>. Rubber<br>. Sugar Cane<br>. Tea |
| 3. GRASSLAND | . Dry<br><br>. Inundated | . Burnt<br>. Unburnt |
| 4. FOREST LAND | . Montane<br><br><br>. Mixed<br>. Monsoon<br>. Swamp<br>. Mangrove<br>. Predominantly sago palms<br>. Plantations | . Lower montane (400-1500 m)<br>. Mid nontane (1500-2700 m)<br>. Upper montane (over 2700 m)<br><br><br><br><br><br><br>. Softwoods<br>. Hardwoods |
| 5. IDLE LAND | . Rock outcrops<br>. Sand dunes<br>. Land slides | |
| 6. WATER BODIES | . Lakes<br>. Rivers/Streams | |

It is of utmost importance that very good base maps be used for easier identification and location of natural features and built-up areas. Preferably the scale should be the same as the imagery being interpreted. The above classes are subject to changes when verified in the field and also when the study is expanded over the whole country.

Source: ESCAP/UNDP Report of the training course on remote sensing applications in vegetation and land use classification and mapping (RAS/81/034) Port Moresby, Papua New Guinea, 8-16 Dec. 1986. 100pp.

Table 2

SUMMARY OF IDENTIFYING FEATURES BY CATEGORY

As seen on Landsat MSS color composite scale 1 : 250 000

| CATEGORY | COLOR | TEXTUR | OTHER FEATURES USED IN IDENTIFICATION |
|---|---|---|---|
| 1. Urban land - Cities/Towns | Whitish blue | Coarse | Having a brighter colour. Man made activities |
| - Transportation | White | Coarse | such as roads/airports discernable. |
| - Airports | White | Fine | Usually narrow white strip. |
| 2. Agriculture 1. Arable land | Mixture of Red/Yello | Very rough | Dotted spots of red/yellow/blue showing cultivation |
| 2. Permanent crops | Dark red, Light red | Fine | and different stages, Rectangular shape, patterns distinct. |
| 3. Grassland | Whitish/Yellow | Smooth | Fine texture with absence of shadows. Color changes to greenish blue when burnt. Inundated grassland is light bluish |
| 3.1 Alpine grassland | Bluish white | Coarse | Easily identified on tops of mountains |
| 4. Forests: | | | |
| - Mixed Lowland Rain Forest | Pink | Smooth | Usually near the coastland and on flat lands |
| - Montane | Red/Brown | Rough | Colour changes from red to dark brown and ultimately to Alpine grassland as the altitude increases |
| - Mangrove | Dark red | Smooth | Usually found in estuaries and around natural lakes |
| - Swamp | Light red | Rough | Mainly located in the lowlands - Mixture of Harbaceous. Palms and Degraded forests causing |
| - Forest Plantation | Dark red | Fine | Squarish patterns-in contrast to vegetation surrounding it. |
| 5. Idle land | | | |
| 6. Water bodies - Lakes | Dark blue | Fine | usually having sharp boudnaries. Colour changes |
| - Rivers | Light blue | Fine | to white due to sediments. Rivers - Irregular narrow blue strip |

Note: The color depicted here are just average of the five imageries that was interpreted.
There are stark contrasts between the imageries.

Source: ESCAP/UNDP Report of the training course on remote sensing applications in vegetation and land use classification and mapping (RAS/81/034) Port Moresby, Papua New Guinea, 8-16 Dec. 1986. 100 pp.

## STEP FOUR: COMPARE VISUAL AND AUTOMATIC CLASSIFICATIONS

A. **Overlay** the tracing paper obtained from the visual classification to the automatic classification map. You will note some zones with more detailed information, and some others not so different from your visual map.

B. **Demarcate** the zones in which there is much difference. **Contour** them in **red** pencil.

The first day of the field-checking programme will be spent in the office, for:

- analysis of the **differences** between the two maps. This will enable us to optimise the location of the field-checks.

- discussion and planning on the **different perspectives** in the field work. According to his interest, every participant should consider some particular aspects in the area, like the distinction between various crops or forest types or ages or densities and so on.

The information collected in the field will support the specific analysis that will be the most interesting and important part of the country report.

An outline for the country-reports is the following:

1. INTRODUCTION
2. OBJECTIVES
3. DESCRIPTION OF THE TRAINING IN NOUMEA
4. MATERIALS USED
5. DESCRIPTION OF THE FIELD WORK
6. LAND-USE ANALYSIS AND MAP
7. DESCRIPTION OF THE FIELD WORK
8. FOREST ANALYSIS
   - Goals
   - Findings
9. AGRICULTURE ANALYSIS
   - Goals
   - Findings
10. LAND SURVEY AND MAPPING
    - Goals
    - Findings
11. CONCLUSIONS AND FUTURE ANALYSIS
12. NOTES ON APPLICATION OF THE SATELLITE DETECTION IN THE COUNTRY
13. REFERENCES

APPENDIX 5. EVALUATION OF THE COURSE

## 1. PREVIOUS TRAINING AND EXPERIENCE IN REMOTE SENSING

Two participants attended formal courses in aerial photo-interpretation for more than 1 month.
One participant attended a course in AP interpretation of less than one month.
One participant attended a conference in satellite RS, during the Forest Sector Planning Course, sponsored by FAO RAS/86/036 in Port Vila, Vanuatu 3-21 July 1989.

Use of RS sensing in their work

Two trainees use aerial photos regularly.
One sometimes uses both satellite images and aerial photos.
One uses aerial photos sometimes.
One has never used RS images.

*[NOTE: No one had previous practical experience in satellite RS].*

## 2. SELECTION FOR THE PRESENT COURSE

Two participants applied because they were interested in RS applications in their National Forest Inventory Work.
One applied because he was interested in RS for the updating of base topographic maps.
One was interested in RS applications for agricultural farming system studies.
Three were nominated by their Heads of Dept. without application from other staff.
One was selected from applications among interested staff members.
One did not know how he was selected.

Before the course: Three participants felt that there was no more suitable candidate from their Department.
Two of them thought that someone else could have been more suitable.

After the course: Four thought that no one from their Department would have been a more suitable choice for participation.
One thought that someone else could still have been selected.

## 3. EVALUATION OF THE COURSE BY THE PARTICIPANTS

Travel arrangements, accommodation, allowances were rated VERY GOOD by two participants, GOOD by two and SATISFACTORY by one.
Lectures (content, delivery, duration, notes) were rated VERY GOOD by one participant and GOOD by four.

The General comments were:

a) that some outlines of the lectures should have been given to the participants and that the agenda of the course should have been sent out in advance, to enable some background preparation and to bring along some useful material;
b) that the notes should have been in bound cover;
c) that the course should have been arranged over two weeks;
d) that some difficulties in language were encountered and the delivery of some lectures was too fast.

*[NOTE: The language of the course was English, but all the lecturers were French; this may have caused some difficulty in the comprehension and problems with the delivery of lecture notes.]*

Practical work was rated VERY GOOD by two trainees, GOOD by one, SATISFACTORY by two.
The field demonstration was rated VERY GOOD by one, GOOD by three and FAIR by one participant.
Some would have liked more access to computers, and more involvement in the field identification exercise. Instructions and handouts of the laboratory work would have been useful.

## 4. USEFULNESS OF THE COURSE

For their work: Two people rated the course as VERY USEFUL, two of them as USEFUL and one as SATISFACTORY.
The course provided them a chance to learn the basic knowledge of SPOT imagery possibilities for their work.
One suggested to have the course outline before attending.

Personally: Two people rated the course as VERY USEFUL, and the other three as USEFUL.
One appreciated the real application demonstration.
One of them regretted his little familiarity with computers.
*[NOTE: Almost all the participants did not have a great comprehension of computer systems. This might have limited their full involvement in the laboratory work].*

Cost effectiveness:
*[NOTE: "....of the course". The question, as formulated, as not clear, and the two participants who remarked, gave instead comments on the cost effectiveness of satellite imageries applications]*

"Difficult to make meaningful comparison as to whether using SPOT imageries is cheaper and more reliable than aerial photographs. Anything valuable is costly and requires a longer time to achieve. "Very cost effective for small and medium scale maps at present. Probably advanced technology in the near future will meet higher accuracy in order to cater for large scale maps (eg. 1:10,000 to 1:500 scale)".
Everybody agrees that the participants should all be of different disciplines (forestry, agriculture, surveyors, etc.), because "a mixture helps fill gaps".

## 5. FUTURE RS PROGRAMMES IN THE RESPECTIVE COUNTRIES

ESCAP/UNDP Regional Remote Sensing Programme for the Pacific *[NOTE: The RRSP, Suva terminated in June 1990]*.

{SOI} The AIDAB funded Natural Forest Inventory to be carried out will probably include some RS analysis.

{VAN} None at the moment, but further collaboration between the Forestry Department and ORSTOM, Port Vila, in the near future is possible, after this course.

## 6. FINAL COMMENTS AND SUGGESTIONS

There should be a follow-up after the completion of the reports.

FAO could inform on RS courses, publications, notes, etc. There should be more sub-programs, seminars, workshops for the Pacific countries.

{SOL} "We certainly need a RS program in the Solomons. Unfortunately we do not seem to have the resources in terms of finance and technical equipment, as well as manpower."

# PART 2. COUNTRY REPORTS

# COUNTRY REPORT - REPUBLIC OF VANUATU

*by P.F. CALAME, M. VAGAHA*
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*PORT VILA*

## 1. INTRODUCTION

### 1.1 BACKGROUND

Remote sensing in Vanuatu began in the late 1970's and mid 1980's when the black and white aerial photos were flown by the Royal Air Force and the Royal Australian Air Force. The aerial photos were flown at an average scale of 1:30,000 and were mainly used for mapping, land surveys and other minor works. The most recent photos were flown in 1986 with colour photos in some parts of the country. Remote sensing is now rapidly becoming an important tool for development in Vanuatu.

Government Departments responsible for development and control of over the country's natural resources are now using remote sensing methods to measure, record, monitor and control impacts which may have adverse effects on the natural resources. The Forestry Department for example, is now using aerial photos and Geographical Information Systems (GIS) to assist in carrying out its first National Forest Resource Survey (NFRS). The data collected will assist the Department in planning short, medium and long term forest development projects and operational plans.

In addition to aerial photos, satellite images are now being tried in some fields, primarily in resource mapping and assessment. The french organisation ORSTOM (Institut Francais de Recherche Scientifique pour le Developpement en Cooperation) has carried out work on coastal resource assessment and mapping in parts of the country (David, 1989).

As the need for more precise estimates of data and information is required, steps are taken not only in Vanuatu, but also in other Pacific countries to experiment with the available cost effective technologies

### 1.2 OBJECTIVES

The objectives of the study undertaken in Vanuatu were as follows:

a) to evaluate remote sensing methods as a tool for data and information collection, resource assessment and other fields in the development process.
b) to identify different land uses using SPOT images
c) to classify and map the different land uses.

d) to try to differentiate between Agriculture and Forestry land uses based on the colour and texture as displayed on the SPOT images.
e) to determine the potential of SPOT images for future remote sensing work in Vanuatu.

## 2. DESCRIPTION OF THE STUDY AREA

### 2.1 LOCATION

Efate and small satellite islands of Nguna, Pele, Mao, Moso and Lelepa are situated between latitude 17°25' North and 17°50 South, and longitude 168°9' and 168°35'. They belong to the Vanuatu archipelago (Fig. 1) in South West Pacific Ocean and are located in the South Tropical zone.

The satellite image area is situated in North West Efate, including a part of Moso island (Fig. 2, 3).

### 2.2 CLIMATE

The Efate climate is insular Equatorial and characterised by irregular but frequent South-East trade winds. It is most of the time hot and humid in the major part of the island. However, we can distinguish two seasons : one hot, humid and very rainy from November to April-May, another one slightly more fresh, more dry and less rainy from July to October. They seasons appear clearly on the mean monthly rainfall and average monthly temperature charts (Fig. 4, 5).

The feature of Efate (and the "high islands" in general) is irregular patterns of the local climate due to the influence of trade winds and of altitude. The South-East coast (Forari-Rentabao) is more rainy and more humid than the North-West coast. Port-Havannah to Undine Bay is more hot and dry, and at high altitude, on Mount Mac Donald, the rainfall and the humidity are high. So, we can distinguish three climatic zones :

- Low altitude windward zone (≤ 550 m) on the South-East Coast (Forari-Rentabao);
- Low altitude leeward zone (<400 m) on the North-West coast and inland towards Mount Erskine plateau between Port Havannah and Undine Bay. The satellite image area is located in this zone;
- High altitude windward zone (550 to 650 m), South-East sides of Mont Mac Donald;

### 2.3 GEOLOGY

Efate and the small islands north of Efate consist of predominantly volcanic eruptive rocks, coral limestone plateaus and sedimentary terraces. The islands began to form at the end of the Eocene age and were subject to major volcanic activity.
This activity was accompanied by rapid tectonic uplift (≈1m per 1000 years) which gave rise to the gradual emergence of a number of new coral limestone plateaus. Most of the emerged land rose during the Quaternary period.

The form of relief encountered in Efate and Moso was developed in elevated and eroded Miocene and Pliocene volcano sedimentary rocks, with a capping plateau of Quaternary coral limestone. The relief encountered in Nguna, Pele and Mao is typical of young volcanic islands whose cone and eruptive crater shapes are relatively intact.

## 2.4 GEOMORPHOLOGY

We can distinguish on the following geomorphology units Efate, Moso and Lelepa:

- Very eroded volcanic rock (tuff): Mac Donald, Fatmalapa and Quoin Mountains;
- Land-form gently undulated in stratified fine volcanic rock (tuff): above Rentabao-Forari limestone plateaus;
- Limestone plateaus: Rentabao-Forari plateaus;
- Recent dissected plains (graben plains): Teouma, Mele, Tagabe and Marona plains;
- Recent coastal plains : Nguna, Pele and Mao islands of recent volcanic relief form, only slightly eroded.

## 2.5 VEGETATION

Vegetation directly related to the climatic zones described above can be seen. At low altitude, tropical rain forest is on the windward side, and semi-deciduous tropical forest and pyrogenous formations of forest and savanna to the leeward side. At high altitude, the "perhumid" summits are overgrown with a low forest cover, rich in epiphytic plants, known as "nephelophile" plants.

## 2.6 POPULATION

On Efate, most of the population is located in the South (Fig. 6), in the urban area of Port Vila. According to the 1989 census, the population of Vila was 19,400 whereas 11,600 were living in rural zones.

Table 3 gives us an idea of the population and land-use in Efate in comparison with the other islands of Vanuatu in 1980. It appears that only 17.5% of the cultivable area is under cultivation, and the land-use consists mainly of coconuts and pasture, and subsistence crops representing 25%.People from the small islands (Moso, Lelepa, Nguna, Pele, Mao) cultivate gardens on Efate due to the land-pressure on their small islands. The early settlements of missionaries and planters have had a big influence on the current land use patterns and vegetation cover by logging and clearing of forests, by creating grasslands for cattle breeding and by creating coconut plantations.

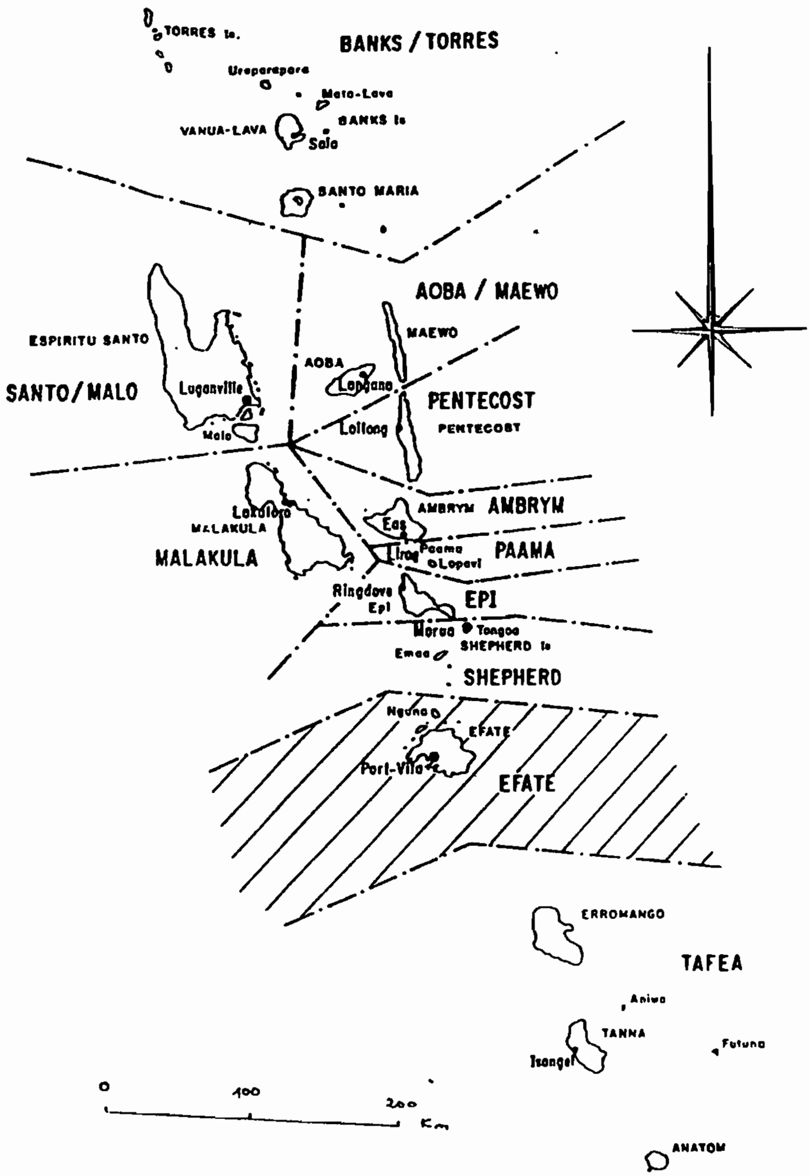



Figure 1. Location of the island Efate in Vanuatu (from Anonym, 1984)

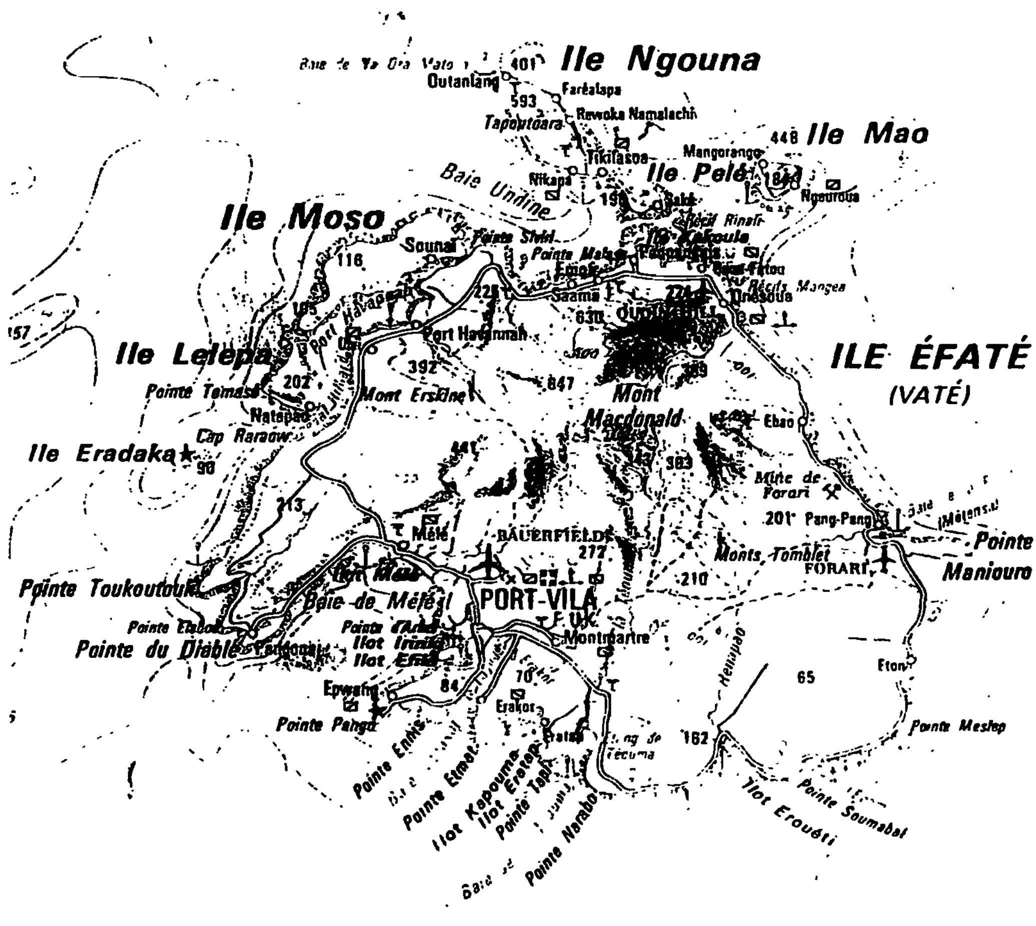



Figure 2. The island Efate, Vanuatu (from 1:50,000 map, I.G.N., 1976))

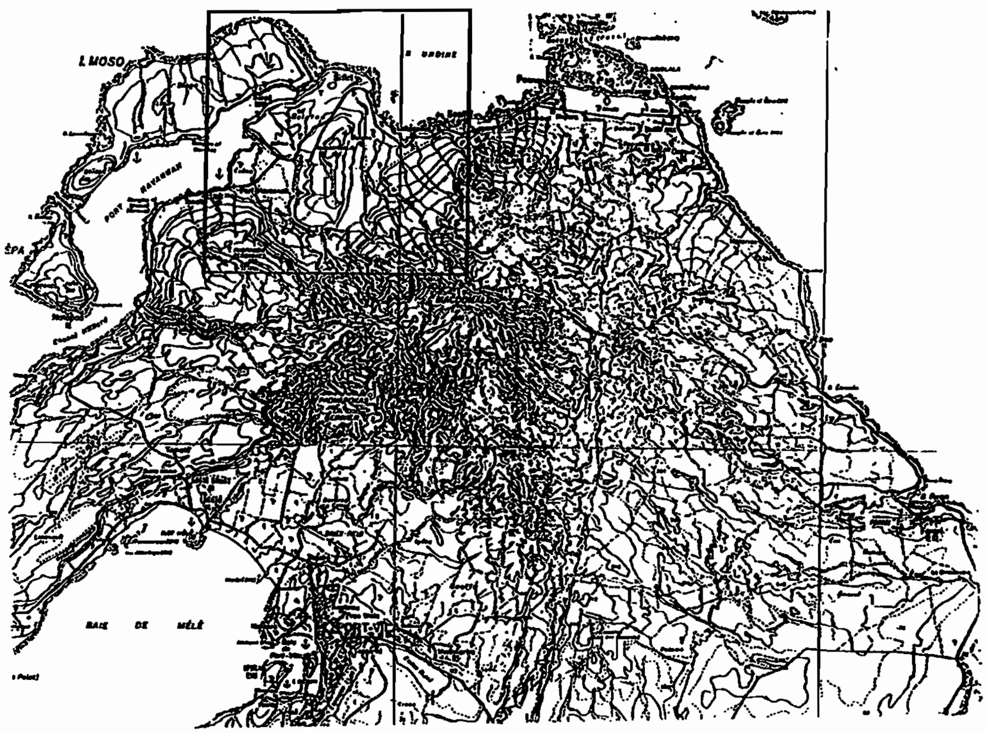



Figure 3. Location of satellite image on Efate (I.G.N., 1979)

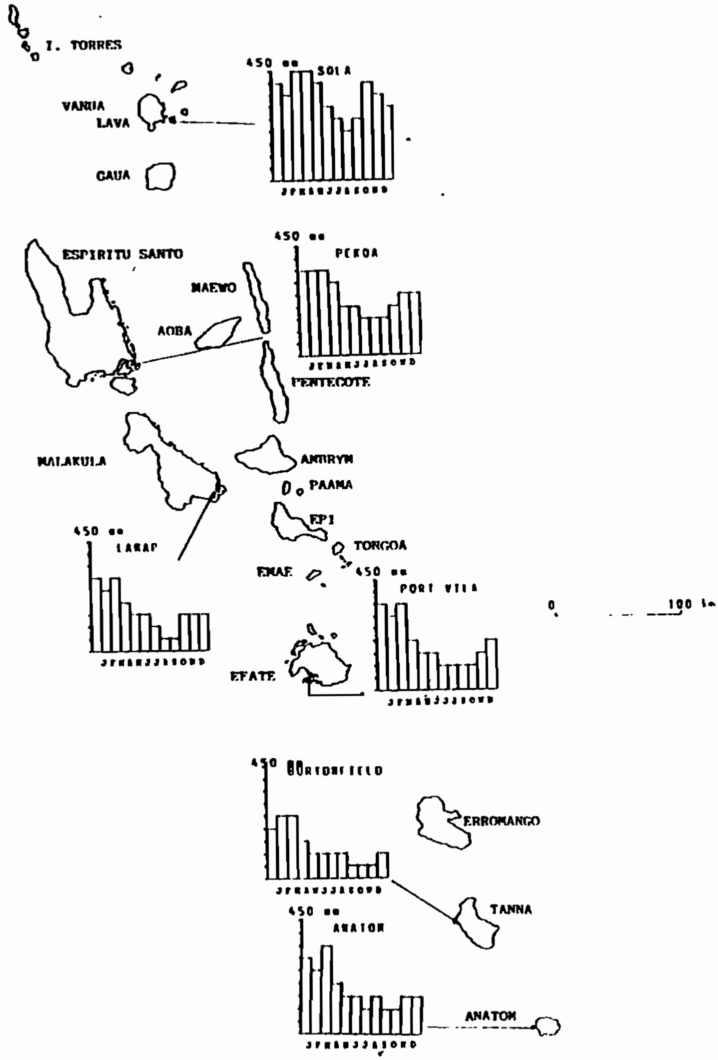



Figure 4. Mean monthly rainfall from 1961 to 1983 (David, 1990)

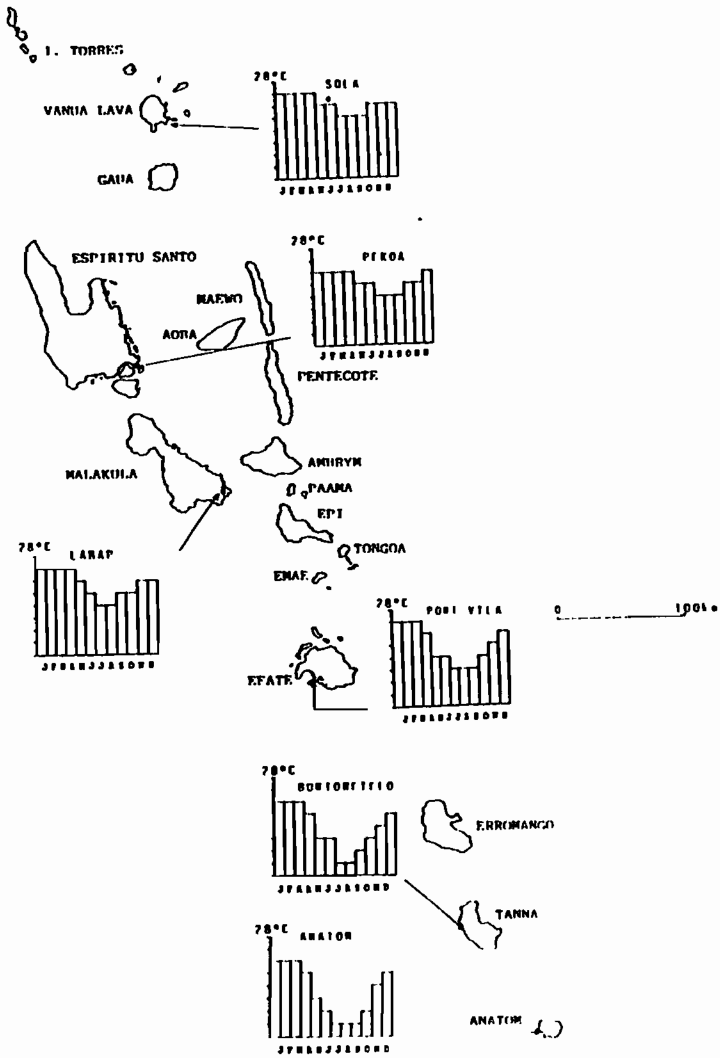



Figure 5. Mean monthly temperature from 1961 to 1983 (David, 1990)

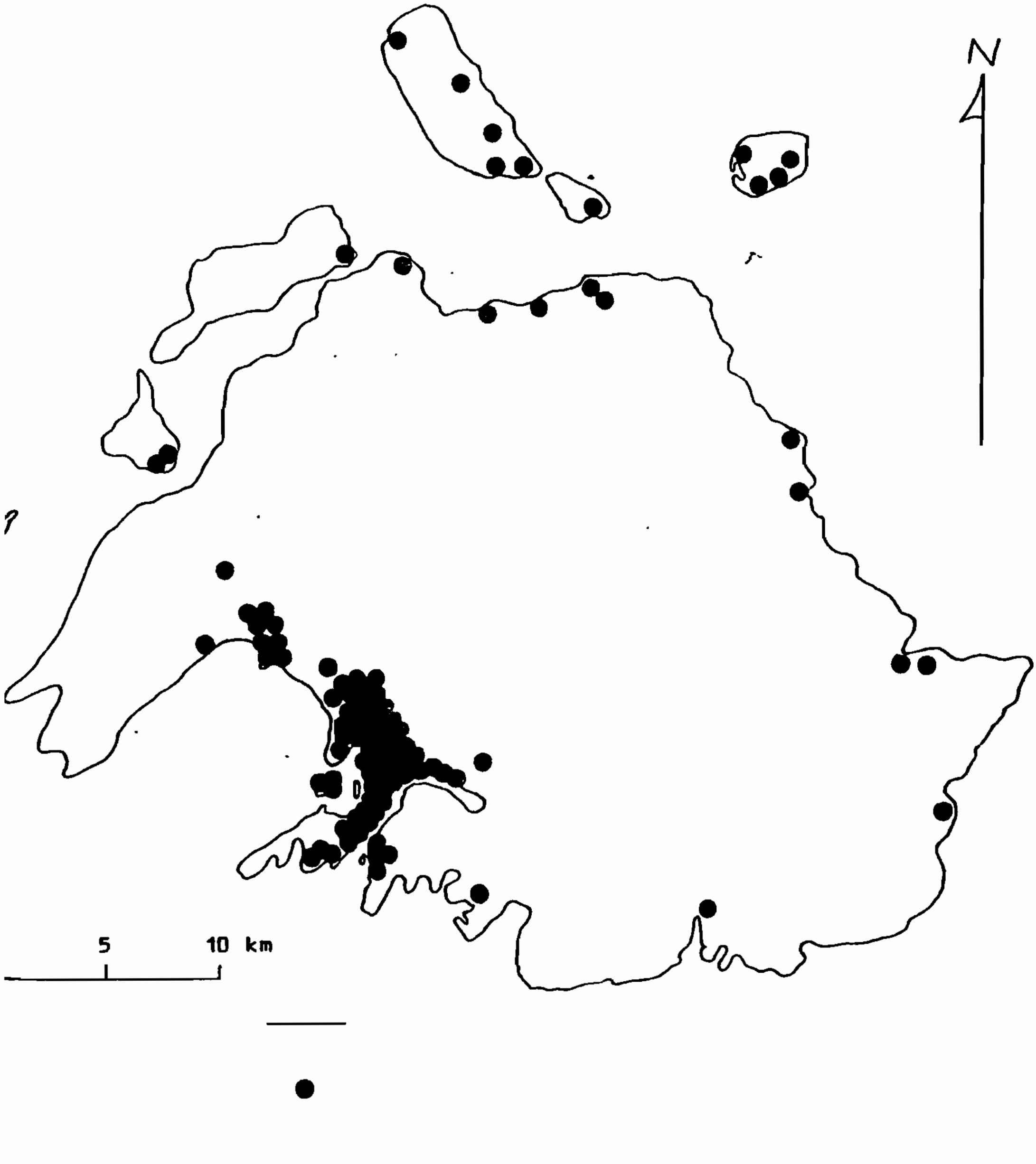



Figure 6. Location of the main population densities on Efate (Anonym, 1984)

Table 3 Population and land use in Vanuatu (Source : Government of Vanuatu National Planning and Statistics Office)

| ISLANDS | Surface km² | | Land use in Km² | | | | Population | |
|---|---|---|---|---|---|---|---|---|
| | Total area | Cultivable area | Area under cultivation | Export crops (1) | Pasture (2) | Subsistence crops (3) | Total | Density per Km² |
| Torres | 121 | 98 | 11 | 5 | – | 6 | 325 | 2 7 |
| W. Banks | 700 | 178 | 72 | 16 | 8 | 52 | 1 971 | 2.8 |
| E. Banks | 61 | 37 | 34 | 9 | 2 | 23 | 2 643 | 43.3 |
| Espiritu Santo | 4 248 | 1 831 | 725 | 175 | 240 | 410 | 18 876 | 4.4 |
| Malakula | 2 053 | 836 | 235 | 80 | 50 | 120 | 15 935 | 7.8 |
| Maewo | 300 | 103 | 20 | 5 | 2 | 13 | 1 771 | 5 7 |
| Pentecost | 499 | 185 | 135 | 65 | 5 | 70 | 9 544 | 19 1 |
| Aoba | 399 | 173 | 150 | 63 | 5 | 87 | 7 820 | 19.6 |
| Ambrym | 666 | 135 | 130 | 39 | 2 | 90 | 6 324 | 9 5 |
| Paama-Lopevi | 60 | 24 | 30 | 23 | – | 10 | 2 354 | 39 2 |
| Epi | 446 | 173 | 88 | 38 | 2 | 50 | 2 672 | 6 0 |
| Shepherd | 86 | 59 | 53 | 36 | 2 | 17 | 4 421 | 51 4 |
| Efate | 923 | 600 | 105 | 60 | 60 | 25 | 20 100 | 21 8 |
| Erromango | 887 | 203 | 10 | 2 | 1 | 7 | 945 | 1 1 |
| Tanna-Aniwa | 569 | 319 | 300 | 45 | 5 | 150 | 16 064 | 28 2 |
| Anatom-Futuna | 171 | 17 | 16 | 6 | – | 10 | 821 | 4.8 |
| Total | 12 189 | 4 971 | 2 114 | 667 | 384 | 1 140 | 112 596 | 9 2 |

(1) Export crops : predominantly coconut, plus a little coffee and cocoa.
(2) Grazing : prairie alone or pasture under coconut.
(3) Subsistence crops : mainly shifting agriculture, and terraced gardens.

## 2.7 SOILS

Very diverse soils are recorded, due partly to intense volcanic activity and tectonic up-lift, and partly to climatic variations. The principal soils occurring are : andosols on recent volcanic ash ; brown soils and immature (weakly developed) erosion soils on the oldest (Mio-pliocene) volcano-sedimentary chains, deeply modified by erosion ; fersiallitic and ferrallitic soils, depending on wind exposure, on little eroded plio- pleistocene formations (sedimentary limestone and volcanic rock) and very humus-rich andosol type soils on the "perhumid" summits. Because of their youth and deposits of volcanic origin, many of these soils are very fertile (Quantin, 1972, 1982a).

Figure 7 shows the agronomic potential from the satellite image area, it appears that most of the area has good - (West side of Mount Erskine, Siviri plateau, Undine Bay valley, Moso) to average - (Marona Valley, Moso and Samoa coast) agronomic potential, while the Port Havannah coast is poor.

## 3. MATERIAL AND METHODS

### 3.1 DESCRIPTION OF THE FIELD WORK

Two field trips were organised :

- before the workshop in New Caledonia (16-17 July) to have an idea of the zones we would work in and to define our objectives and interests ;
- after the seminar (20-24 August) to carry out field-checks of the visual interpretations drawn and the automatic classification map processed at Noumea.

#### 3.1.1 Pre Course field-trip (16-17 July);

All the zones visited during this tour were not located in the area studied at Noumea because the main goal was to find types of land to work on. The land types (landscape and land use types) are outlined in figures 7 or 8.

**16 July**

- Paonangisu : visit to gardens in cleared forest or old coconut plantation (fig. 8). It was already difficult to distinguish them on the aerial photos and we expected that it would be difficult on satellite images.

- Lakenasua (on the study area) : route through Leucaena -, Acacia - and rain forests to identify their features (density, colour, etc.) and their location. It appeared that Leucaena occurs most often on slopes, Acacia on plateaus or gentle slopes, rainforest on slopes or bottom of valleys.

**17 July**

- Teouma : visit along a logging road (in use) in very humid rainforest in order to register changes caused by logging activities (fig. 8).

- Epule : visit along a former logging road in order to register the evolution of the remaining forest. It appears that part of the logged over area is used to create gardens, in the remainder of the area the forest is growing back (plenty of tree seedlings) but the forest is less dense than the original.

#### 3.1.2 Field-checking trip

The field-check was limited to the study area in order to check the conclusions drawn from the visual interpretation and the automatic classification. The zones checked are represented outlined on the figures 9,10,11,12.

**20 August**

Work at Port Vila to finish and compare the visual interpretation maps drawn by participants, and to determine the location of the field-checks.

a) Map

Figure 7. Agronomic potential of area covered by satellite image

*ECOLOGICAL LIMITS*

**Physiographiques** - *Physiographical*

▲ sommet - *peak*

300 m – 1000 m

altitude au-dessus de laquelle l'insolation restreinte limite les aptitudes agricoles pour certaines plantes (cocotier, etc.)
*altitude above which restricted sunshine limits agricultural suitability for certain plants (coconut, palm, etc )*

limite inférieure du climat "montagnard" plus frais (Tm < 20° C) et souvent nuageux et perhumide, limitant très strictement les aptitudes culturales.
*lower limit of cooler "mountain" climate (T 20° C), often cloudy and permanently humid, imposing very severe limitations on land use capabilities*

**Climatiques** - *Climatic*

E Climat "équatorial" régulièrement chaud et humide
*Regularly hot and humid "equatorial" climate*

$E_1$ altitude < 300 m
*$E_1$ altitude < 300 m*

$E_2$ altitude 300 à 800 m
*$E_2$ altitude 300 to 800 m*

T Climat "tropical", régulièrement chaud, à courte saison sèche
*Regularly hot "tropical" climate, with short dry season*

$T_1$ saison sèche > 2 mois (2 à 4 mois)
*$T_1$ dry season > 2 months (2 to 4 months)*

$T_2$ climat de "transition" à saison sèche de 1 à 2 mois
*$T_2$ "transitional" climate with short (1 to 2 months) dry season*

H Climat "perhumide", néphélophile, à ennuagement presque permanent
*Permanently humid, "nephelophile" climate with almost constant cloud cover*

$H_1$ "submontagnard" altitude 500 à 800 m
*$H_1$ "Sub-mountain" altitude 500 to 800 m*

$H_2$ "montagnard" altitude > 800 m
*$H_2$ "mountain" altitude > 800 m*

| | | |
|---|---|---|
| *Optimum* | I | Optimum |
| *Good* | II | Bonne |
| *Average* | III | Moyenne |
| *Mediocre* | IV | Médiocre |
| *Poor* | V | Mauvaise |
| *Very poor* | VI | Très mauvaise |
| *Nil* | VII | Nulle |

b) Legend
Figure 7. Agronomic potential of area covered by satellite image

**21 August**

- Mount Erskine :
  + 1st stop : at the beginning of the 2nd plateau from the road (see fig. 9). The vegetation of Leucaena on slope, Acacia on flat areas, and grassland on plateau confirmed the visual interpretation.
  + 2nd stop : top of Mount Erskine (radio station). It allowed a very wide view of the different types of vegetation around the Mount (see fig. 9). Some areas confirmed the visual interpretation and the automatic classification (Malafao, Meten, Lakenasua and Western Rumakimala plateau, Erskine Northern slopes, and end of Marona river valley) whereas some land use types had not been detected on the satellite image (gardens along Marona river, Havannah Harbour old coconut-tree plantation).
  + 3rd stop : walk on Sentier Bernier until the cliff (see fig. 9). The humid forest on the bottom of the valley confirmed the signature detected on the satellite image.

- Checking of the zones observed from Erskine (see fig. 10).
  + Rumakimala plateau : The zones distinguished on the satellite image, Leucaena on slopes and Acacia on plateau or on gentle slope, confirmed the visual interpretation.
  + Malafao plateau : The zone distinguished on the satellite image, abandoned pastures, confirmed the visual interpretation.
  + Meten plateau : The zones distinguished on the satellite image, Leucaena on top and slope, and dense forest (canoe-tree) at sea level, confirmed the visual interpretation.

**22 August**

- Marona Valley (Havannah Harbour) : Along a former logging road (see fig. 11). Although there was a high density of gardens during the first 2-3 kilometres along the river, it had been difficult to identify them on the satellite image. At the end of the logging road, a very humid rainforest on the bottom of the valley and the acacia on the Erskine slopes confirmed the zones delimited on the maps.

- Undine Bay (fig. 11) :
  + Coconut tree plantation : The swamps, waterlogged areas, well maintained coconut trees and the zones invaded by weeds corresponded to the specific signatures noted on the satellite image.
  + Eastern Rumakimala plateau : As seen from the coconut plantation the vegetation was only acacia forest and confirmed the zone delimited on the maps.

**23 August**

Visit to Moso Island (fig. 12) across a plateau (Leucaena and Acacia) and along a cliff (dense dry forest). The main feature was the aftermath of cyclone Ouma that appeared on the plateau, especially with Leucaena trees wind-felled but still growing.

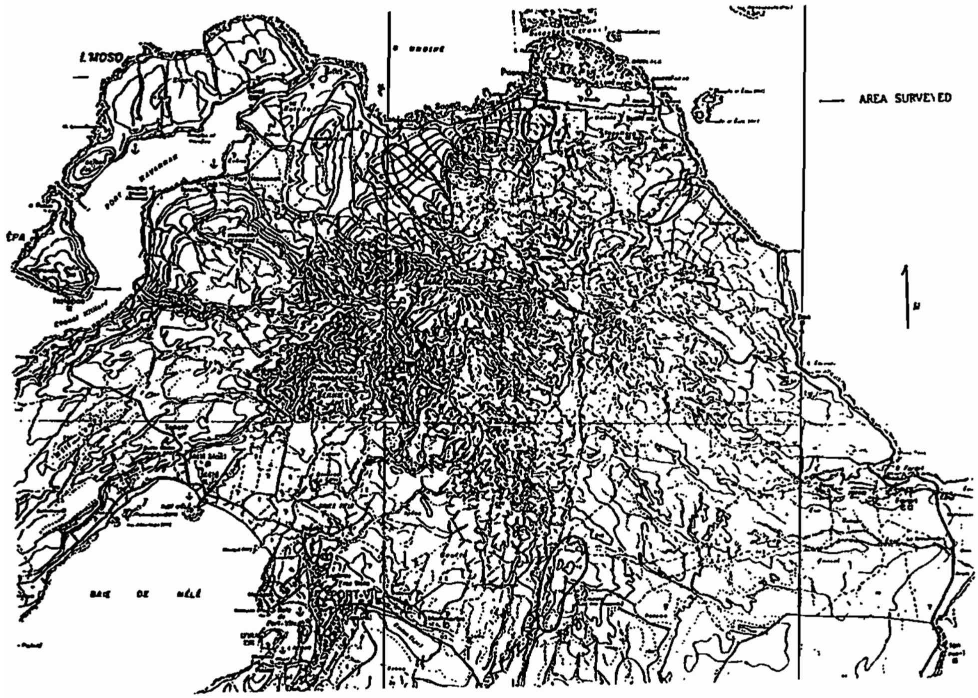



Figure 8. Pre-course field triep (16 - 17 July 1991)

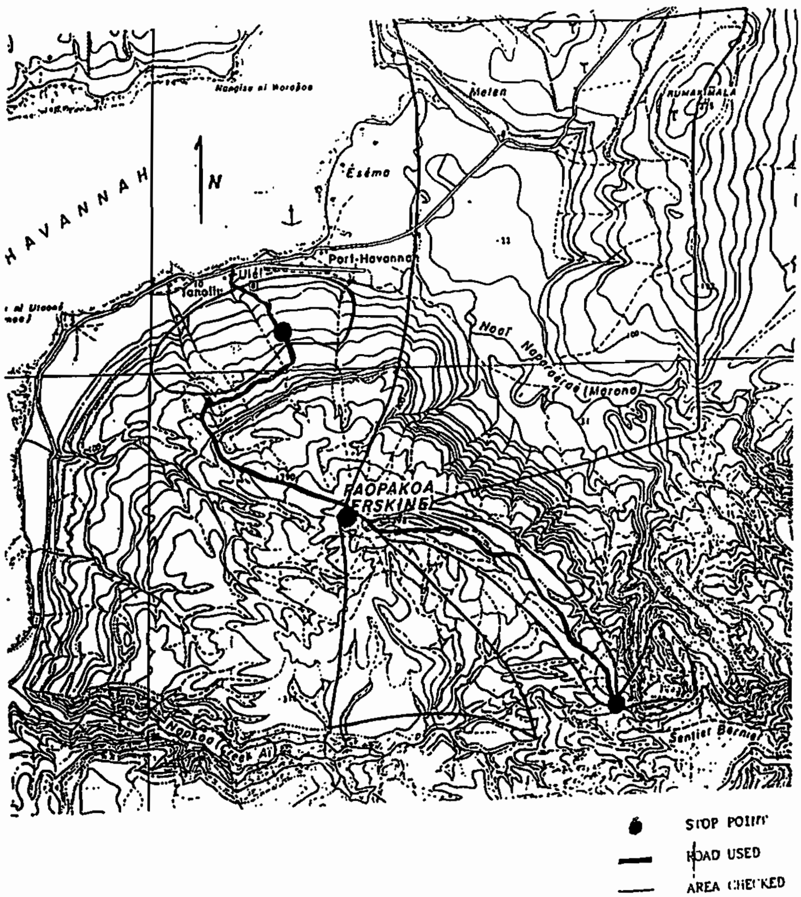



Figure 9. Field check (21 August in the morning)

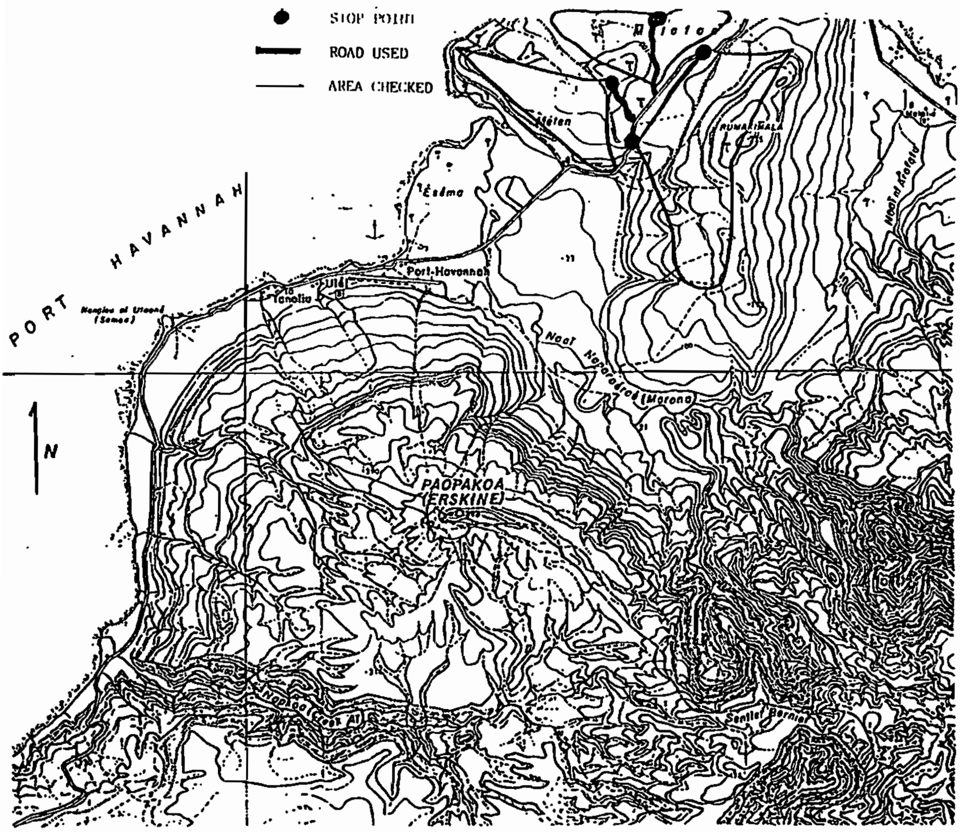



Figure 10. Field check (21 August in the afternoon)

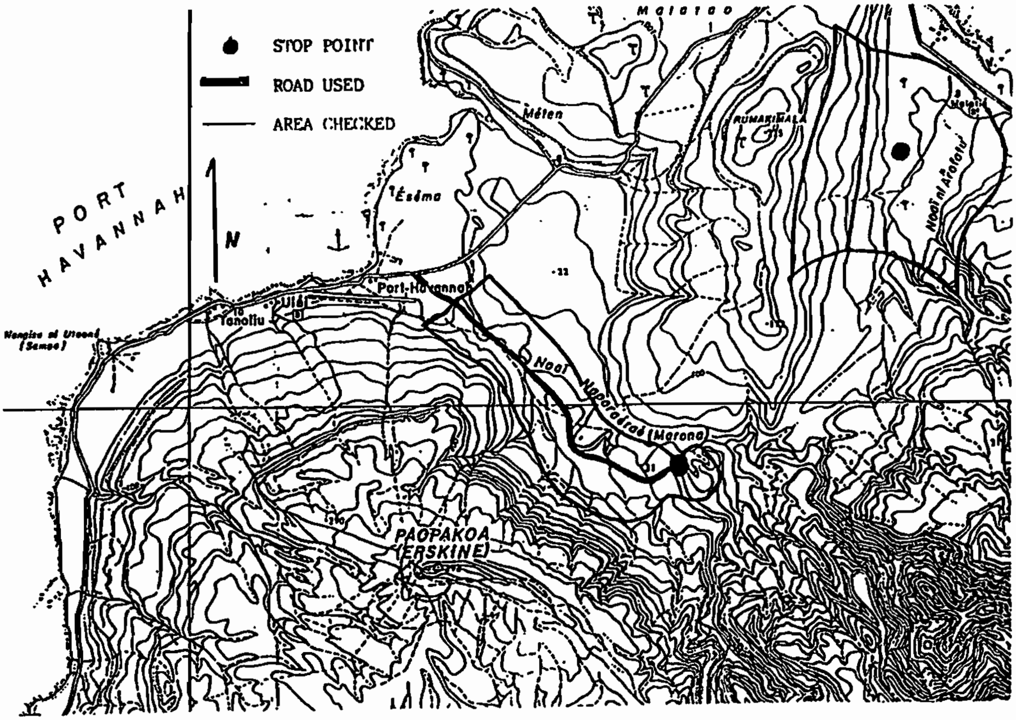



Figure 11. Field check (22 August)

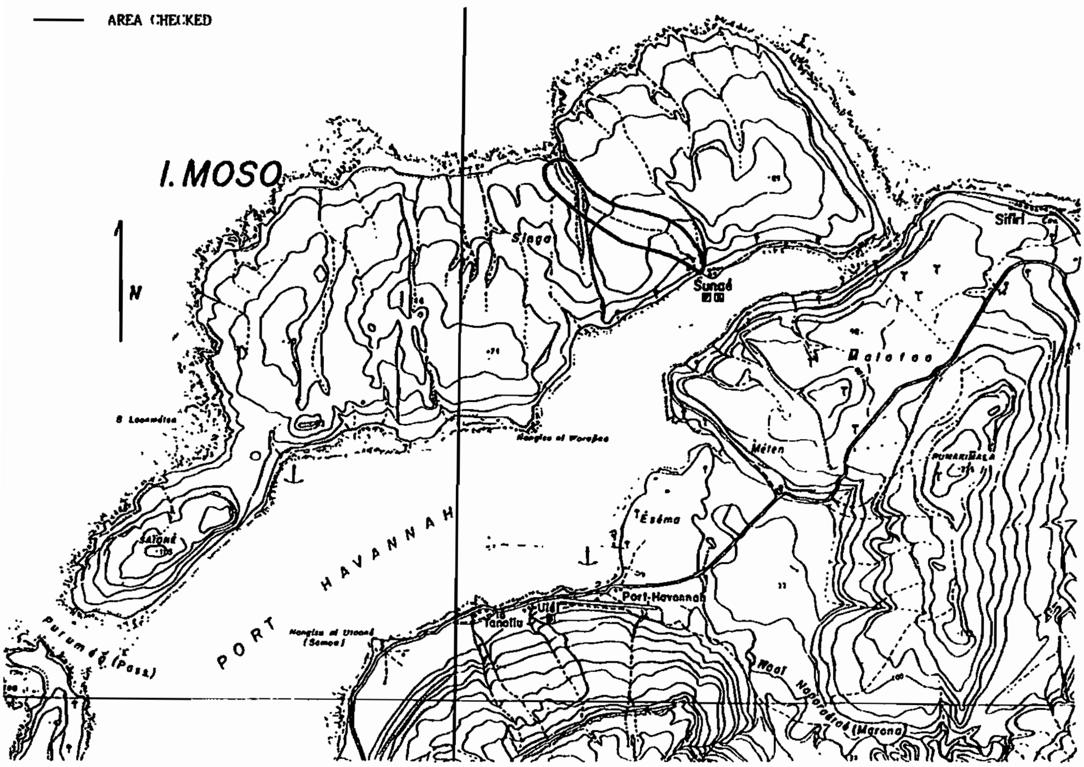



Figure 12. Field check (23 August)

**24 August**

Work at Port Vila to correct the limits of the zones, discuss the findings and the outline for the country-report.

## 3.2. SOURCE MATERIAL AND MAPPING METHOD

### 3.2.1. Source Material

The data used in this study included the following:

- A scene shot at 30th June 1989 in the multi-spectral mode. This system is equipped with three channels known as XS1, XS2 and XS3 which corresponds respectively to green and yellow bands (0.50-0.59um), red bands (0.61-0.68um) and infra red bands (0.79-0.89um). The satellite image was printed at the scale of 1:25,00 (figs. 13, 14).

- An automatic classification of the forest types and land use patterns of the area done by an satellite image processing software developed by LATICAL.

- A satellite image of the vegetation index, which was used for comparison purposes between different images and for the analysis of the main image when doing the visual interpretation. The vegetative index is done as follows;

$$V.I. = \frac{XS3 - XS2}{XS3 + XS2}$$

- A topographical map of the area at the scale of 1:50,000 showing contour lines at 20m intervals, rivers, roads, villages and other features.

- Black and white aerial photos flown by the Royal Australian Air Force in 1985, 1986 and 1987 at the scale of 1:30,000.

- Soil and vegetative maps by P. Quantin (1982)

- Forest typing map of Efate done by Saunders J. (1988), based on aerial photos.

### 3.2.2. Land Use Mapping Method

The visual interpretation mapping method followed during the training course is carried out by the following steps:

a) First identification of the Land use patterns. The land use map is drawn by placing a transparent sheet over the SPOT satellite image and then, based on colour and texture, the land uses are differentiated. Based on the classification results, the boundaries between different land uses are delineated (table 4).

b) Use of the automatic classification printing and the vegetation index image to compare and adjust interpreted results.

c) Select training zones out in the field for ground truthing and re-interpretation of the satellite image.
The interpretation of the SPOT satellite image is done visually assisted by field checks, ground truthing, panchromatic photos taken at the sites and aerial photos. Discussions with local people living around the study are held and recorded for cross checking. The soil, geology and topographical maps of the area are used extensively and in some cases in detail where certain areas are difficult to classify.

d) Viewing of aerial photos to assist in areas where classification of the land use is difficult, e.g on slopes and some agricultural land uses etc., and to check if the vegetation cover or land-use type have changed. Aerial photos are also used in verifying the information obtained both from the field and the satellite image.
Re-interpretation of the satellite image after field checks and viewing of aerial photos where difficulties are encountered to re-adjust or correct. A quick check back in the field to verify information contained in the map.

The land use map is finally re-drawn onto another plain paper which then becomes the final map (at the same scale as the satellite image).

## 4. RESULTS AND DISCUSSION

### 4.1 AGRICULTURE ANALYSIS

#### 4.1.1. Goals

The main objective for the Agronomy section of the Department of Agriculture is to assess the suitability of farming systems (ie. both traditional Melanesian gardens and plantations, mainly coconut plantations ).

#### 4.1.1.1. Traditional gardens

In the interpretation of the Spot satellite image the main points of interests are :

- Location : distance of gardens from the village, relief (along rivers, on slopes on plateaus, etc.) and kind of areas (in cleared forest, along former logging roads, in old plantations, etc.) where gardens are created;

- Distribution of gardens in space in relation to one or several different villages ;

- Area of gardens belonging to one or several villages.

A satellite image should therefore give information on the traditional gardens' organisation in space, the importance of gardens (area, number) throughout a zone or a country, and locate relevant areas for field trips.

Table 4- Summary of Identifying Features by Category

| CATEGORY | COLOR | TEXTURE | OTHER FEATURES USED IN IDENTIFICATION |
|---|---|---|---|
| 1. Urban land<br>-village<br>-roads | Mixture of blue and white | Coarse<br>Coarse | Roads usually narrow whitish-blue strip |
| 2. Agriculture<br>-coconut<br>-garden area | Reddish brown<br>Mixtured of red, pink bluish brown | Coarse<br>Very coarse | Blue spots show bare ground where garden area is cleared of vegetation |
| 3. Grassland | Light blue | Fine | Spots of reddish pink and brown in light blue background |
| 4. Forest<br>-Leucaena<br>-Acacia<br>-Humid valley<br>-Canoe-tree | Purple mixture with brown and red<br>Light brown<br>Mixture of red-brown<br>Dark brown | Coarse<br>Coarse<br>Very rough<br>Rough | Identified on leeward side of island<br>Identified in valley and slopes<br>Identified on plateau |
| 5. Water bodies<br>-swamp | Dark blue | Coarse | |

4.1.1.2. Plantations

The main points of interest are:

- Management : planting density and weed control, location of available lands or suitable areas for extension, etc.;
- Area (total, planted, available for extension, etc.). This information could be used by individual plantation owners but also by the country to assess a specific crop potential (production, area, etc.)

Two maps were produced from the visual interpretation of the SPOT satellite image. The first map covers the Havannah Harbour area and the Marona valley. The land use is mainly subsistence farming and Grassland (fig. 15). The second map covers the Undine Bay coconut tree plantation and the surroundings (fig. 16).

### 4.1.2. Overview of Agricultural Practices and Findings

4.1.2.1. Subsistence farming system

A. *Overview*

In subsistence agriculture, the garden is prepared by clearing away vegetation under forest. The vegetation is then left to dry and later burnt. In the process of clearing, large trees are felled while medium to small trees are left. These trees are killed by burning or ring barking at the base of the stem, and then used for staking yams and/or as firewood.

The first crop to be planted is yams (*Dioscorea spp.*) which is intercropped with maize, watermelon and other vegetables. After harvesting the yams (the crops intercropped with yams are harvested before the vines completely cover the ground), sweet potato (*Ipomoea batatas*) or taro (*Colocasia esculenta*) is planted. The border of the garden is planted with cassava (*Manihot esculenta*), banana and sugar cane.

The garden area boundaries can also be planted with coconuts, fruit trees like "navel" (*Barringtonia spp*), "nangai" (*Canarium indicum*), breadfruit (*Artocarpus communis*), "nandao" (*Pometia pinnata*) and forest trees like "namanau". In areas without land-pressure (i.e low population density), gardens may be planted with coconuts at the end of the planting cycle. Some productive garden areas retained can therefore be isolated in coconut plantations.

Two kinds of gardens can be defined:

- A community garden system where all members of the community, clan or extended family manages individual small gardens side by side. The collective garden can be misinterpreted as one garden. After the gardening of one area, the community then moves to another area.

The extent and number of garden areas available depends on:

* availability of land
* population of the community
* natural boundaries e.g rivers, mountains, swamps,...

- An individual garden system: in this system of gardening, gardens are small and isolated and not grouped as in the communal system. Farmers who practice this system are those that have more land and do not have the labor or the capital to develop it.

  The farmers use their nuclear family or some extended family labour to make gardens or plant coconuts.This type of farmer often follows a linear type of system as shown in the diagram above :

  Virgin Bush --> Garden --> Coconuts with cattle or cocoa.

  The farmer clears virgin bush, makes his garden and after the food crops, he plants coconuts. Later, when the coconuts are big enough, the farmer puts in cattle or intercrops with cocoa. There is no fallow period after gardening because the former garden is converted to a permanent crop.

  This system can only continue to convert virgin forest until a land dispute arises or until the farmer realises he has run short of land.

B. *Findings*

The use of the SPOT satellite image in this study to classify the different traditional landuses had limitations. Most important, there are no clear differences between the spectral signature of the gardens and forest because both virgin forest and developed gardens have a dense cover of green leaves, which appear red on the satellite image. To solve this, different kinds of information and data were combined from the aerial photo, field checks and the satellite image itself. With the data from the three combined it was possible to classify the land uses.

Only a zone with a high density of gardens along the Marona river identified during the field trips gave a specific spectral signature. This means that only this kind of gardening (high density of individual gardens or community gardens can be analysed by satellite images (fig. 15).

We can identify two stages of gardening : Garden as bare ground (cleared forest) and garden after the crops have grown up and the first years of fallow. There would be contrast between the stages if the satellite image were taken at the right time. The stage with the most outstanding contrast is bare soil stage. The growing stage of the garden will have the same spectral signature as the fallow and there would not be any contrast between the two stages.

Coconut plantations, especially coconut which are closely spaced (a characteristic of small coconut stands in garden areas), gives a different spectral signature. Therefore, there will be contrast between the coconuts, gardens and fallow vegetation.

New fallow vegetation is mainly regenerated crops such as banana, cassava and small trees (shrubs) so they will give a different spectral signature than larger forest nearby. Natural boundaries such as rivers, swamps, cliffs, etc.. can also show up the limits of garden areas (fig. 15).

4.1.2.2. Plantations

*A. Coconut Plantations*

+ Overview

Large coconut plantations do not have uniform canopies due to several factors : Variation in the age of the trees, soil type, spacing and disease attack.

In a normal healthy coconut tree, the maximum crown development occurs between the age of 10 to 40 years after which age the crown size starts to diminish.

Soil types play an important part, e.g in wet marshy lands where there is likely to be a clay pan under the top soil the crowns quickly diminish due to lack of nutrients. Diseases and pest attacks can strip the chlorophyll off the leaves or deform them to make a smaller crown. The initial spacing of coconuts does normally not have a marked significance on the canopy density during the first 20 years of growth.

+ Findings

It appears that the spectral signature of coconuts is not specific and depends on the ground cover underneath. The size of the canopy is too small for the resolution of the images even if the image is very accurate. Other factors such as planting density and relatively young plantings at a normal spacing can only be identified after training (ground work). With the young and the dense coconuts, we can mark the boundaries (fig. 16) but with the small crown it would be difficult without ground work since the signature is actually that of the undergrowth. The undergrowth species would sometimes extend outside the plantation.

*B. Former Plantations*

The processed image gives a specific signature to large areas which have been used for agriculture earlier but are now under fallow or completely abandoned. It was confirmed during the field-checking trip that these areas correspond to old pastures or former cultivated plots.

4.1.3. Future Prospects in Agriculture

Remote sensing using SPOT images can be beneficial to agriculture in several ways :

- identifying farming systems;
- scope of land-use;
- strategic agricultural project planning.

Figure 13. The North-West coast of Efate seen by SPOT Satellite

Figure 14. The study area on Efate seen by SPOT Satellite

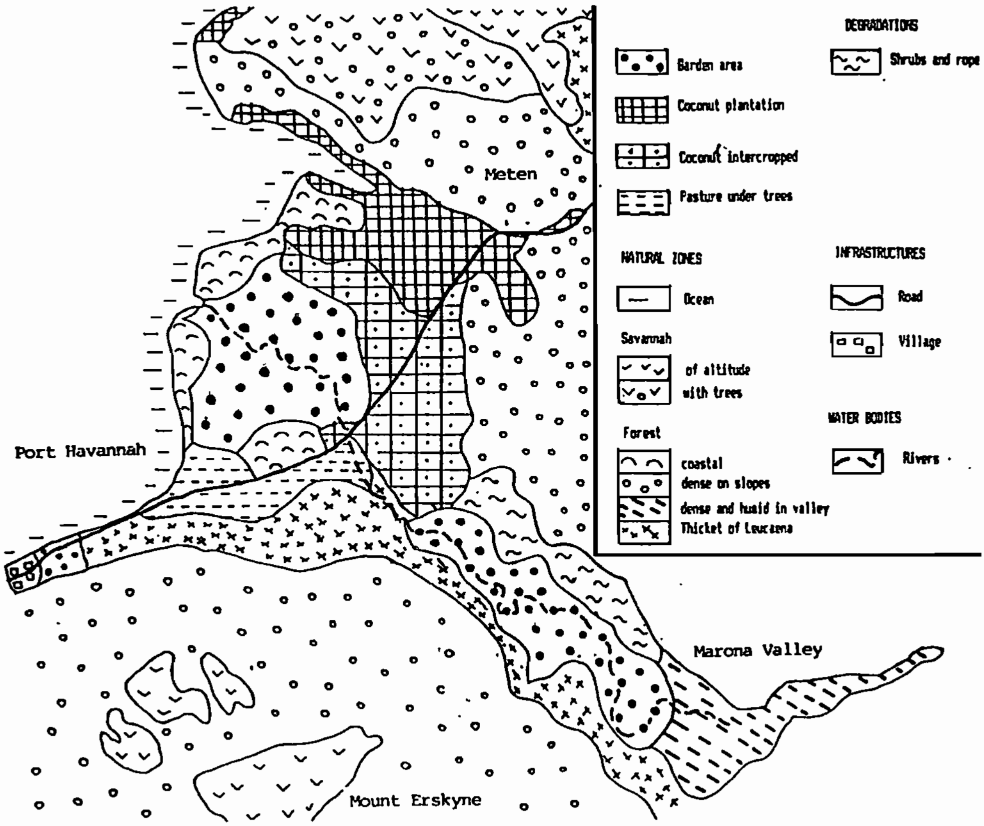



Figure 15. Agricultural analysis, Port Havannah

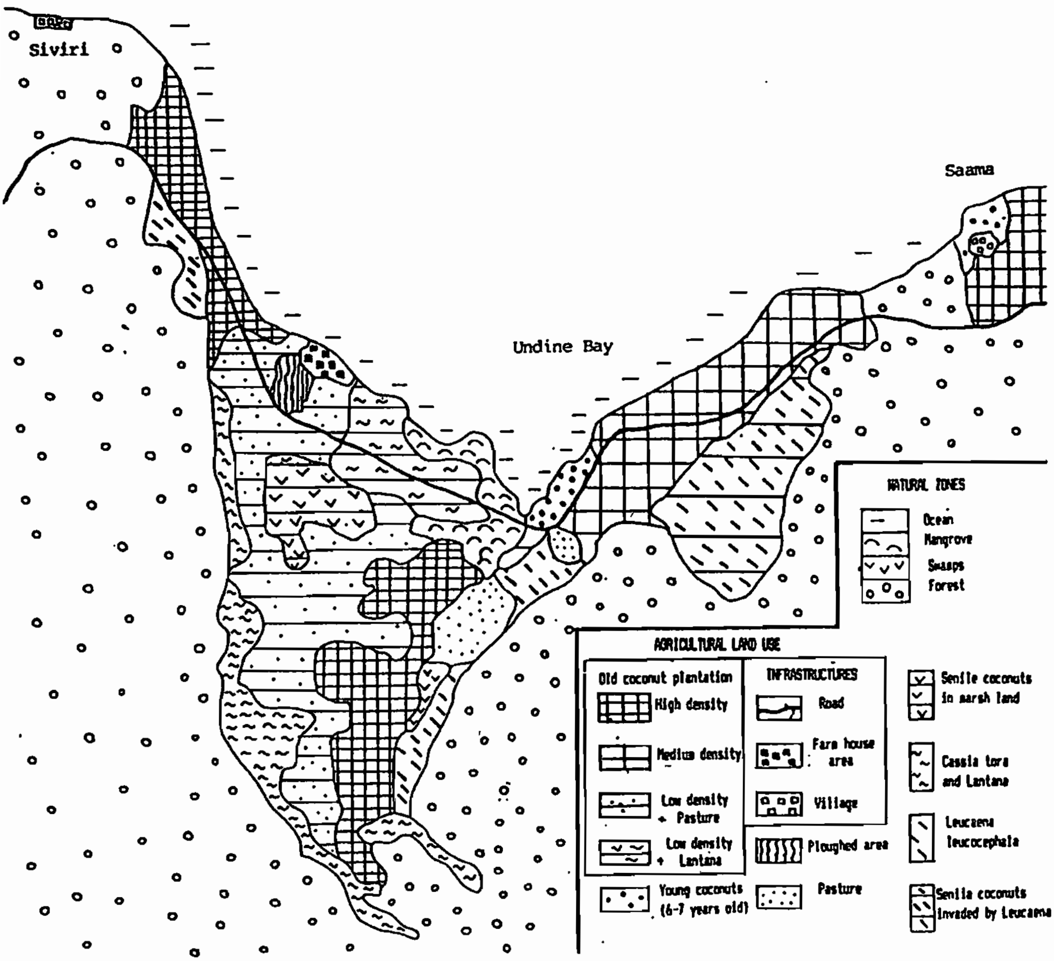



Figure 16. Agricultural analysis, Undine Bay

4.1.3.1 Identifying farming systems

The case study of North Efate did show several farming systems practices which was identified to be:

- Large coconut plantation (single-crop) at Undine Bay (figs. 11, 16), cattle grazing under the coconuts ;
- Grasslands on Mount Erskine after being abandoned from cattle grazing (figs. 11, 13, 15);
- Grasslands on Malafao plateau used for cattle grazing (figs. 10,11,13,14,15);
- Smallholder coconut plantation intercropped with food gardens and cocoa at Havannah valley (figs. 11, 13, 15);
- Smallholder coconut plantation (single-crop) at Havannah valley (figs. 11, 13, 15);
- Food gardens and garden areas in fallow along Marona river (figs. 11,13,15).

Small or individual gardens were not shown or not highlighted and collective gardens are therefore the last limit of study.

4.1.3.2. Scope for Land-Use

By using the Versatec print, we can see the extent of the different land-uses, e.g we can tell that in the Undine Valley there is more coconut than any other crops. We can also define a ratio of arable land in use and arable not in use. If we take the case of Rumakimala plateau between its two valleys of Undine Bay and Havannah Harbour, the ratio is almost nil whereas in the Havannah valley it is 2 to 1. It can also be very useful to know the evolution of land-use and to locate zones available for new implementations or extensions of projects and farms or to assess the location and areas that can be restored.

4.1.3.3. Strategic Agricultural Project Planning

Remote sensing can help in the planning of strategic agricultural projects.

*A. Havannah Harbour Valley*

One of the conclusions that could be made after the field trips and the interpretation of the satellite image, is that we may be short of land in the not so distant future especially wrt. the small subsistence gardens. Some of the solutions that might be able to address the problem in advance are:

- To intercrop coconuts with high value crops such as pepper and vanilla;
- Extensive vegetable gardening.

*B. Malafao Plateau*

The Malafao plateau is dry, with thickets of Leucaena and Acacia (Fig. 12). The grass species growing here are adapted to the dry conditions. To raise cattle would require a good watering system and a low stocking rate. A suitable livestock for that area would be goats because they are adapted to drought and have modest demands on the type of fodder they eat. Few crops could grow without irrigation.

*C. Rumakimala Plateau*

In this area of Acacia and "canoe tree" (*Gyrocarpus americanus*) forest situated between Undine Bay and Havannah Valley (fig. 11,12), crops such as sweet yam (*Dioscorea esculenta*) can be cultivated but the cropping system should be well managed. Indeed, if the trees are removed and "slash and burn" system of gardening is used, the soil erosion would become important and the soil would degenerate very quickly. A system of cropping such as alley cropping would be appropriate and is recommended.

*D. Undine Bay Coconut Plantation*

As the valley is fully covered with coconuts, remote sensing can be used for management (fig. 11) as follows:

- To identify areas of coconuts where the canopy is closed, a sign that the coconuts are healthy. Production of copra is recommended.
- To identify development of weeds such as "wild pistach" and Lantana.
- To give a "history" of the plantation, e.g differences in age of the coconuts could indicate time of planting.
- To survey the possibilities for extension of coconut areas.

However, the cost of a remote sensing exercise can be prohibitive for plantation owners if it is used individually or for medium size plantations. On the other hand, this problem could be overcome if remote sensing is used for surveying a large number of plantations throughout an island or a country.

Finally it should be noted that other classifications may be needed on others islands like Malekula or Santo where the coconut plantations cover large areas in order to confirm the above findings.

## 4.2 NATURAL LAND USES

### 4.2.1. Savanna grassland

#### 4.2.1.1.. *Overview*

In the past the leeward side of the large islands in Vanuatu had relatively large savanna grasslands. The soil there could either be deep (e.g North West Malekula) or shallow (e.g North West Efate). Pure stands of indigenous species of trees such as "namariu" (*Acacia spirorbis*) were often associated with the grasslands. When travelling between islands became easier, Leucaena was introduced to the grasslands where it invaded at a fast rate. The result today is a widespread occurrence of almost pure stands of Leucaena and "namariu".

With the introduction of cattle grazing new weeds such as "wild pistach" (*Cassia tora*), *Acacia farnesiana, Lantana camara* and "horse guavas" (*Psidium guajara*) also began to invade the grasslands.

#### 4.2.1.2.. *Findings*

Using remote sensing, we can map the grasslands (what is left of them) as the spectral signature is almost like that of soil (in the dry season). The signature has a distinct contrast (colour) to the vegetation around it (fig. 13). The horse guavas mainly grow on Mount Erskine that shows up by contrast with the grass.

In the Leucaena forest on the grassland, pure stands do not show up too well depending on the age and time of year. In a wet climate, the Leucaena may show up well.

The "namariu" forest shows up well, therefore the areas where it dominates can be mapped out. Weeds such as "wild pistach" can grow and spread very vigorously during the wet season and then dies during the dry season. Its spectral signature, when it is growing would be highlighted whereas during the dry season, it would be difficult to discern. Lantana grows together with "wild pistach" but as it is a perennial plant its signature would be constant throughout the year. It has a similar signature to "wild pistach" because they both grow together (e.g. northern part of the Malafao plateau, figs. 13,14).

### 4.2.2. **Forests**

#### 4.2.2.1. *Overview*

On the leeward side of the large islands of Vanuatu the zonation of the forest is closely related to the climate and topography. Altitudes over 600 meters are covered with evergreen forest with 20-30 meter canopy. The plant diversity is high. At lower and drier altitudes the species poor forest dominates.

#### 4.2.2.2.. *Findings*

Using remote sensing we can classify some of the forest types by their distinct patterns and colours (table 3), but not all forest types can be easily recognised on the satellite image. Setting up of training zones and continuous field checks are needed to ensure right typing and classification. The dominating species in our study area are Leucaena and Acacia. Thicket of mixed species with variable crown sizes and heights could be classified by colour and texture. On the SPOT image they are grey with medium to coarse texture. Pure stands of Leucaena can be identified by thin strips of lighter red with smooth texture located on steep to gentle slopes (with reference to the topographic map). Valley bottom forests are clearly identified by heavy red colour with fine texture, following the drainage pattern (figs. 13, 14).

In figure 17 we have identified:

- four types of humid forest,
- eight types of dry forest thickets,
- one type of humid forest thickets,
- three types of coastal forest and wetlands,

In this study, a strong correlation is found between the forest type and the soil type. A good soil usually supports a better forest, not necessarily in terms of timber, but particularly in the foliage colour and crown size. An example is clearly shown by the alluvial plain forests, which like the forests on plateaus of hydromorphic soils are dark red and fine in texture. Swamp lands and water bodies vary from light to dark blue with coarse to fine texture (figs. 13,14).

## 5. FROM AERIAL PHOTO TO REMOTE SENSING AND GIS

Increasing pressure for effective natural resource development is being experienced by Pacific Island Nations as a consequence of the demand for economic development in rural areas and the need to provide more food for rapidly increasing populations. Vanuatu as a South Pacific Country, and developing country, is currently experiencing the mechanisms of development and the impacts these developments can have socially and economically both at village and national level. As a result, various institutions within the country have now started carrying out studies which attempt to measure the country's various natural resources, to record and control developments and to try to assess the impacts these developments can have. Although remote sensing and geographic information system (GIS) is fairly new in Vanuatu, attempts have been made to use both these systems by various agencies and technical departments (Agriculture, Forestry and Fisheries, etc). Studies carried out by these organisations can be used for resource planning and management. Remote sensing and geographic information system are important tools in the development and in the proper planning and management of the country's resources.

### 5.1. EXISTING USES

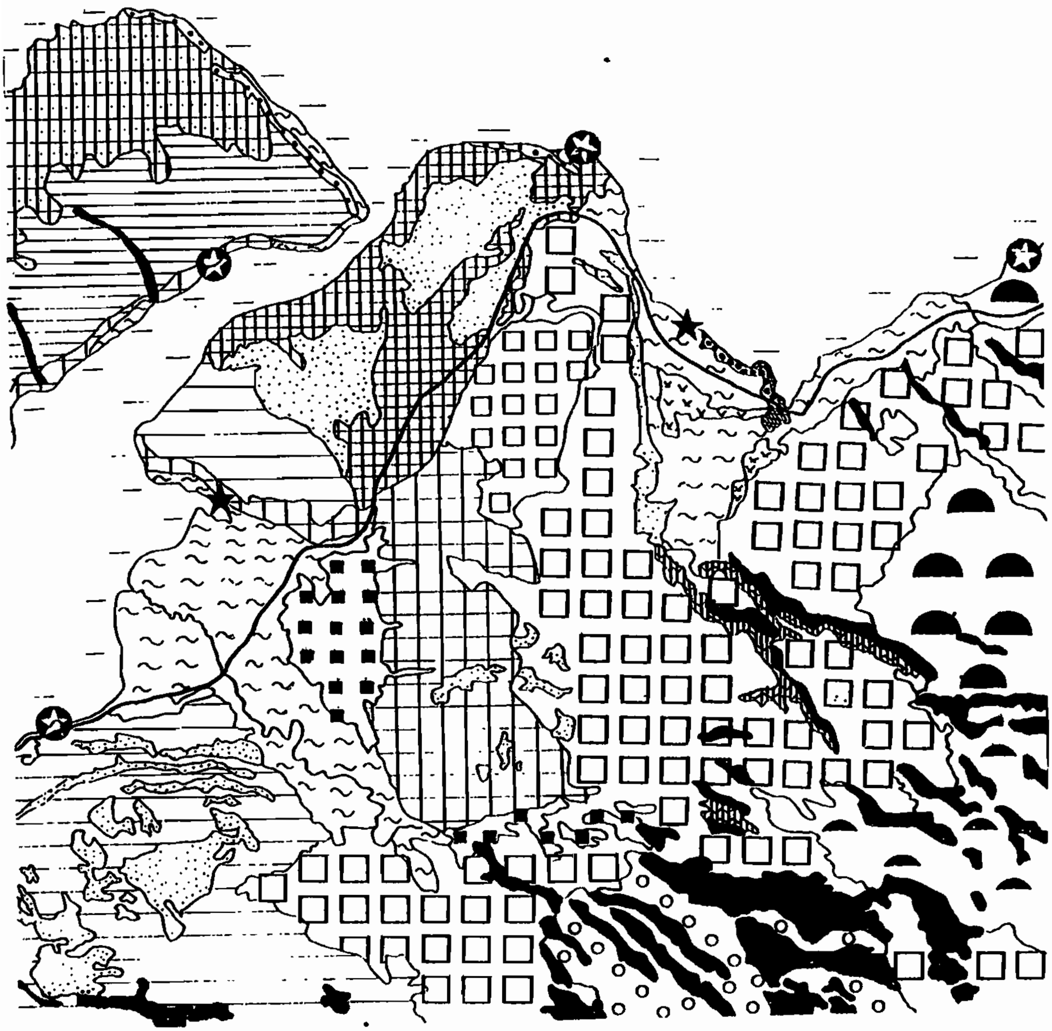
#### 5.1.1. Aerial photos

For 3 or 4 months each year between 1984 and 1986 the Australian Royal Air Force (RAAF) flew black and white aerial photos at the scale of 1:30,00 covering 93% of the country. The main purpose was to provide the survey control and photographic coverage necessary to delineate the country's 200 mile exclusive zone (EZZ). Although some areas are not completely covered because of cloud coverage, the photos are now being widely used for other purposes as well.

The Department of Forestry has purchased a full set of its own to assist in carrying out the Vanuatu National Forest Resources Survey (VNFRS). The photos are used for forest type mapping, forest sampling, navigation and other related uses. Attempts to have certain areas re-flown failed because of bad weather and improper timing. To date, the Department has with the aid of Queensland Forest Service run two short courses for its staff on how to use aerial photos for navigation and particularly on aerial photo interpretation.

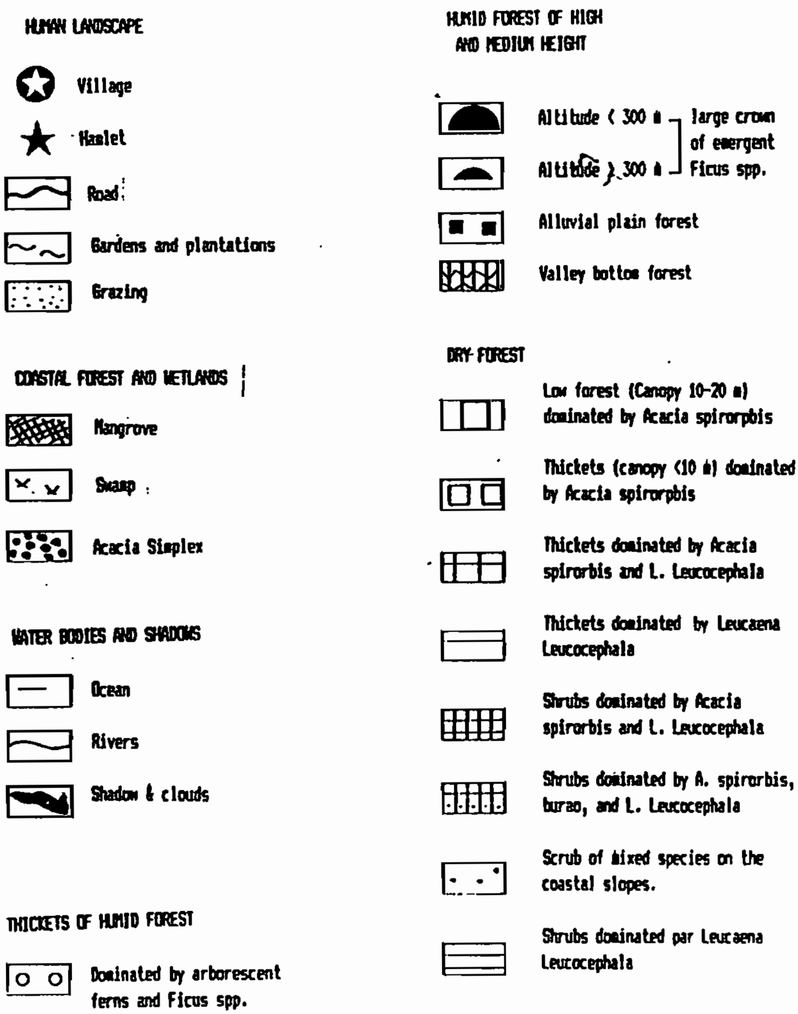
#### 5.1.2. Satellite images

The use of satellite images as mentioned earlier is fairly new to Vanuatu, but through meetings and workshops its applications have generated great interest among potential users in the country.



a) Map

Figure 17. Natural land use and Forest analysis




b) Legend

Figure 17. Natural land use and Forest analysis

The satellite system now being used is the French SPOT. Through the ORSTOM office in Port Vila, Vanuatu and their laboratory in Noumea, New Caledonia, SPOT is now being used in Vanuatu. The ORSTOM office in Port Vila has conducted several studies of resource assessment using SPOT (David, 1989). The application of remote sensing became more widely known and appreciated after a remote sensing workshop in Vila in 1989 organised by ESCAP/UNDP, RAS/86/141 which many people and organisations in the country attended. The training course was a good opportunity for the Forestry Department to test the potential of SPOT in resource inventory and landuse studies. The decision to use SPOT in updating the data collected by the National Forest Resources Survey is now being seriously considered. Because of the interest shown by users in the country, a proposal is under way to set up an in-country working committee on remote sensing. This committee could act as a medium by which information data and techniques will be made available for remote sensing users in the country and if necessary outside of the country. The aim of the committee will be to promote the use of remote sensing, its application and development.

### 5.1.3. **Geographic Information System (GIS)**

Most Pacific countries are lucky in that studies have already been carried out to map certain features and resources like soils and vegetation during the pre-independence era (In Vanuatu, mission ORSTOM have done a lot in data collection and recording).

In Vanuatu the existence of the data and information already collected and recorded means that a GIS can be set up at a relatively low cost. Thus through AIDAB, the Vanuatu National Forest Resource Survey (VNFRS) was set up using the techniques of GIS. The VNFRS is a broad data base co-established by CSIRO and Queensland Forestry Department in collaboration with the Vanuatu Department of Forestry (Vanuatu National Forest Resource Survey, CSIRO and Queensland Forest Service working Paper 1: report on Pilot study on Efate, march 1990).

The Project was started in 1989 and will end in July, 1992. Already at this stage of the project information could be extracted e.g. matching crop or tree species to site (soil type). A special GIS computer package is now being developed by CSIRO to operate the whole data system.

## 5.2. REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS)

### 5.2.1. **A Tool for development**

Undoubtedly the use of remote sensing and GIS are important tools in national development. In most Pacific countries both methods have been tested or are in the process of being tested. Studies carried out in Vanuatu using both tools in resource assessment have clearly indicated that they have great potential, are effective and can be established at an optimum cost.

Experience gained with the VNFRS project using GIS technology already show that the information and data base created will be of great benefit in the planning processes at both the local and national level. Equipped with the system, plans can be drawn, predictions and forecasts can be made and unfavourable situations avoided. In addition quick estimates or updating of resources or impacts of various developments can also be made at a relatively low cost. Vanuatu Department of Forestry is now working closely with ORSTOM in Vila and working agreements are under way concerning data acquisition, technical help and use of the laboratory in Noumea.

5.2.2. **Constraints to Remote sensing and GIS**

The most obvious constraint is the lack of skill and knowledge. Remote sensing and GIS can be quite technical and require proper training and follow up. In addition to seminars and workshops there should be practical training to expose participants to real life situations and to give them hands on practice. Lack of funds for data acquisition and laboratory analysis of data have created limited the advancement in these new but interesting technologies.

**5.2.3. Overcoming the Constraints**

There are three main areas to look at;

a) Training:
Training needs should be studied thoroughly by donor or sponsoring agencies. There are different levels of knowledge, experience and technology in the South Pacific. While some countries may have much experience, others may still be behind in the same technology. The courses should be geared in such a way as to meet each country's needs and aspirations. For example if a country has no computer hardware or capability, training should emphasise on visual interpretation (in R.M.S) and not too much on auto- classification by computer.

b) Setting up of a regional centre and laboratory for remote sensing and GIS accessible to all users e.g. at SPEC or USP, where users can go to process their data and also be assisted in their work.

c) Sharing of information, methods of assessment and techniques between countries. Although some paper comes out regularly, it is not enough. It would also be appropriate if each country have their own remote sensing and GIS committee who will issue and distribute information to other users in Pacific.

With the current problems of development, proper plans of action must be applied by individual countries. The need to survive economically (be economically independent) experienced by most Pacific countries has driven them to speed up development without proper measures and control. Remote sensing and GIS technology is one way to minimise these problems if applied appropriately and soundly.

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## LOCAL NAME OF TREES AND THEIR BOTANICAL NAMES

| | |
|---|---|
| Wild pistach | Cassia tora |
| Lantana | Lantana camara |
| Big leaf | Merremia peltata |
| Guava | *Psidium guajara* |
| Pico | *Solanum torvum* |
| Matala | *Kleinhovia hospita* |
| Namariu (dry area) | *Acacia spirorbis* |
| Namariu (coastal) | *Acacia simplex* |
| Burao | *Hibiscus tiliaceus* |
| American rope | *Mikania mierantha* |
| Coconut | *Cocos nucifera* |
| Canoe tree | *Gyrocarpus americanus* |
| Nambakura | *Calophyllum inophyllum* |
| Cassis | *Leucaena leucocephala* |
| Nabanga | *Ficus spp.* |
| Natoro | *Intia bijuga* |
| Navel | *Barringtonia spp* |
| Nangai | *Canarium indicum* |
| Breadfruit | *Artocarpus communis* |
| Nandao | *Pometia Pinnata* |
| Namamau | *Securinega flexuosa* |

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# COUNTRY REPORT - SOLOMON ISLANDS

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## 1. INTRODUCTION

The Remote Sensing Training course on Interpretation of Satellite Imageries (SPOT) was jointly arranged by RAS/86/036 South Pacific Forestry Development Programme, Port Vila, Vanuatu with technical assistance from ORSTOM (French Institute of Scientific Research for Development and Cooperation). ORSTOM was to provide the SPOT Imageries for the training at their Remote Sensing Laboratory in Noumea. Also, ORSTOM was to be available for occasional assistance during the field work in Vanuatu (Efate Island) and Solomon Islands (Guadalcanal).

Participants attending this course were from Vanuatu and the Solomon Islands.

## 2. OBJECTIVE

To develop techniques and skills in Visual Interpretation of Satellite Images (SPOT) for continuous monitoring of Landuse changes.

## 3. DESCRIPTION OF THE TRAINING IN NOUMEA

The satellite interpretation training consisted of both Lectures and Practical exercises in the field.

The first part of the training course took place at ORSTOM Caledonia Remote Sensing Laboratory (LATICAL) in Noumea 23-29 July 1990. The second part of the training was carried out in the home country of the participants and consisted of field checks of the maps prepared in Noumea.

## 4. MATERIALS USED

### 4.1 NOUMEA EXERCISE

ORSTOM - LATICAL (Laboratory for Image Processing in New Caledonia).

a) The Digital Image processing equipment necessary for preprocessing and processing of remote sensed images includes hardware (computers, magnetic tape sub-system, colour plotter/printer, etc.) and the necessary software.

b) An Enhanced Coloured Composition Image (SPOT, 30.6.86), a portion of the overall image (60km x 60km) covering the Northern region of Guadalcanal Island, was extracted and produced.

The image print:

| | | |
|---|---|---|
| Size | : | 52cm x 52cm |
| Area | : | 20.8km x 20.8km (ground) |
| Approx. Scale | : | 1:40,000 |
| Resolution | : | 20m x 20m (pixel) |

An automatic sorting image map of 1 more restricted area was extracted again from the above image, representing the contact zone "foot hills", enlarged and produced.

c) Aerial Photograph and Topographical Maps of Guadalcanal Island brought by the participant to the training course.

4.2 SOLOMON ISLANDS EXERCISE

a) The Coloured SPOT Image (see 4.1.2 above) obtained in ORSTOM, Noumea with supporting and reference material from the training course.

b) Aerial Photograph :

| | | |
|---|---|---|
| 1984 (SN 6464) | - | Black and White photo<br>Nominal Scale 1:50 000 |
| 1984 (SN 6437) | - | Black and White photo<br>Nominal Scale 1:25 000 |
| 1986 (SN tour) | - | Black and White photo<br>Nominal Scale 1:25 000 |

c) Topographic Maps:

| | | |
|---|---|---|
| Scale 1:50 000 | - | 40m contour interval showing divisions of Guadalcanal Island. |
| Scale 1:150 000 | - | 200m contour interval showing whole of Guadalcanal Island. |

d) Transparent film used for tracing over the SPOT image. Other Photogrammetric and Cartographic material, tools or simple equipment used for assisting in interpretation and processing of the map such as mirror stereoscope, light table, etc.

## 5. FIELD WORK

### 5.1 FIELD PROGRAMME, SOLOMON ISLANDS

The field programme in Guadalcanal took place from the 27th of August to 1st of September 1991 under the supervision of the ORSTOM Coordinator.

Monday 27 August

Completion of the visual interpretation of the SPOT Image and planning of field programme.

Tuesday 28 August

Field check of the North Eastern part of the zone covered by the image, from the Mberande river to the Mbalisuna river. The ground truth zone includes the coastal plain (with oil palm plantations, subsistence farming and village plantations) as well as forest at the foot hills.

Wednesday 29 August

Field check of the central part of the zone covered by the image from the Mbalisuna river to the Mateposo river including old paddy fields, cocoa plantations, industrial plantation settlements, small scale village farming and foothill grassland.

Thursday 30 August

Morning: Field check of the western part of the zone covered by the image from the Mateposo river to Ngalimbu point including new oil palm plantations on the flooded areas hit by cyclone Namu in 1986, and subsistence farming areas.
Afternoon: Field check of foothill forest between Mbalisuna river and Mateposo river.

Friday 31 August

Morning: Field check trip to solve remaining problems of the interpretation.
Afternoon: Preparation of legend of the final land use map.

Saturday 1 September

Preparation of legends of the spatial organisation map and hazard map.

## 5.2 DESCRIPTION OF THE STUDY AREA

The study area which covers the North East part of Guadalcanal Island has three types of landscapes:

i) Coastal plain;
ii) Foot Hills and
iii) Mountains situated some twenty kilometres away from Honiara, the capital city of Solomon Islands.

a) The Coastal Plain (figure 18) is the largest plain on the island which is otherwise dominated by mountainous terrain. The plain is more than 10km wide and stretches more than 40km along the coast. The variation in altitude on the coastal plain is from 0 to 40 meters height above mean sea level. The plain has favourable potential for agricultural development. The main landuses at the time the image (SPOT) was taken were as follows:

- Rice, Oil Palm, Copra, Cocoa,
- Poultry, Cattle,
- Logging.

b) The Foot Hills are about 2km wide and their altitude vary from 40 to 200 meters. The vegetation is mainly degraded forest land (logged over) and has poten-tial for agricultural expansion, and reforestation activities.

c) In the mountains at heights of more than 200m the terrain is very steep the vegetation is mainly dense undisturbed forest with potential for logging.

## 6. LAND USE ANALYSIS AND MAP

### 6.1 MAP PREPARATION

This exercise was done by the following steps:

a) General Visual Interpretation of the printed SPOT Image (figure 19). Differentiation of features on the image, description of colour and textural characteristics of each coded unit (feature) was recorded and a table was created.

b) Drawing the units on transparent material. The boundaries of the coded units were then traced from the image on to the transparency. Combination of different colours, symbols and number codes were also used to differentiate each unit.

c) Automatic Classification Map. Prepared from a tentative list of features expected to be distinguished, in order to verify if the image gives all the information required.

d) Combining Visual and Automatic Classification Demarcation of zones in which there are obvious differences.

e) Field Check for ground truthing in order to correct and prove accuracy of interpretation and analysis.

### 6.2 FINDINGS

The table 5 presents in detail the main landscape patterns identified by the visual interpretation of the Spot Image. The combination of textural and colouring patterns allow a fairly good detailed identification in terms of differentiation between two landscape patterns but spatial also sometimes in terms of temporal differentiation in a landscape pattern between two stages of its vegetation or of the land use. With this reference the following example of the oil palm plantation is very clear.

- When very young (less than 1 year) palm plantations are characterised by a very faint/light brown colour.
- When growing their colour on the image changes from reddish brown to bright red which is characteristic of near maturity.
- Mature oil palms appear on the image with reddish grey to grey hue.

The use of topographic maps and aerial photograph, taken during the same period, could assist the usual interpretation of the satellite image.

- Topographical maps provide height information and could assist boundary demarcation where contours are used.
- Aerial photography is mainly used for verifying the validity of the interpretation. In this way they could be very useful in assisting ground truthing in order to reduce the time spent in the field and thereby save time in obtaining the final product of the interpretation.

Three interpretation maps were extracted from the colour composition:

i) A land use map,
ii) A spatial organisation map and
iii) A natural hazard map.

These three maps as a whole, resulting from an interpretation of the satellite image, represent an analytic and synthetic document which could prove useful for planners. They form the final product of our visual interpretation.

6.2.1. The Land Use map

The first map relates to the occupation of the land. Most of the coastal plain is occupied by industrial crops (palm oil plantations, cocoa, coconut, pastures for cattle, rice paddies). Food crops and village plantations are located on the edges of this zone, along the coast and the rivers, where there are also patches of degraded forest. A grassy savanna has evolved in areas of considerable deterioration of the natural forest. The plain is bordered by foot hills, at the base of which a promising secondary growth forest was developing in 1986. The hills are predominantly covered with a tall grass, *Themeda australis*. Gallery forest found in the valleys, badly dissected by erosion. Higher up, the grasses are replaced by the "dense hill forest" which extends to the mountains, up 300-400m, the zone of dense humid forest.

The preparation of the land use map produced for this exercise required the following processing steps:

a) To map the boundary details between the different land uses zones and to select for each of them a symbol which was filled in (fig. 20a).
b) To map the road detail. A differentiation is made between the main road (tar sealed, 2 lines) and the other roads (fig. 20b). The advantages of utilising separate transparencies for boundaries and roads detail are: minimises confusion between boundary lines and road lines; easy to make correction (including revision) without erasing other information already on the map.
c) To compile the above 2 maps to produce the final map. Place names, Universal Transverse Mercator (UTM) and geographical coordinates, title, legend and additional information were added on to the map before final proofing and correction to obtain the completed land use map (fig. 20c).

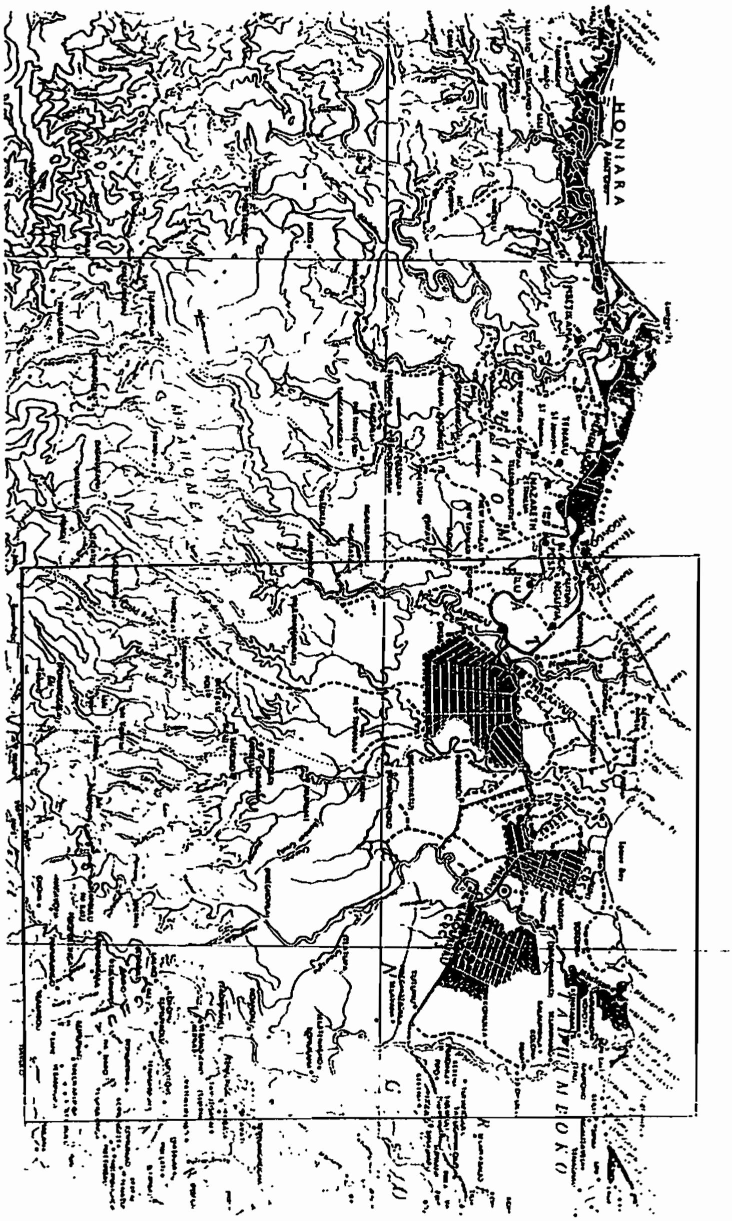


Figure 18. The Guadalcanal Plain

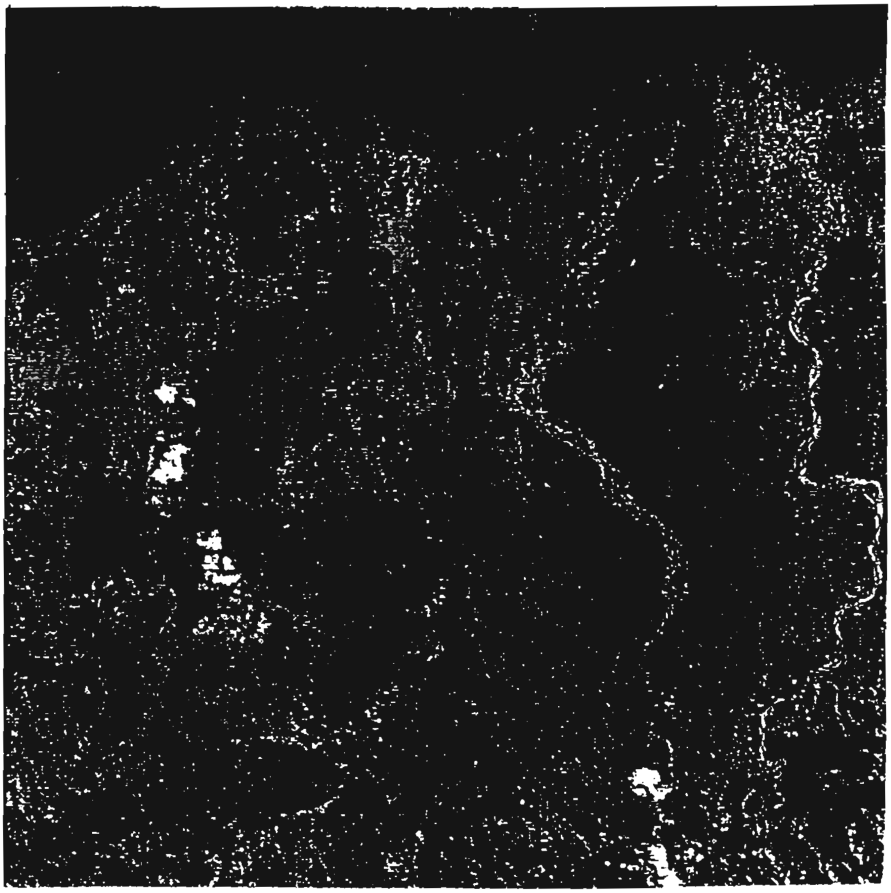

Figure 19 - The study area seen by the spot satellite

Table 5. Identification of the landuse features by visual interpretation of the Spot satellite image

| CATEGORY and SUB-CATEGORY of LAND UNITS | TEXTURE CHARACTERS AREA LINES DOTS Granularity Linearity Contrast Shape size Connexity Order | COLOURING CHARACTERS | OTHER FEATURES AND REMARKS |
|---|---|---|---|
| 1. WATER BODIES | | | |
| - Sea | Wide and Large area<br>Very fine granules | Dark Violet-Light Blue | Sharp defined Boundaries along the sea-shore |
| - Main Rivers | Very lengthy and irregular strips<br>Fine Coarse granules<br>Good connexity | Dark Blue-Whitish Blue | Irregular long strips which gradually narrows in-land wider strips usually have good connexity displayed |
| 2. INDUSTRIAL PLANTA | | | |
| Oil Palm with creeping Legumes for ground<br>- Young 10yrs | Wide and Large area.<br>Good Linerity<br>Very fine - coarse granules<br>Good order | Red - Light Brown Light Blue | Newly planted palms have more light. Blue colour due to flooding palms planted a few months earlier shows a very light brown colour-more reddish brown to a bright red. |
| - Matured 10yrs | Wide and large area<br>Good linerity<br>Fine-Coarse granules<br>Good order | Orange Red-Greyish hue | Newly matured palms have a bright red to much older matured palms from reddish grey-to grey hue. Very matured palms have more dark grey spots. |
| COCOA | | | |
| - Under Oil Palm | Small area<br>Some fine linearity<br>Coarse granules | Reddish dark grey | The large canopy of tall very matured palms shading the cocoa gives a reddish colour having more dark grey spots. |
| - Under Legume Trees (Gralecidia) | Small area<br>Good linearity<br>Very fine coarse granules | Red reddish grey | Has more bright red over grey due to much more dense canopy of cocoa through thin legume canopy shading cocoa. |
| - Under Coconuts | Small area, Good linearity<br>Very fine granules | Red | Likewise dense cocoa under coconuts gives almost 100% red colour. |
| COCONUTS | | | |
| - With Pastures | Small area, Good contrast<br>Coarse-Rough granules | Reddish Brown hue | Tall matured coconut palms with pasture along river gives a good contrast of reddish brown hue. |
| PASTURES | Medium size area, Good linearity<br>Some order, Coarse granules<br>Flat definition contrast | Red - Reddish Brown hue | Pastures have abit more greyish brown colour than red patches for threes in pastures provide shade etc. |
| 3. SUBSISTANCE FARM AND VILLAGE PLANTATIONS | | | |
| Gardens in open area of Forest | Medium area<br>Very fine coarse granules | Red - Dard Dense Blue | Forest area has a flat contrast of red - reddish grey colour. Open areas of forest with some gardens have patches of dark dense blue. |
| Village Coconuts and Cocoa Plantations and Subsistance Gardening | Medium area<br>Very fine coarse granules | Red - Greyish Red hue | Usually having excess to roads especially for travelling and transportation. Has a higher percentage of bright red. |
| PADDY FIELDS | Medium area<br>Some good linearity<br>Fine coarse granules<br>Some order | Dark dense Blue-Whi | Sharp define boundaries but now abandon since 1986 after Cyclone Namu. Same period this satellite image was taken. |
| 4. FOREST WITH PATCH OF CULTIVATION | | | |
| Coconuts and Coastal Forest | Large area<br>Good contrast<br>Coarse-rough granules | Red - Dark Dense Blue | Sharply defined boundaries along the shore but approximately estimated for boundaries inland. The red and dark dense blue coarse to rough granules provide a good contrast. |

Table 5. Identification of the landuse features by visual interpretation of the Spot satellite image (contin.)

| CATEGORY and SUB-CATEGORY of LAND UNITS | TEXTURE CHARACTERS AREA LINES DOTS Granularity Linearity Contrast Shape size Connexity Order | COLOURING CHARACTERS | OTHER FEATURES AND REMARKS |
|---|---|---|---|
| Mixed Degraded Forest and subsistance Gardening with Mangroves and Wet Forest along or near Rivers. | Large area with some long trials /tails. Coarse-Rough granules Some good contrast | Pale Red-Dark Dense Blue | Quite similar contrast to extremely degraded forest below only that it has more red patches due to cultivation present. |
| Extremely Degraded Forest | Very large area (includes Foothill Forest) Rough granules Flat definition contrast | Pale Red-Dark Dense Blue | Very large area includes Foothill Forest. Its flat definition contrast is more distinctive as compared with Foothill Forest which is also extremely degraded |
| 5. NON CULTIVATED FOREST | | | |
| Gallery Forest | Large area Coarse-Rough granules | Pale Red-Reddish Black | Gallery forest usually in-between patches of high grassland (mountain/ slopes). Note that the area is much larger than shown on map. |
| Foothill Forest | Wide, very large area Flat definition contrast Coarse-Rough granules Some good connexity | Pale Red-Reddish Black | Commence at the edge of cultivated lowland boundaries and moves in-land to approx. 200m contour (edge of mountain forest). |
| Mountain Forest | Very large area Good contrast Very rough granules Good connexity | Pale Red-Reddish Black | Terrain is more rugged with very narrow ridge Very rough granules give & good contrast exposing terrain relief. Potential for logging ie. Forest still undisturbed. |
| 6. GRASSLAND Low Grassland | | | |
| - with coconut strips along the shore | Medium area Some order Coarse granules Some good linearity | Red-Brownish Blue hue | Sharp boundary definition with some linearity corresponding to roads, also showing some order. The coconut stips have a brownish red hue and grassland colour ranges from red-brownish blue hue blue. |
| - with some subsistance Gardening | Large area Some good linearity Fine-Coarse granules | Dark Dense Blue Brownish Red | Main colours rangers from dark dense blue-blue-brownish red. Few small patches of bright red are visible which indicate dense subsistence gardening |
| - being ploughed | Small area, Good linearity Coarse granules, Some order | Red - Reddish Grey | More quantity of red and light red. Good linearity and order. |
| - Regrowth | Rectangular/Small area Good linearity | Dark Blue-Light Blue/Brown | Good define line boundary and rectangular shape. More dark dense blue and light blue portion with a few small brown spots. |
| - without cultivation | Medium area Some good linearity Smooth-Coarse granules | Dark Dense Blue-Dark Grey | Approximately 90% dark dense blue hue to flattened grass beneath thick layer of flood sediment dense with water. |
| High Grassland - without cultivation | Medium area Some good linearity Smooth-Coarse granules | Dark Dense Blue-Light Grey | Themeda grassland on hill/mountain/top ridges and slopes. Usually having some good distinctive boundaries, a light reddish grey hue and patches of dark dense blue. |
| 7. OTHERS | | | |
| Cloud | Small-very small area Very fine smooth granules | Dense White-Faint White | 90% plus of very dense white. |
| Shadow | Small-very small area Very fine smooth granules | Dense Black-Faint Black | 90% plus of very dense black for cloud shadow. |
| Settlements | Small-very small area Some good linearity Smooth-coarse granules | Blue-mix Blue/Red-Re | Includes factories, mills, residential buildings, playing fields etc. etc. |

Since this is the first time a satellite image was used by the participant from Solomon Islands in the production of a Land Use Map, the procedures used were kept as close as possible to normal mapping procedures in order to experiment with the possible adoption of this useful technology for mapping purposes in the Solomon Islands.

### 6.2.2. The Spatial organisation map

This second map relates to the organisation of space. On the coastal plain, three settlements, one cocoa research station, an oil mill, two rice grinding units, copra dryers, water pumping stations, irrigation network, drainage network and road network support the industrial agriculture which is the main activity and the main source of employment in the area. Each settlement has its trading centres and services, especially health and education, surrounded by an agricultural zone. Zones of potential agro-industrial development corresponding to the plain forest at the base of the foot hills were also identified on the map.

The many coastal villages are the core structure of the space devoted to food crops. In addition to the zones commonly utilised, zones of potential development were also mapped -these zones are available in the remnants of the coastal forest and the savannas on the foot hills.

Forest exploitation is the third main field of activity built into the space. While the logging is carried out mostly on the foot hills, the squaring is done near the shore, at the Pacific Timber sawmill, which supplies Honiara with timber.

### 6.2.3 The Natural hazard map

The third map relates to the risks of floods and erosion jeopardising human life and economic activities. Cyclone Namu which devastated the area in May 1986, about two months prior to the SPOT image, showed that the risk of floods is very high due to the dense network of catchment areas, as shown on the map by the boundaries of the catchment basins, the rivers and the structure of the network in mountainous areas. Three different textures were established: less than 150m between rivers, 150 to 600m and in excess of 600m between them. The risk of floods was deemed to be:

- uppermost in the zones under water following cyclone Namu
- average in the neighbouring lower ranges
- minimal in areas two to three km or more away from there.

The risk of erosion was assessed as the risk of landslides and soil flows. Mountain or hill forests are very susceptible to landslides during heavy continuous rain. The slopes which are cultivated or burnt are very susceptible to soil flows. And the ridge of the hills which have been logged or cleared are susceptible to both.Planning proposals have been put forward for each of the principal areas mapped, taking into account the risk factor.

Due to time constraints and new allocation of job for the participant it was not possible to draw these two last maps relating to spatial organisation and natural risks in time for this country report. We hope to publish them later with the assistance from the Land Survey Department.

## 7. CONCLUSION

Spot satellite remote sensing appears to have an important potential for contributing to planning in the Solomon Islands especially in the areas of:

- to update topographic and land use maps;
- to evaluate the risk for Natural disasters and the influence of man on the Natural environment.

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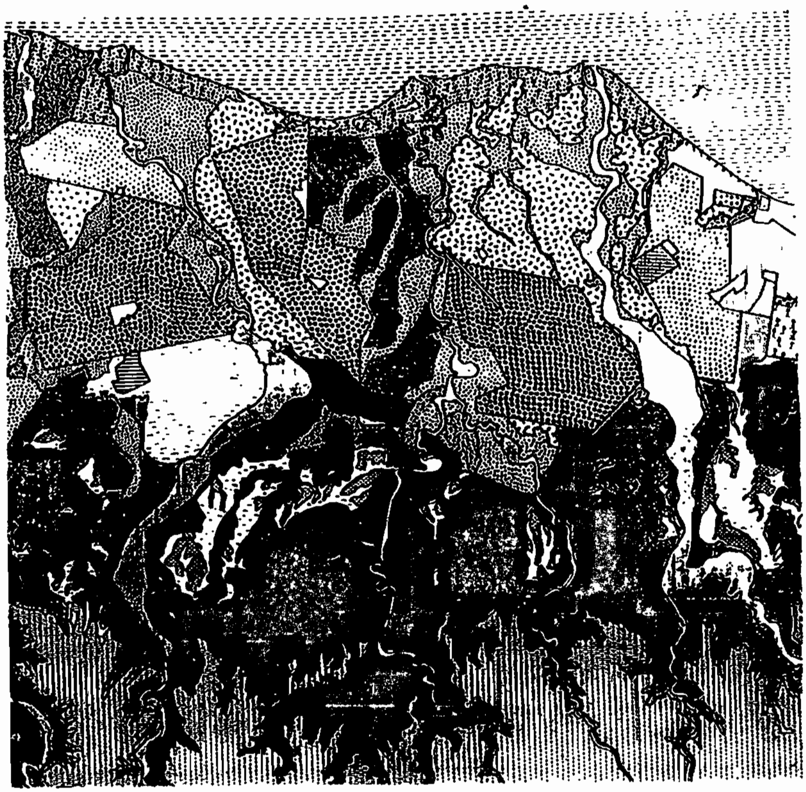
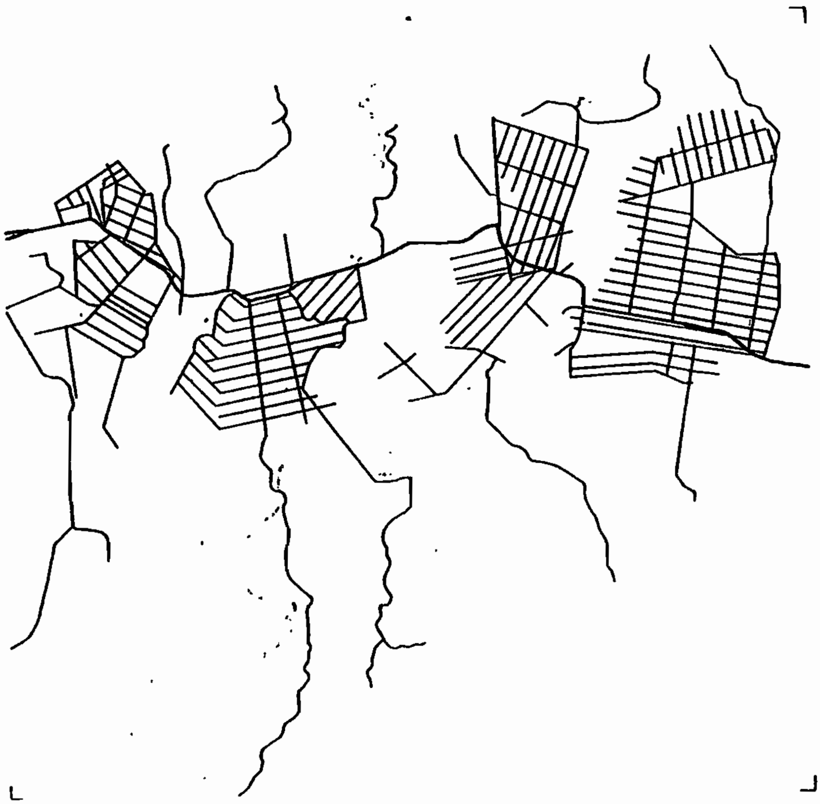


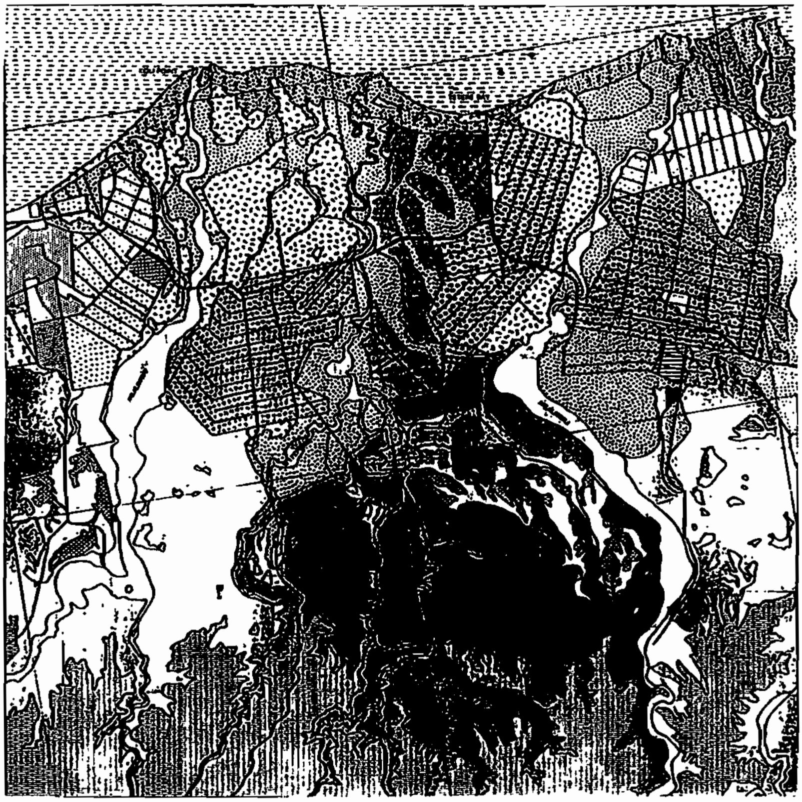
a) Boundary details

Figure 20. Land use mapping of the North East Guadalcanal plain by visual interpretation of spot satellite image.




b) Road details

Figure 20. Land use mapping of the North East Guadalcanal plain by visual interpretation of spot satellite image.



c) Land use map

Figure 20. Land use mapping of the North East Guadalcanal plain by visual interpretation of spot satellite image.

WATER BODIES

Sea
Main rivers

INDUSTRIAL PLANTATIONS

Young oil palm
Matured oil palm
Cocoa under oil palm
Cocoa under legume tree
Cocoa under coconuts
Coconuts with pastures
Pastures
Paddy fields

SETTLEMENT

Residential, factories etc...
Main roads
Other roads
Boundaries

NON CULTIVATED FOREST

Gallery forest
Foot hill forest
Mountain forest

FOREST WITH PATCHES OF CULTIVATION

Coconuts and coastal forest
Extremely degrated forest
Mixed degrated forest with plantations
Mangroves and wet forest along rivers

SUBSISTANCE FARMING AND VILLAGE PLANTATIONS

Garden in open areas of forest
Village coconuts and cocoa plantations
and subsistance gardening

GRASSLAND

Low grassland with coconuts strips along the shore
Low grassland with some subsistance gardening
Low grassland
Grassland being plough
High grassland
Regrowth

d) Legend of the Land use map

Figure 20. Land use mapping of the North East Guadalcanal plain
by visual interpretation of spot satellite image.

## LIST OF FIGURES AND TABLES

**FIGURES**:



**TABLES**:

# PART 3. SUMMARY LECTURE NOTES

# PRINCIPLES OF REMOTE-SENSING

*by Didier LILLE*
*LATICAL - ORSTOM*
*NOUMEA*

## 1. DEFINITIONS

Remote sensing is the acquisition of information without physical contact between the object analysed and the receptor.

## 2. WHAT IS BEING MEASURED?

Energy is propagated by electromagnetic waves (EMW). A wave is characterised by its wave-length.

Natural surfaces emit radiation on a continuous wave-length band, giving a sum of monochromatic waves.

This radiation is analysed in certain wavelength bands by receptors fitted on the satellites.

## 3. THE DIFFERENT TYPES OF SATELLITE

a) Satellites which measure the reflection of a light source from an object. e.g. the SPOT satellite, where the light source is the sun.

b) Satellites which measure the actual emission of an object. e.g. the meteorological satellite METEOSAT (Geostationary Satellite).

c) Satellites which emit a signal and measure the reflection of this signal from the object. e.g. radars

## 4. PROBLEMS OF ACQUISITION

a) Atmosphere
b) Relief
c) Diffusion

## 5. ADVANTAGES OF REMOTE-SENSING

a) The information is numerical Data and can be easily stored and re-used as necessary.

b) Large surface areas can be covered.
c) The data are multitemporal and can be compared with each other.

## 6. FIELDS OF APPLICATION

a) Map-making
   Drawing up of spatial maps
b) Geology, e.g. Detection of fault lines
c) Land use and thematic studies of, agricultural potential area calculations, changes over time.
d) Urbanism e.g. Study of development of urban areas (essentially using SPOT panchromatic data)
e) Monitoring the environment e.g. Impact studies

## 7. GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Satellite images form the basic raw material necessary for compiling GIS.

It makes it possible to pinpoint a location, ascertain the condition of the terrain at any given time and quantify any changes in its condition over a period of time.

# THE SPOT SATELLITE SYSTEM - AN OVERVIEW

*by DIDIER LILLE*
*LATICAL - ORSTOM*
*NOUMEA*

***SPOT = Multi-Purpose Earth Observation System***

## 1. INTRODUCTION

The earth observation programme using the SPOT satellites is run by France with the participation of Sweden and Belgium.

The first SPOT satellite was launched in February 1986. It will be followed by a series of satellites which will ensure the continuity of the programme beyond the year 2000.

## 2. ORBIT

SPOT has been placed at an altitude of 830 km in a circular orbit at an angle of 8° to the geographical north (Table 6).

TABLE 6. SPOT SATELLITE 1 AND 2

- HELLO-SYNCHRONIC ORBIT
- ALTITUDE OF SATELLITE: : 832km
- INCLINATION OF ORBIT: : 98.7°
- LOCAL SOLAR TIME AT DESCENDING NODE : 10h 30m
- PASSAGE OVER SAME SITE EVERY 26 DAYS
- PHOTO POSITION UP TO 27° FROM THE VERTICAL
- PICTURES ACCESSIBLE OVER WIDTH OF 850KM
- AT 45° LATITUDE INTERVALS BETWEEN SUCCESSIVE VISIBILITY ARE 1.4, 1.4, 1.4 .... DAYS, PERMITTING FREQUENT ACQUISITION OF STEREO COUPLES IN A 24-HOUR PERIOD
- PROGRAMMING OF FILMING BY REMOTE CONTROL THROUGH ON-BOARD COMPUTER
- TELEMETRY IMAGE: BAND 8-8.4 GHz AT 50 M.BITS/S

## 3. HRV INSTRUMENTS

SPOT has two instruments for recording HRV 1 and HRV 2 (High Resolution in the Visible spectrum) which operate independently (Table 7). Each instrument covers an area of approximately 60 km x 60 km.

TABLE 7. HRV INSTRUMENT (HIGH RESOLUTION IN THE VISIBLE SPECTRUM)

- CHARACTERISTICS

| | SPECTRAL MODE | PANCHROMATIC MODE |
|---|---|---|
| RESOLUTION ON THE GROUND | 20 m x 20 m | 10 m x 10m |
| NUMBER OF PIXELS PER LINE | 3000 | 6000 |
| WIDTH OF IMAGE | 60 - 80 km | 60 - 80 km |
| WAVE LENGTHS | 0.50 - 0.59 um<br>0.61 - 0.69 um<br>0.79 - 0.90 um | <br>0.50-0.75um |
| INFORMATION CODING | 8 LINEAR BITS | 6 LINEAR BITS OR DPCM |
| INFORMATION FLOW | 25 M BITS/SEC | 25 M BITS/SEC |

- SELECTION OF MODES BY REMOTE LOADING
- LATERAL ORIENTATION OF VIEWING AXIS

  Maxi + 27° makes it possible to observe scenes centred at 426 km from the track of the satellite

## 4. ACQUISITION MODES

SPOT can operate in two modes (Figure 21) :

- Multispectral mode:
  - The satellite translates the reflection of objects on the ground in three spectral bands, the green band (0.50/0.59), the red band (0.61/0.68) and the near infra-red (0.79/0.89).
  - The combination of these three channels (bands) makes it possible to create coloured compositions.
  - The size of the pixel is 20 metres.

- Panchromatic mode:
  - Observation is in a single spectral band, the visible part of the spectrum without blue (0.51/0.73).
  - The size of the pixel is 10 metres.

## 5. LATERAL VIEWFINDING

The orbital cycle is the period of time separating two passages over the same point. For SPOT this is 26 days.

SPOT's two HRV instruments are fitted with mobile mirrors which permit oblique viewfinding and make it possible to obtain stereoscopic vision and repeated observation of the same zone within the 26-day cycle.

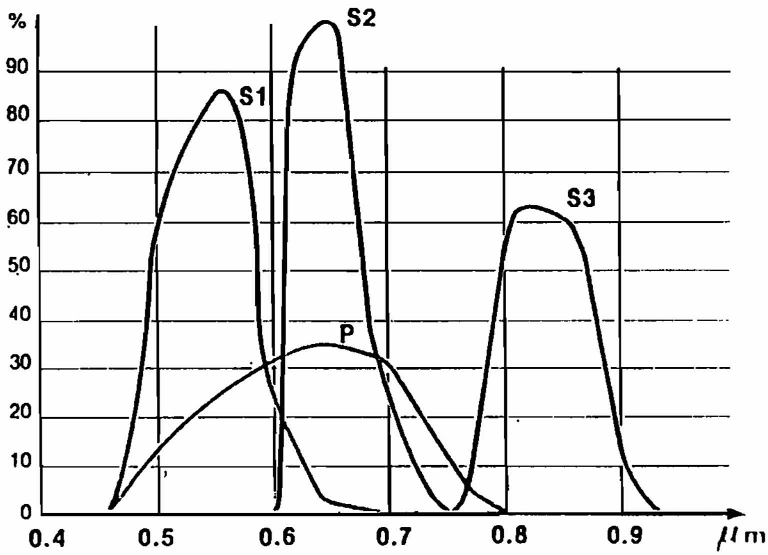



Figure 21. SPOT spectral bands

**Summary Lecture Notes**

# INTRODUCTION TO IMAGE PROCESSING

*by F. ALBERT*
*LATICAL - ORSTOM*
*NOUMEA*

## 1. WHAT IS A NUMERICAL IMAGE?

Definition of the concepts of:

a) spatial quantification and pixel
b) resolution, precision and quantity of information.

Illustration of the fundamental differences between a numerical image and a similar photograph.

Importance of numerical processing of information.

## 2. MAIN METHODS OF NUMERICAL PROCESSING

### 2.1 COLOUR

Concept of pseudo-colour and relativity of contrasts

### 2.2 IMAGE ENHANCEMENT

Attempting to enhance the visual quality of the image in order to highlight certain information by:
a) improving contrasts
b) eliminating noise

### 2.3 SPATIAL SEGMENTATION

Extracting from the image structural information (roads, fields towns) present in geometric form.

### 2.4 SPECTRAL CLASSIFICATION

Explaining the concept of multispectral images. Extracting information from the image concerning the spectral matter of an object (type of vegetation, soil, etc.)

### 2.5 GEOMETRIC TRANSFORMATION

This stage concerns all the usual operations for manipulating images such as photographs:

a) cutting out, masking, inlaying, mosaic, etc.
b) enlargement, rotation, etc.
c) internal deformation of the image.

2.6 PHYSICAL PROCESSING OF THE IMAGE

The image is processed as a numerical signal, the information from which is not yet representative of the physical scale on which we need to work (radar images, temperature maps, etc.).

2.7 STATISTICS

Once segmentation is complete, numerical processing enables a multitude of statistics to be obtained (surface, perimeter, orientation, etc.).

## 3. CONCLUSION

Illustration of the advantages and limitations of the numerical processing of images.

# GEOMETRIC CORRECTION

*by F. Albert*
*LATICAL - ORSTOM*
*NOUMEA*

## 1. INTRODUCTION

Determine the value of geometric correction by means of:
- setting the image against a pre-established map,
- diachronic analysis,
- surface estimates.

Why should geometric corrections be made?

## 2. ERRORS DUE TO ACQUISITION PRINCIPLE

Explanation of main effects of distortion caused by the satellite:
- panoramic effects, rotation of the earth
- altitude and inclination of orbit
- relief of earth

## 3. ERRORS DUE TO SATELLITE

Explanation of the principle of the localisation and stabilisation of a satellite:
- global positioning errors
- dynamic errors of deflection (pitching, rolling, swaying)

Assessment of quality of SPOT images.

## 4. PROBLEM OF RE-SETTING ON MAP

Explanation of different methods of cartographic projection (UTM, Lambert, etc)

## 5. SOLUTIONS

Explanation of different methods of correction, depending on the problem concerned:
- direct
- localisation grid
- use of land-marks

Implementation of a rectification strategy, depending on the precision required, the cost and the type of error.

## 6. SPOT IMAGE AND DIFFERENT PRODUCTS

Introduction to the different products offered by SPOT and assessment of quality.

## 7. CONCLUSION

Illustration of the real problem of geometric rectification and the relative costs involved depending on the degree of precision required.

# COLOUR IN REMOTE-SENSING

*by D. LILLE*
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*NOUMEA*

## 1. COLOUR

### 1.1 COLOUR - SOME DEFINITIONS

a) Light is made up of the group of electromagnetic rays to which the human eye is sensitive.
This group corresponds to the white light emitted by the sun which behaves approximately like a black body at 6500°K.
This is perfectly natural since man has adapted to the conditions of life on earth, with regard to his visual sensitivity to the sun's rays, which are filtered by the earth's atmosphere.

b) Colour is an interaction between an object, a light which illuminates it and a receptor who analyses the fraction of the signal transmitted in his direction.

### 1.2 HISTORICAL BACKGROUND

In 1669 Newton used a prism to decompose white light into monochromatic light (infinitely small spectral band):

Violet, Indigo, Blue, Green, Yellow Orange, Red

### 1.3 SOME CHARACTERISTICS OF THE HUMAN EYE

The human eye consists roughly of three types of photoreceptors sensitive to blue, green and red (BGR). The human eye is very sensitive to Green/Yellow but has greater powers of discrimination in red.

## 2. REPRESENTATION OF COLOURS

### 2.1 THE SYSTEM (R.G.B)

a) Example of the numerical decomposition of a colour B/blue G/green R/red

A colour C is written as $C = b \times B + g \times G + r \times R$, where b, g, r are the coordinates of the colour C in the system (R,G,B). b,g,r represent the percentages of primary colours.

C = (156,227,70) = (70,70,70) + (86,86,0) + (0,71,0)
b g r          Grey          Cyan          Green

The colour C is thus predominantly green.

b) the chromatic circle / graphic representation

c) complementary colours

Yellow = complementary colour of Blue (Yellow + Blue = White)
Cyan = complementary colour of Red (Cyan + Red = White)
Magenta = complementary colour of Green (Magenta + Green = White)

2.2 THE SYSTEM (Y.M.C)

Yellow, Magenta, Cyan) thus for a colour c,
if c = (b,g,r) in the system (B,G,R)
then c = (255-b, 255-g, 255-r) in the system (Y,M,C).

It is possible in this way to simplify the correspondence between additive synthesis and subtractive analysis.

## 3 COMPUTER CODING

a) 8 bit screen there are 2^8 possibilities of coding the colour, in other words 256 colours.

b) 24 bit screen there are 2^8 possibilities of coding the Blue component, 2^8 for the Green component and 2^8 for the Red component, in other words 16 million colours available.
For accurate remote-sensing work a 24 bit screen is often essential.

c) Colour tables (LUT/Look Up Table) A technique which makes it possible to change the colour of a pixel without changing its radiometric value.

d) Coloured compositions
For visualising a 24 bit file in 8 bits

e) Transfer functions.
These make it possible to improve the dynamics of an image by adjusting its histogram

## 4. ADDITIVE SYNTHESIS

The colour is obtained by superimposing the basic components in the system (R,G,B) E.g. computer screens.

## 5. SUBTRACTIVE ANALYSIS

The colour is obtained by suppressing part of the components of the incident light beam.

Filtering using three successive filters, Yellow, Magenta and Cyan, makes it possible to obtain the complementary colour for each filter.

## Summary Lecture Notes

Intermodulation of the saturation of the three filters makes it possible to obtain any colour. e.g. on ink-jet printers. Three overprints are made, one of Cyan, one of Magenta and one of Yellow.

Very often a fourth overprint of black is required, since the superimposing of Cyan, Magenta and Yellow rarely produces an acceptable black.

# REMOTE SENSING APPLICATION: FORESTRY AND LAND USE IN THE SOUTH OF NEW CALEDONIA

*by P. NOSMAS*
*LATICAL - ORSTOM*
*NOUMEA*

## 1. THE PROJECT

Commissioned from LATICAL by the South Province of New Caledonia.

The final product consists of 3 maps for each area studied
- a gradient map (NLM)
- a vegetation map
- a combined classification map (gradient x vegetation)

Study zone :
- Mont Dore
- St Louis
- Yate
- Prony

## 2. METHODOLOGY

a) Selection of vegetation types in conjunction with ORSTOM Botany Laboratory:
- rain forest
- maquis (3 kinds)
- savanna
- open ground

b) Digitalisation of contour lines from an IGN 25000 map.
Interpolation:
- relief map
- gradient map

c) Creating a mosaic of two SPOT images on Ouen Island and Yate to cover the whole of the study area.

d) Rectification of mosaic to superimpose it on gradient file and IGN 50000 maps.

e) Masking of zones with gradient >40 (considered unsuitable for development).

f) Classification proper.

Selection of sample plots on the ground, if possible several for each type of vegetation :

i) Visualisation of plots on ISIS
ii) Recovery of spectral response in the 3 SPOT channels

## Summary Lecture Notes

iii) Identification of zones with spectral response identical or similar to sample plots. Inclusion of these zones in relevant vegetation study.
iv) Production of a preliminary vegetation map.
v) Field expedition to obtain data and refine results
vi) Production of final vegetation map.

# ASSESSING A REMOTE-SENSING PROJECT

*by F. ALBERT*
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## INTRODUCTION

Illustrating the importance of an effective strategy for the definition and assessment of a project. e.g.

## 1. DEFINITION OF PROJECT (SPECIFICATIONS)

It is necessary to define as clearly as possible:

a) the type of work to be carried out (precision, spatial, temporal)
b) the size of the zone to be covered
c) the final documents to be provided

## 2. INVENTORY OF RESOURCES

a) possibility of on-site verification (cost, frequency, accessibility of zones concerned)
b) documents available for on-site verification (aerial photos, maps, etc.)
c) availability of experts
d) type of image required (precision, frequency, evolution, quality, number, spectral definition)
e) computation facilities, storage capacity
f) verification of feasibility of study, possible modifications.

## 3. PROCESSING STRATEGY

a) Segmentation of work with regards to
   i) area
   ii) subject
b) Definition of control zones, defining the methods of controlling the refinement of the operation
c) Strategy for geometric rectification
d) Strategy to be adopted for diachronic processing

## 4. COSTS

Examples of costs to be incurred at different stages, depending on the objectives set. Actual examples from various fields.

## 5. CONCLUSION

Emphasis on the importance of proper advance assessment of content of a project.

# DIGITAL ELEVATION MODELS DEM

*by P. NOSMAS*
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## 1. DEFINITION

A digital elevation model (DEM) is a file image of a region where each pixel has as its value the altitude of the point (or zone) it represents. It is also possible to use these altitudes to calculate the gradient by knowing the size of the pixel (e.g. 10 x 10 m or 20 x 20 m for SPOT).

## 2. ADVANTAGES

### 2.1 FLEXIBILITY OF NUMERICAL INFORMATION

An DEM makes it possible to rapidly mark out zones corresponding to a particular topographical criterion (e.g. zones of altitude higher than 300 m or gradients lower than 40%). In addition, if the size of the pixel is known, the surface area of these zones can be calculated almost instantly.

### 2.2 ADDITIONAL INFORMATION FOR CLASSIFICATION

In classifying vegetation, for example, knowledge of the gradient may make it possible to distinguish between different types of vegetation which give the same radiometric response but which in one case grow only on flat ground and in another only on slopes.

### 2.3 3-D VISUALISATION

By superimposing the DEM on the radiometric image of the zone concerned, it is possible to determine the colour and 3 coordinates of each pixel. It is therefore possible to obtain a view in 3-D using various image synthesis techniques, thus enhancing the visualisation of the terrain.

## 3. METHODS OF ACQUISITION OF DEM

### 3.1 DIGITALISATION OF CONTOUR LINES ON A SURVEY MAP (MANUAL OR BY SCANNER)

Interpolation of these contour lines to obtain the altitude in each pixel located between the contours.

## 3.2 STEREOSCOPIC IMAGES

Stereoscopic images are used (eg. SPOT) representing aerial views of the same zone, slightly out of phase. By means of processes similar to viewing, it is possible to simulate an image in relief and visualise it in 3-D. This method is the opposite of the previous one, since by starting from a 3-D model with points for which the altitude is known, it is possible to produce contour lines for the zone concerned.

## Lecture notes

# PART 4. LECTURE NOTES

# VISUAL INTERPRETATION OF COLOURED COMPOSITIONS OF SATELLITE IMAGES AND MAPPING OF LANDSCAPE UNITS

*by Gilbert DAVID*
*ORSTOM - VANUATU*

How should satellite images be read, how should this visual reading be interpreted and how can the elements necessary for mapping landscape units be identified? These are questions faced daily by users of high-resolution SPOT satellite images in the fields of agriculture, forestry and other land uses. The following we shall attempt to describe the main parameters making it possible to draw up a grid for the reading and interpretation of SPOT images in multispectral mode, with particular emphasis on the problems of recognising and describing the visual entities identified in this way.

## 1. WHAT CAN BE SEEN ON AN IMAGE?

### 1.1. FROM PIXEL TO IMAGE

Any satellite image is made up of picture elements known as *"pixels"*, which in the case of the SPOT satellite represent land areas of 400m$^2$ (20m x 20m) in multispectral XS mode associating the three satellite channels, XS1, XS2 and XS3. In panchromatic P mode or in combined P + XS mode, obtained by mixing spectral bands XS1 and XS2 with band P and re-sampling band XS3 at 10m, the land area represented is 100m2 (10m x 10m).

Depending on the type of screen used, the image which appears covers an area of either 262 144 pixels (512 x 512), or an area of 1 048 576 pixels (1024 x 1024 pixels), as is the case of the equipment used by LATICAL in Noumea. In multispectral mode, the resolution on the ground being 20m, the screen represents an area 20.480 km long (1024 x 20m) and 20.480 km wide, i.e. 419.43 km$^2$. In multispectral P + XS mode, the dimensions of the area appearing on the screen are 10.24 km by 10.24 km, representing a total area of 104.85 km$^2$. The whole of a SPOT image covers an area of 3600 km$^2$ (60 km x 60 km), a total of nine million pixels (3000 x 3000) in multispectral XS mode and 36 million pixels in multispectral P + XS mode.

When the three channels of the multispectral mode are on the screen, each pixel is represented by a colour corresponding to the combination of the spectral signatures in channels XS1, XS2 and XS3 of the landscape occupying the geographical area identified by the pixel. A total of 255 spectral signatures combined in this way can be represented on the screen by 255 different colours, ranging from white to black.

## Lecture notes

### 1.2 THE IMPORTANCE OF SCALE AND THE PERCEPTION OF COLOURS

In general terms, scale is an indication, expressed as a fraction, of the difference between a distance represented graphically (numerator) and the actual physical measurement of the distance (denominator). By small scale we mean a fraction where the numerator is very small compared to the denominator; for instance, on a scale of 1/100 000, each centimetre represents a value 100,000 times greater, in other words 1km. Similarly, a large scale differs from a small scale by the higher value represented by the numerator. Thus, on a scale of 1/25 000, each centimetre corresponds to an actual distance of 250m and each kilometre is represented by 4cm. In other words large scale will show the details whereas a small scale will show an overview.

On the screen, observation of an image enlarged to the point where each pixel can be visually identified shows that:

i) the pixels corresponding to different spectral categories are intimately mixed,
ii) groups of pixels belonging to a single spectral category are rare,
iii) it is difficult to visualise groups of pixels corresponding to landscape units by means of colour differences.

A gradual reduction in scale makes it possible to gain a clearer view of colour groupings.

It is impossible for the eye to distinguish 255 colours. In addition to black and white, the pupil can distinguish easily 6 shades, the three primary colours (blue, red and yellow), together with the colours produced by these colours in combination: violet (blue + red), green (blue + yellow) and orange (red + yellow). Depending on the amount of black or white they contain, each of these six shades forms the origin of a whole range of tones. Pink, for example (red + white), is a tone red. Beyond five tones of the same shade, it appears that the perception of the retina begins to weaken (Brunet, 1987). We therefore feel that the eye can easily distinguish up to 32 colours (6 shades x 5 tones + black and white) on a screen. But with 255 colours, the retina will tend to reduce the spectrum by amalgamating neighbouring colours into one single colour.

The smaller the scale, the smaller the size of the pixels on the screen and the easier it is for the eye to distinguish colour combinations. As the scale is reduced, of course, so is the amount of information, but this is often useful as it enables the interpreter of the image to gain a clearer perception and to identify the main trends, which in many cases are not apparent on a larger scale.

Generally speaking, a combination of pixels of identical or similar colour will produce three different kinds of geometrical figure on a satellite image:

i) points or circles of very small radius,
ii) lines or bands,
iii) areas, often similar in shape to a polygon.

When using a large scale, the forms making up the image can be identified only in accordance with the criteria of colour or structure, in other words the way the forms fit together with one another. On a small scale the criterion of *texture* is also used, the internal arrangement of the forms, regardless of their colour. In general terms, texture takes the form of dark lines which, when they accumulate, give the sector in question a granular appearance.

## 2. IDENTIFICATION AND DESCRIPTION OF GROUPS OF PIXELS

A total of eleven parameters can be used to describe and identify the forms making up a satellite image: *size, form, texture, colour, order, linearity, connexity, direction, continuity, homogeneity* and *contrast* (GASTELLU, 1985).

These parameters can be divided into two groups, those of strict differentiation, such as contrast, homogeneity or heterogeneity, continuity or discontinuity, and those of description and differentiation.

### 2.1. PARAMETERS OF DESCRIPTION AND DIFFERENTIATION

Two sub-categories can be identified: primary and secondary parameters.

#### 2.1.1. Primary parameters of description and differentiation

There are four Primary parameters: *size, form, texture* and *colour*. These are basic parameters which make it possible to distinguish between two groups of pixels and describe them. *Size* and *form* refer to the contours of the groups of pixels, in other words to what separates them and what surrounds them. *Texture* and *colour*, on the other hand, refer to the content of the groups.

(a) **Size**

Five size categories will be distinguished:
i) *very small, from 1 to 10 pixels,*
ii) *small, from 11 to 100 pixels,*
iii) *medium, from 101 to 500 pixels,*
iv) *large, from 501 to 2500 pixels,*
v) *very large, more than 2500 pixels.*

(b) **Form**

If size can be described in terms of quantity and the number of pixels concerned, form can only be described in qualitative terms.

We shall therefore distinguish five basic forms:
i) *square;*
ii) *rectangle;*
iii) *triangle;*
iv) *circle;*
v) *star;*
vi) *and a composite form, incorporating 2-5 basic forms, which we shall call "multiform".*

In addition to these six forms, defined solely in terms of quality, we shall also include three "mixed" forms, combining qualitative and quantitative aspects, which could also be called "complementary" since each of them complements one of the six forms listed above, with the exception of the circle, which by definition can be described quantitatively only in terms of its size. These three "mixed complementary" forms are:

i) *narrow form;*
ii) *wide form;*
iii) *extended form.*

A *narrow form* is distinguished by the small distance between its sides. The description applies essentially to triangles, rectangles and stars. In the case of the triangle, the description *"narrow"* refers respectively to the base of the triangle and the ratio between the base and the height. For the rectangle it is the small breadth and small breadth/length ratio which marks it out as narrow. Finally, in the case of the star, the description applies to three cases: where one of the star's axes is substantially longer than the others, where the base or width of this axis is very small and, lastly, where the width/length or base/height ratios of the axis are very small.

The term *"wide"* is applied where the distance between the sides is great and, in the case of a star, where the length of all the axes is similar.

The description *"extended"* applies to the width/length ratio in the case of a rectangle, the base/height ratio in the case of a triangle and the ratio between the main axis and the other axes in the case of a star. Unlike the description "narrow", however, the extended form does not imply any intrinsic limitation of the width of the rectangle, the base or the triangle or the base of the principal axis of the star.

(c) **Colour**

As was seen above, colours may be described in terms of shades and tones. In view of the vast spectrum of possible shades and tones on the screen, a full description of all colours is impossible and we shall confine ourselves here to nine different shades:

i) the three primary colours: blue, red and yellow;
ii) the three secondary colours: violet, green and orange;
iii) pink, which as we have seen is actually a tone, but we will treat it as a shade because of the wide range of pinks and reds existing;
iv) brown, combination of orange and black;
v) grey, combination of black and white which we shall also treat as a shade because of its extensive range.

Each of these shades may be described in terms of four tones:

vi) *very pale*, where there is a large quantity of white in the shade;
vii) *pale*, where the quantity of white is smaller;
viii) *dark*, where there is an addition of black rather than white to the shade;
ix) *very dark*, where there is a substantial quantity of black.

A further tone description, *"quite dark"* could be used, but it can sometimes be difficult to apply and is best avoided.

In all then 38 colours (9 shades x 4 tones + black and white) are available to describe the colours of the groups of pixels on the screen. The addition of an extra tone ("quite dark") would bring this figure up to 47.

### (d) Texture

*Texture* is a concept whose meaning often creates difficulties and is frequently confused with that of structure. It is necessary to draw a distinction between these two concepts. Of all the natural sciences, it is probably the soil sciences which offer the clearest definition. Soil scientists define the *"texture of a soil"* as its granulometric composition and measure it in terms of the soil's percentage content of coarse and fine sand, alluvium, clay, humus or limestone. They define *"soil structure"* on the other hand as the way in which the solid constituents of the soil combine (SOLTNER, 1982).

The application of these concepts to the reading and visual interpretation of satellite images leads us to define *structure* as ***"the way in which visually different groups of pixels combine, from the point of view either of their colour or their texture or a combination of these two factors"***. *Texture*, however, like colour, refers exclusively to the content of the groups of pixels. It can be described as "the internal disposition of these groups, irrespective of colour". In visual terms, this can be expressed by four characteristics:

i) the presence or absence of clearly defined dark lines;
ii) the presence or absence of dark lines which are not clearly defined and are composed of granules;
iii) the "coarseness" of these groups of granular lines, which can be assessed in terms of the size and form of the granules and corresponds to the granulometric composition of the area in question;
iv) the uniformity of the granulation, measured by the distribution of granule density over the area.

Using these four characteristics, we shall distinguish between 10 main texture categories:

1 *Uniformly smooth,* where there is a total absence of granulation, as for example with a homogeneous grassy savanna;

2 *Smooth with a few, clearly defined lines,* e.g. grassy areas crossed by a screen of trees or by roads;

3 *Smooth, with a large number of clearly-defined lines,* e.g. areas of bare land furrowed by erosion gullies;

4 *Heterogeneous granules or scattered points,* e.g. grassy savanna with thick bush cover;

5 *Heterogeneous granules or scattered points interspersed with a large number of clearly-defined lines.* This type of texture is characteristic of grassy slopes with sparse woodland, the lines corresponding to treeless crests, erosion gullies or water courses.

6 *Low to medium uniform coarseness,* as in pasture land created in forest areas and dotted with clusters of surviving trees;

7 *Large-grain, very coarse;* this texture is usual for areas of rain forest;

8 *Fine-grain, very coarse,* found in less dense rain forest;

9 *Low to medium coarseness, with superimposed lines;* this texture has two kinds of lines, those marking the edges of the granules and thicker straight lines often corresponding to a road network. It is characteristic of young tree or shrubbery plantations and fully exposed adult shrubberies;

10 *Medium to high coarseness with superimposed lines;* this texture differs from the previous one only in its greater degree of coarseness, which reflects a denser and more heterogeneous plant cover. It is frequently found in adult forest plantations or shrubbery plantations (coffee, cocoa) under forest cover.

Variations in uniformity of granulation are the distinguishing features of ***compound textures,*** of which there are two types relating mainly to forest areas:

i) *contact texture,* an example of which is where secondary forest meets primary forest, which, with its broader crowns gives coarser granulation;
ii) *sland texture,* which often corresponds to clearings in forests or islands of primary forest surrounded by degraded forest.

2.1.2. Secondary parameters of description and differentiation

These are four secondary parameters: *order, linearity, direction* and *connexity.* They are described as secondary because they are used mainly in conjunction with primary parameters whose meaning they complement.

(a) **Order**

Applied to space, the concept of *order* implies regularity and equidistance, which are generally the marks of human activity. *Order* is thus characteristic, and by the same token, indicative of a landscape bearing the imprint of human activity.

As a secondary parameter, *order* can be employed in conjunction with each of the four primary parameters mentioned above -*size, form, colour* and *texture* - to create the following four combined parameters: *ordered size, ordered form, ordered colour* and *ordered texture.*

*Ordered size*

This combination is closely linked with man's technological potential in the shape of the control he exerts over his natural environment. Village gardens created by clearing the bush and tended manually by the members of a single household are an excellent illustration. The size of these gardens is directly related to the means of production and the workforce employed to establish and maintain them.

Villages at a similar stage of technological advancement and with comparable demographic trends will have gardens of similar size, thus creating an order in the landscape.

*Ordered form*

This combination is mainly characteristic of urban areas or urbanised rural zones where the distribution of residential areas and communications networks produces ordered forms. In agricultural areas, this order can be found mainly in the patchwork patterns made by pasture land or, more rarely, in the concentric circles in which crops are laid out around a population settlement.

*Ordered colour*

This combination is frequently found in urban centres because of the uniformity of the materials used in roofing. In rural areas it is mainly found in village gardens where it reflects a seasonal similarity in the agricultural calendar. More rarely, it may indicate a similarity in the crops grown.

*Ordered texture*

Of the four combinations involving the parameter "order", this is the most widespread. It applies in particular to road networks or patches of forest surviving in pasture areas.

**(b) Linearity**

This parameter is essentially an attribute of the primary parameters of *"form"* and *"texture"*. Linear form relates to any element of the natural or man-made landscape whose contours take the form of straight line segments. With regards to *texture linearity* applies to the contents of a group of pixels. *Linearity* is particularly apparent in the following three texture categories:

i) smooth with clearly-defined lines,
ii) low to medium coarseness with superimposed lines and
iii) medium to high coarseness with superimposed lines.

Linearity can be described in three terms: *perfect linearity, medium linearity* and *low linearity*.

**(c) Direction**

*Direction* is a parameter linked closely to *linearity* and is expressed by reference to the four cardinal points.

**(d) Connexity**

This parameter is also associated with linearity, of which it is a complex variant. It occurs when a straight line encounters successively several small segments of straight lines. An example would be the confluence of rivers or a line of crests.

## 2.2. PARAMETERS OF STRICT DIFFERENTIATION

Three parameters can be identified : *contrast* and the two pairs of opposites, *heterogeneity/homogeneity* and *continuity/discontinuity* . These parameters cannot be used to describe groups of pixels. Their use is limited either to the recognition of distinct groups of pixels, as in the case of contrast, or the visualisation of the internal disposition of the image and the recognition of its structure, as in the case of heterogeneity/homogeneity and continuity/discontinuity. These parameters can therefore be called "*structural parameters*".

### 2.2.1. Contrast

This parameter quantifies a difference in kind or quantity between two or more contiguous landscape elements. This difference relates either to the form of these elements or to their size, colour or texture.

#### (a) Contrast in size

This is a purely quantitative parameter. It makes it possible to distinguish between one or more groups or pixels belonging to two or more of the five size categories mentioned above: *very small, small, medium, large, very large.* These five size categories can be graded according to their "proximity" on a scale of increasing values. We can therefore distinguish between:

i) four categories of proximity of degree 1: (very small - small), (small-medium), (medium-large), (large-very large);

ii) three categories of proximity of degree 2: (very small to small-medium), (small-large), (medium-very large);

iii) two categories of proximity of degree 3: (very small-large), (small-very large);

iv) one category of proximity of degree 4: (very small-very large).

The further apart the two categories, the easier it is to distinguish between two groups of pixels; thus it is easier to distinguish a group of 11-100 pixels (small size) from a group of 500-2500 pixels (large size), than from a group of 101-500 pixels (medium size).

#### (b) Contrast in form

This is a qualitative parameter. *Contrast* derives from the difference in form between two groups of pixels belonging to two or more of the form categories defined above. In general terms, two forms possessing the same number of angles are difficult to distinguish. However, forms with few or no angles, like the triangle or the circle can easily be distinguished from an angular form such as a polygon.

When they are the same size, the basic forms which are hardest to distinguish are the circle and the square, and the square and the rectangle.

(c) **Contrast in colour**

This parameter is both qualitative and quantitative. The contrast lies in the variations in *shade* (qualitative) and in *tone* (quantitative gradation).

(d) **Contrast in texture**

This contrast is both qualitative and quantitative and refers to two parameters of *texture*, granulometry and the existence of clearly-defined lines.

*Contrast in granulometry*

The greater the difference in granulometry between two groups of pixels, the greater the contrast and the easier it is to distinguish between them. A classification of the five types of *texture* defined above (*smooth, heterogeneous granules, low to medium coarseness, medium to high coarseness, high coarseness*) in accordance with their proximity on a scale of increasing values makes it possible to distinguish four categories of proximity of degree 1, three of degree 2, two of degree 3 and one of degree 4.

The four categories of proximity of degree 1 are:

i) (smooth-heterogenous granules);
ii) (heterogeneous granules-low to medium coarseness);
iii) (low to medium coarseness-medium to high coarseness);
iv) (medium to high coarseness-high coarseness).

The three categories of proximity of degree 2 are:

i) (smooth-low to medium coarseness);
ii) (heterogeneous granules-medium to high coarseness);
iii) (low to high coarseness-high coarseness).

The two categories of proximity of degree 3 are:

i) (smooth-medium to high coarseness);
ii) (heterogeneous granules-high coarseness).

The category of proximity of degree 4 is:
i) (smooth-high coarseness).

*Contrast in terms of clearly-defined lines*

Two zones with the same or similar granulometry can be clearly identified if one contains clearly-defined lines and the other does not.

### 2.2.2 Structural parameters

#### (a) Homogeneity

The concept of *homogeneity* refers to an identity or similarity between two or more groups of pixels. This identity or similarity relates essentially to the colour and texture of the groups of pixels. More rarely, form may be taken into account.

*Homogeneous colour*
Two or more groups of pixels are said to be homogeneous if their colour is identical, irrespective of their texture or form.

*Homogeneous texture*
Two or more groups of pixels are said to have homogeneous texture when their texture is identical or similar, regardless of their colour or form.

*Homogeneous form*
Two or more groups of pixels are said to be homogeneous in form when they all have one of the five basic forms (square, rectangle, triangle, circle, star), whatever their colour and texture.

*Homogeneity of two criteria*
This relates to similarity of:
i) colour and texture, regardless of form, or
ii) colour and form, regardless of texture, or
iii) texture and form, regardless of colour.

*Homogeneity of three criteria*
Although possible, this is rare; it would require similarity of colour, form and texture between two or more groups of pixels.

#### (b) Heterogeneity

Two or more groups of pixels are said to be heterogeneous when no similarities of colour, form or texture can be identified between them.

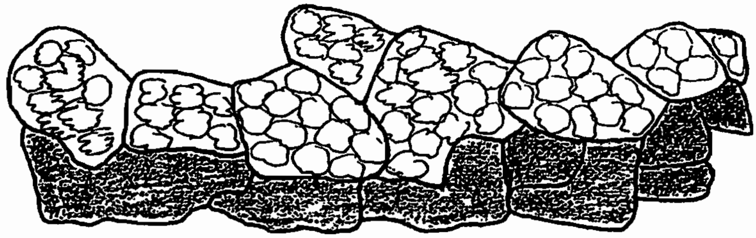
#### (c) Continuity

The notion of continuity refers to shared borders.

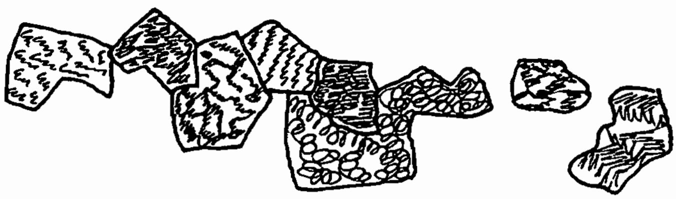
Two groups of pixels are said to be continuous if they have at least two shared edges. This notion is particularly useful for the visual interpretation of satellite images, when combined with the concept of homogeneity, in determining the continuity of several homogeneous groups of pixels (fig. 22a).

#### (d) Discontinuity

Two groups of pixels are said to be discontinuous when they possess no shared boundaries. Similarly, several groups of homogeneous pixels will be described as discontinuous when none of their edges touch (fig. 22b).



a) Zones which are continuous and homogeneous from the point of view of texture



b) Zones which are discontinuous and heterogenous from the point of view of texture

Figure 22. Homogeneity/heterogeneity, Continuity/discontinuity

## 2.3. FROM STRUCTURE TO TEXTURE - THE DIALECTICS OF INTERLOCKING SCALES

We have seen above that there are four primary parameters (size, form, texture and colour) which enable us to describe and distinguish between separate groups of pixels, which will henceforth be referred to as *"units of visualisation"*. The application to these units of the parameters of strict differentiation contrast, homogeneity/heterogeneity and continuity/discontinuity makes it possible to divide these groups of pixels into *"structural units"* made up of several *"homogeneous units of visualisation"*. This process is illustrated in the form of a diagram in figure 23.

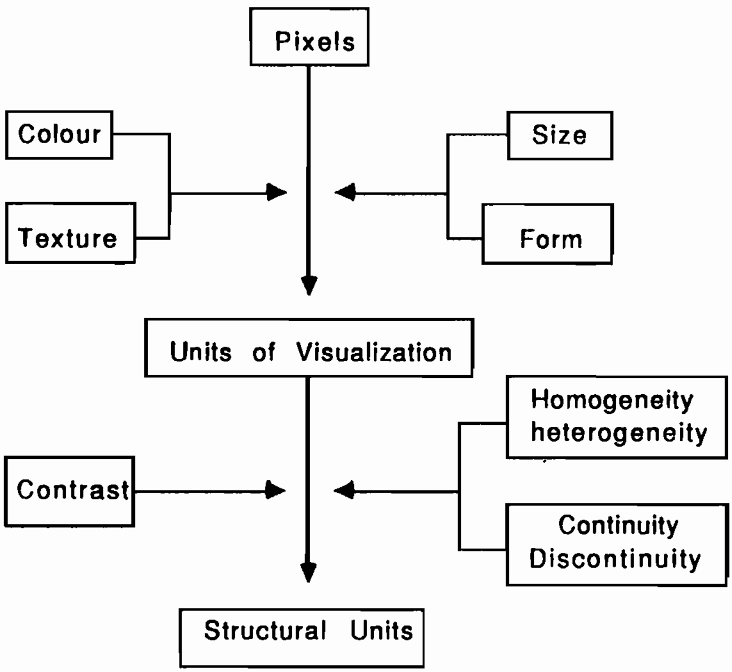



Figure 23. Process of differentiation of structural units of Spot image by visual interpretation

The structural units change in size depending on the scale used. Thus, a reduction in scale causes a regrouping of the structural units into a smaller number of units which we shall call *"first degree derived structural units"*.

On a small scale, the size of the original structural units is so small as to make it possible to obtain a clear idea of the structure of the image. However, these original structural units have become excellent units of visualisation, which we shall call *"first degree derived units of visualisation"*, the original units of visualisation having lost all relevance on this scale because of their small size. In fact, the original structural units, which on the original scale reflected the structures of the image, now reflect only its texture, in other words the internal arrangement of the new groups of pixels produced by the change of scale.

Any **decrease in scale** for a given group of pixels therefore **tends to transform structure into texture.** Symmetrically, any **increase in the scale** creates new units of visualisation, smaller than the original ones, and **texture tends to be trans-formed into structure.** Thus, according to the degree of accuracy desired in the visual interpretation of a satellite image, several *degrees of derivation of structural units* can be used (structural units derived to the degree n - 1, n, n + 1, etc. where n > 1).

**This interlocking of structural units is concomitant with the interlocking of scales.** Thus a structural unit derived to the "degree n" corresponds to a larger scale than a structural unit derived to the "degree n+1". Symmetrically, this same structural unit derived to the "degree n" will correspond to a smaller scale than a structural unit derived to the "degree n-1".

## 3. LANDSCAPE UNITS AND ORGANISATION OF SPACE

### 3.1. GEOFACIES, GEOSYSTEM AND REGION

#### 3.1.1. Geofacies

According to the definition suggested by the French geographer, G. BERTRAND (1970), ***landscape*** is "*a portion of space characterised by a dynamic, and thus unstable combination of different geographical elements - physical, biological, anthropic which, by reacting dialectically with one another, make the landscape an indissoluble geographical whole which develops en bloc, as much from the influence of the interaction between the elements composing it as from that of the individual dynamics of each of the elements considered separately*".
Like a SPOT image, which is a two-dimensional representation of the landscape, the landscape is composed of elementary units which may interlock to form larger units. These elementary units are called *"geofacies"* in the terminology used by G. BERTRAND (1968) and also adopted by J.F. RICHARD (1975). In the tropical countries, the *"geofacies"* is the unit of description of geographical space; it is the smallest homogeneous spatial unit (RICHARD, op. cit.). Its dimensions can be of the order of one hectare (10 000 $m^2$) or one square kilometre (1 000 000 $m^2$), which corresponds to a margin of 25 to 2500 pixels on a SPOT image in multispectral XS mode and 100 to 10 000 pixels in P + XS mode. It may be a coconut grove, a forest in a valley bottom, a grassy slope, etc.

Any *geofacies* can be identified by its geographical location in longitude and latitude and by the combination of elements of landscape it contains. These elements can be divided into three levels, the physical environment, the ecosystem and human activity.

A *geofacies* has a homogeneous physiognomy. This is only possible under the following conditions:

- either the combination of landscape elements making up the geofacies are homogeneous over the whole area it occupies, or

- where one or two landscape levels predominate in the geofacies - whether it is the physical environment, the animal or plant community or the human environ-ment - the elements making up the level(s) must be homogeneous.

The *"units of visualisation"* identified by the interpreter on SPOT images also have a homogeneous physiognomy. The homogeneity of colour and/or texture which characterises its visual units reflects either a homogeneous physical environment or homogeneous vegetation which may itself sometimes reflect a homogeneous human environment when the vegetation is essentially a product of agriculture or forestry. In this respect, ***units of visualisation may be equivalent to geofacies***, since they are of the same size and have the same meaning.

### 3.1.2. Geosystem and region

The *geosystem* is the second landscape unit widely used by French geographers. About 10 to 100 times larger than the *geofacies*, the *geosystem* occupies an area ranging from 1 to more than 10 $km^2$. This may be the zone covered by a village territory, a mountain valley, a mangrove, a coral reef, etc. Unlike the *geofacies*, the *geosystem* does not have a homogeneous physiognomy. The *geosystem* is a combination of *geofacies*, but the latter may differ in nature. How do these *geofacies* combine together in a *geosystem* and how are they organised? This is a vital question which merits serious consideration. First, however, we must define the third landscape unit applicable in scale to a SPOT image - the region.

The dimensions of the *region* are of the order of about 100 $km^2$ for the Pacific islands. The *region* is generally easy to identify on a satellite image as it corresponds to the main relief features; it can be a coastal plain or a mountain foothill.

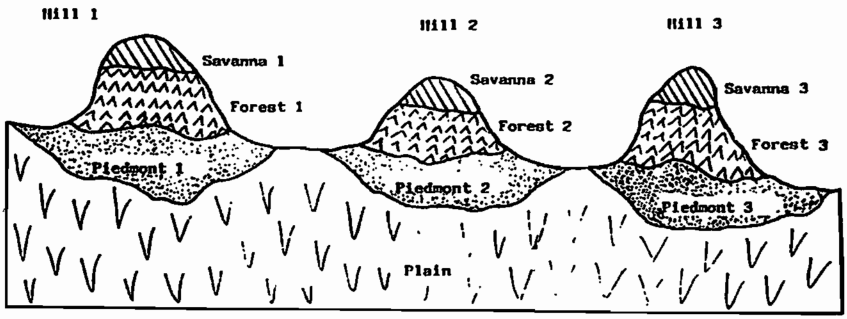
## 3.2. FROM GEOFACIES TO GEOSYSTEM - CHORES AND TAXONS

How do we move from geofacies to geosystem? The process is not a direct one but passes through two stages and requires reference to two key concepts in ecology and geography, *"chores"* and *"taxons"*.

*Taxons* can be defined as a sub-group of elementary areas with a high degree of similarity between them and can thus be distinguish from areas belonging to other categories. This resemblance relates to ecological affinities reflected in either a similar physical environment (especially vegetation) or similar flows. The concept of taxon is already a familiar one and is related to the notion of homogeneity. It was used above to explain the formation of structural units from units of visualisation. Each structural unit is equivalent to a taxon which groups together visual units of homogeneous texture and/or colour.

The concept of *chore* refers to the idea of continuity. A chore is a sub-group of contiguous elementary areas. Figure 24 illustrates these concepts.

Let us now apply the concept of chores and taxons to a problem of concern to us - how is a geosystem built up of geofacies? The first step concerns the formation of taxons from all the elementary areas or geofacies (or "*visual units*") of a region. The taxon which seems most representative is chosen. All the visual units adjacent to it are then combined with it more and more closely until all these visual units, combined with the taxon in the form of successive chores, form one or more other taxons. The limits of the geosystem are then determined.




Four taxons can be identified : savanna, forest, piedmont, plain.

Four chores can be identified : Hill 1, Hill 2, Hill 3, Plain and piedmonts.

Hill 1 consists of zones : Savanna 1 + Forest 1 + Piedmont 1.

Hill 2 consists of zones : Savanna 2 + Forest 2 + Piedmont 2.

Hill 3 consists of zones : Savanna 3 + Forest 3 + Piedmont 3.

The plain and the piedmonts consist of zones :
Plain + Piedmont 1 + Piedmont 2 + Piedmont 3.

Figure. 24. An exemple. of chores and taxons in a landscape.

## 4. CONCLUSION - A METHOD OF VISUAL INTERPRETATION

In conclusion, we shall outline a method to be used for the description and visual interpretation of satellite images. This outline is accompanied by a grid for the description and interpretation of the elements of landscape making up the image.

### 4.1. "INTERLOCKING" SCALES

Comparing different scales for the same area is the most effective method of distinguishing between and ordering the different elements (chores and taxon) composing the structure of the landscape. It is therefore important to use different scales to visualise and interpret the image. These scales will be inter-locked, as children do with tubes of different sizes, beginning with the smaller scales and then moving to the larger ones, which will be used to distinguish between the "units of visualisation", and then, if necessary, returning to the medium and small scales to visualise the "structural units" and interpret them more accurately.

The choice of scale should be based on two criteria:

a) the first is legibility. It is useless to look at a SPOT image on a scale which is either too small or too large. As the islands of the South Pacific generally cover small areas, a scale of 1/500 000, where each centimetre represents 5 km, is generally too small and details cannot be properly seen. Similarly, a scale of 1/10 000 is generally too large for groups of homogeneous pixels to be easily identifiable. The scales 1/100 000 and 1/50 000 seem the most suitable. For small areas to be studied in detail, the scales 1/25 000 or 1/30 000 can also be usefully employed.

b) the second is compatibility with existing cartographic documents, especially survey maps, relief maps and vegetation maps, which can be used as an aid to the visual interpretation of the satellite image.

### 4.2. SIMPLIFYING THE COMPLEX

For any given scale, identifying "*units of visualisation*" and "*structural units*" and interpreting them must be done by moving from the most simple to the most complex. In the case of "*units of visualisation*", the complexity is closely related to the small size of the areas to be examined and the meeting or overlapping of different colours and textures in a small space. It is therefore preferable to concentrate first on the larger and most homogeneous visual units and then move on to the smaller areas afterwards. It is likely that at the end of this process a "*residue*" will be left consisting of numerous small areas with textures and colours which are difficult to distinguish. This "*residue*" should be left as it is and will form a structural unit in its own right or will be visualised on a larger scale in order to break it down, if possible, into several units of visualisation.

### 4.3. USING THE PROPER TOOLS

In order to read and visually interpret a satellite image, it is necessary to use the parameters described above.

a) Begin by distinguishing visual units by using the primary parameters of description and differentiation: *size, form, colour* and *texture*;

b) then, if appropriate, use the secondary parameters of description and differentiation: *order, linearity, direction, connexity;*

c) then group together the visual units into structural units using the parameters of strict differentiation: *contrast, homogeneity, continuity*;

d) use the following grid to describe and interpret the units of landscape making up the image.

## 4.4. READING AND INTERPRETATION GRID

This grid is designed to provide a description in terms of *form, size, colour* and *texture* of all the structural units identifiable on the image and which then give an interpretation in terms of landscape units (table 6).

Table 6. Grid for the reading and visual interpretation of units of Landscape identifiable on a spot satellite image

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Geosystems | | | | | | | | |
| Structural units of geosystem | | | | | | | | |
| Form | | | | | | | | |
| Size | | | | | | | | |
| Colour | | | | | | | | |
| TEXTURE | Granularity | | | | | | | |
| | Linearity | | | | | | | |
| | Other Parameters | | | | | | | |

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# ENVIRONMENTAL FACTORS RELEVANT TO VEGETATION MAPPING, GEOMORPHOLOGY AND PEDOLOGY

*G. DAVID*
*ORSTOM - PORT VILA*

## 1. GEOMORPHOLOGY

### 1.1. WHAT IS GEOMORPHOLOGY?

Geomorphology is the study of landforms and their processes or origin.

#### 1.1.1. Landforms

Landform means the morphology of the ground surface at a given moment in time, and is, described as the combination of relief, slope form and drainage lines (figure 25).

Landforms are usually shown on maps by the contour lines which directly represent altitude and the contour intervals. A contour interval is the vertical distance separating successive contours (figure 26).

#### 1.1.2. Processes

Process is the action of fluid agents causing the forms to change. Three main processes can be identified:

i) erosion,
ii) transport,
iii) and deposition.

In tropical countries the morphological processes are caused by three fluid agents:

i) running water in surface and underground flow systems,
ii) waves,
iii) wind blowing over the ground.

#### 1.1.3. Geomorphology as a system

Geomorphology can be seen as a system composed of three elements:

i) forms,
ii) processes,
iii) and bed rocks; and three relationships:
  a) process to forms,
  b) process to bed rock,
  c) bed rock to forms (figure 27).

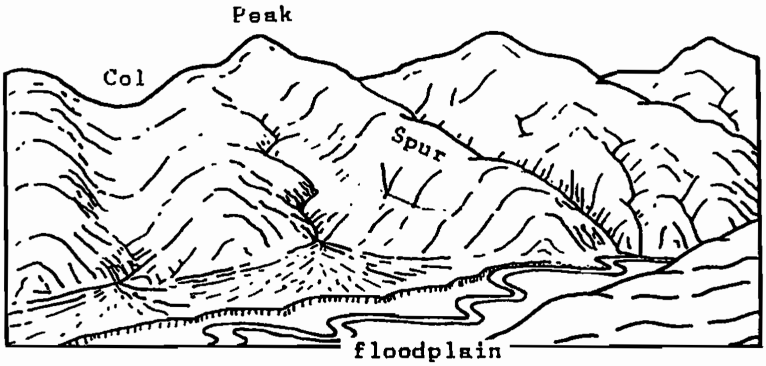


Figure 25. Examples of landforms (after Strahler and Strahler, 1978)

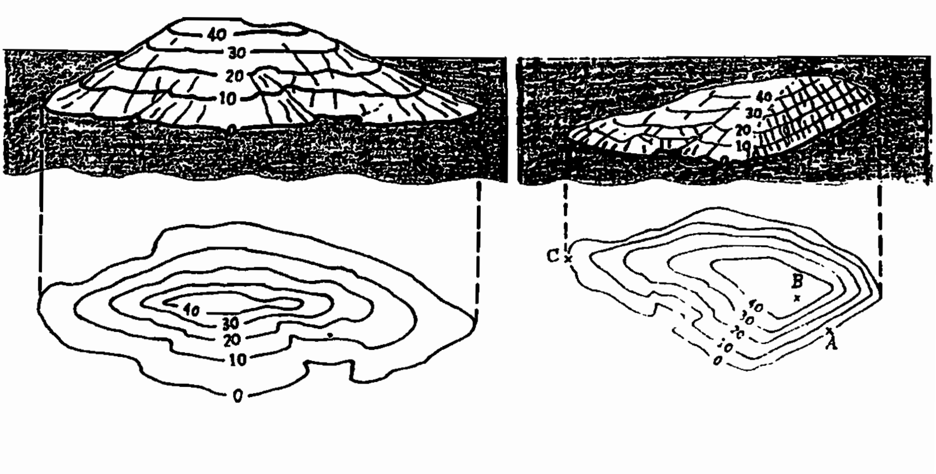


Figure 26. Contours of a small Pacific Island (after Strahler and Strahler, 1978)

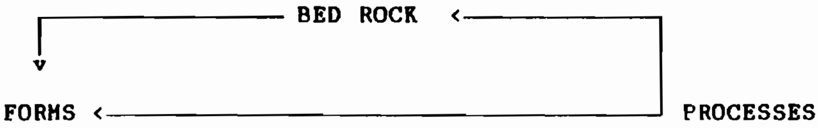


Figure 27. The Geomorphological System

## 1.2 GEOMORPHOLOGICAL UNITS

### 2.1. Slopes

The slope is the basic unit of geomorphology. Slopes may vary from 0° (horizontal) to 90° (vertical).

Slopes are a function of the rock type or surface material and the processes acting upon it. In the upper section of the slope, erosion predominates. In the middle section, transport predominates. In the lower section of the slope, deposition and transport predominate (figure 28).

On a smaller scale, the same classification can be applied between slopes, relative relief and drainage lines (figure 29):

i) slopes are mainly characterised by erosion; relative relief is mainly characterised by deposition;
ii) drainage lines are mainly characterised by transport.

### 1.2.2. Drainage lines

"*The total system of downslope water flow to the point of arrival at the ground surface comprises the drainage system. It consists of a branched network of stream channels, as well as the sloping ground surfaces that contribute overland flow and interflow to those channels. The entire system is bounded by drainage divide, outlining a more or less pear-shaped drainage basis*" (STRAHLER and STRAHLER, 1978) (figure 30).

In wet tropical countries such as the Solomon Islands and Vanuatu, the rocks are very strong. The rivers can not cut through them; the drainage lines can use only the weakest points of the landforms, especially the fault lines. This is the reason why usually the valleys are very narrow in mountainous regions and why the canyons are common.

At low altitudes, alluvial meanders are common (figure 31).

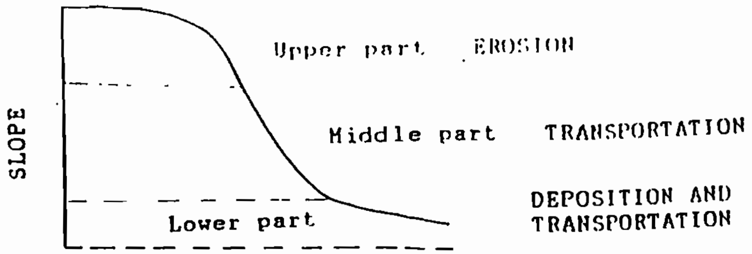


Figure 28 - Morphological processes on a slope

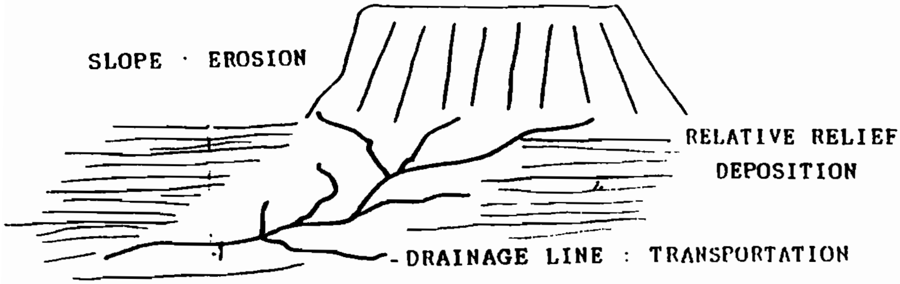


Figure 29 - Morphological processes between slopes, relief and drainage lines

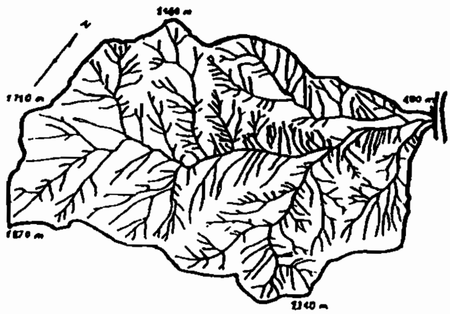

Figure 30 A drainage system

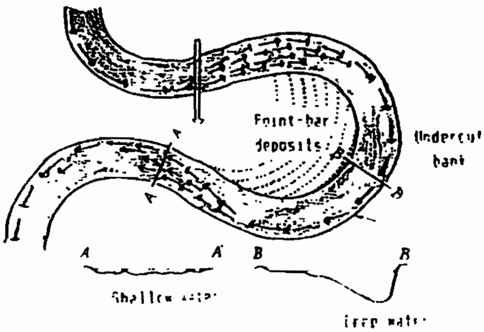


Figure 31 The hydrodynamic of a meander bend (after Strahler and Strahler, 1978)

## 1.3. ROCK WEATHERING

### 1.3.1. Physical, chemical and mechanical weathering

Weathering is the general term applied to the combined action of all processes causing bedrock to be gradually broken down into small bits and pieces then disintegrated physically and decomposed chemically because of exposure at or near the earth's surface. The products of rock weathering tend to accumulate in a soft surface layer called "*regolith*".

The regolith grades downward in bedrock, (solid and unaltered rock). Regolith in turn provides the source for sediment. The sediment consists of detached mineral particles transported or deposited in a fluid agent (figure 32).

In wet tropical countries, the fluid agent is water and the weathering is mainly of a chemical nature, except at high altitude where frost may be responsible for some physical weathering.

When the bed rock is not too deep, the roots of trees may use fractures of bed rock, enlarge them and cause mechanical weathering (figure 33).

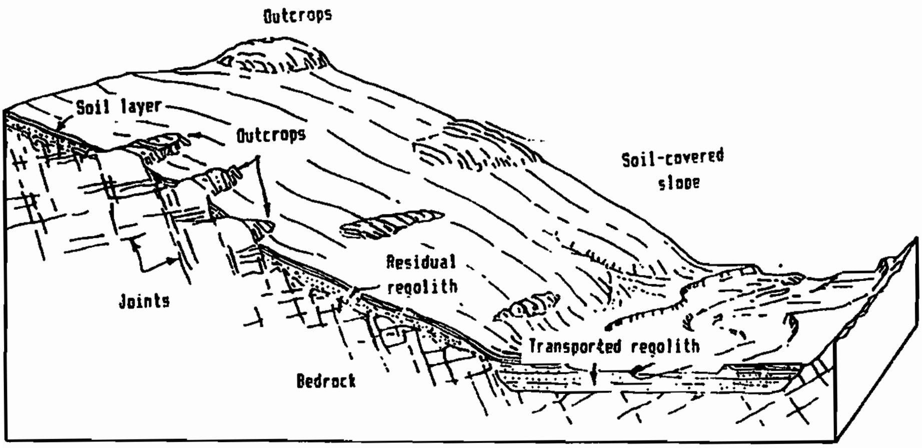


Figure 32. Regolith on a hillslope (after Strahler and Strahler, 1978)

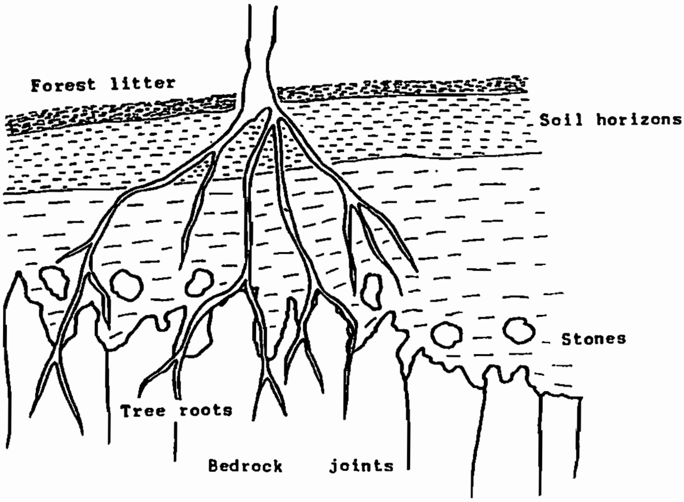


Figure 33. Mechanical weathering caused by tree roots

### 1.3.2. Chemical weathering or mineral alteration

The heat, the humidity and the precipitation are the three climatological agents causing chemical weathering in wet tropical countries (figure 34).

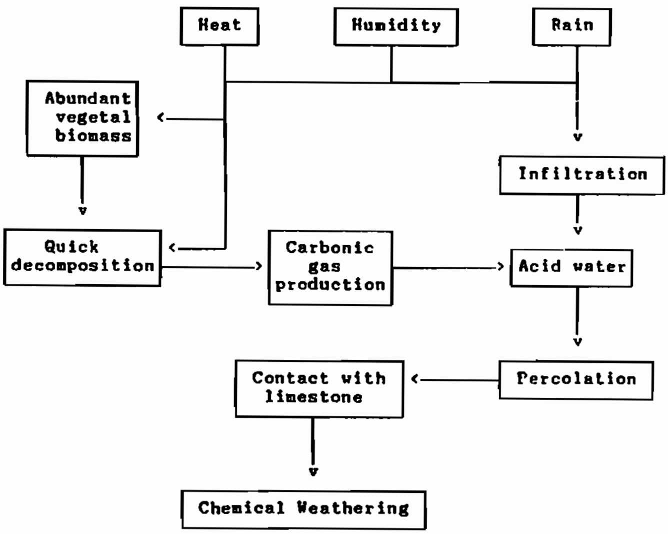


Figure 34. Chemical weathering

## 1.4. THE EROSION AND TRANSPORT PROCESS

### 1.4.1. Surface wash and overland flow

The surface wash is the downslope transport of regolith material along the ground surface through the medium of moving water. The surface wash can be divided into two main categories: the raindrop impact and the surface flow.

i) The raindrop impact causes *splash erosion*, a geyserlike splashing in which soil particles are lifted and then dropped into new positions.
ii) The surface flow can be divided into two types: the sheet *wash* and the *rill wash* (figure 35).
   - The term *"sheet wash"* is used when the ground is entirely or largely covered by a moving layer of water. When the water is very turbid another term is used: *"sheet flood"*, instead of *"sheet wash"*.
   - The term *"rill wash"* is used when the water flows mainly as micro channels. In rill wash, the channels frequently change their route on slopes. Where channels are constant in location the process is called: *"gullying"*.

In a forest environment rill wash is more common than sheet wash. Surface wash is also called *overland flow* " (figure 36).

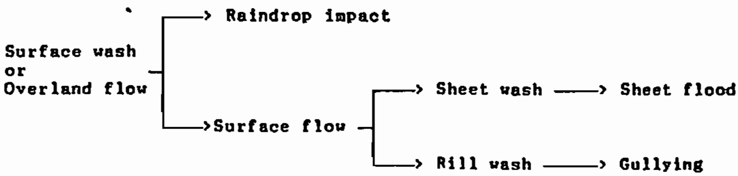


Figure 35. The different components of the surface wash

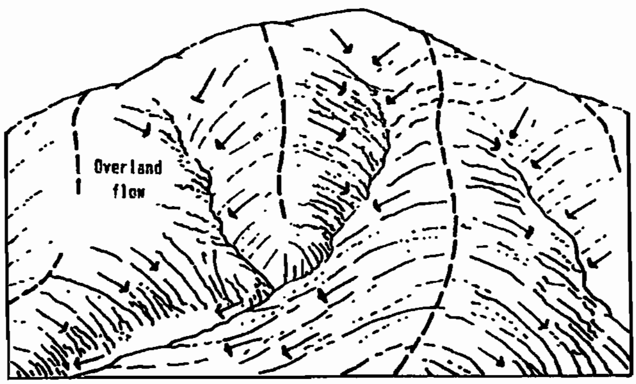


Figure 36. Overland flow from slopes (after Strahler and Strahler, 1978)

1.4.2. Soil creep

The term is applied to the extremely slow movement of soil and regolith.

1.4.3. Earth flow

This process occurs in humid regions. The term *earth flow* means any downslope movement of a mass of water-saturated soil, regolith or weak clay which move down a steep slope under the influence of gravity. An earth flow mass is always sluggish. An earthflow can take several hours. Small earth flows are common on steep forested slopes saturated by heavy rains.

1.4.4. Mud flow

This process is usually common to dry regions, but it can occur in tropical countries as cyclone Namu showed in May 1987 in Guadalcanal (figure 37).

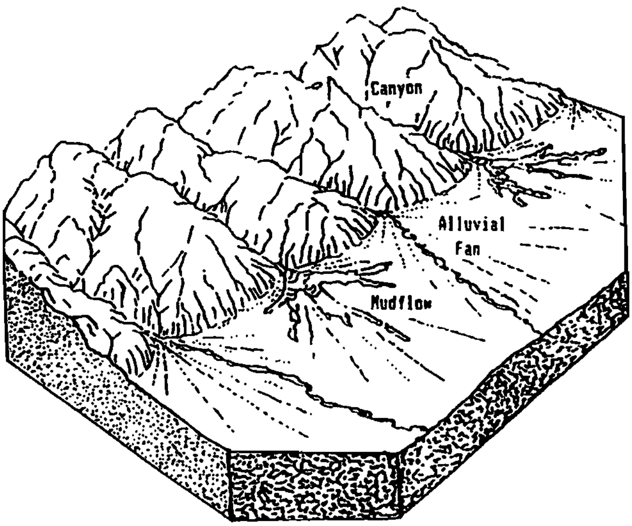


Figure 37. Mudflow on overlogged mountains (after Strahler and Strahler, 1978)

1.4.5. Landslides

*Landslides* and *earth flow* are closely related processes. The only difference is that landslide mass is always rigid, composed of regolith or bedrocks. Two basic forms of landslides are:

i) rockslide which may involve slipping on a nearly plane surface,
ii) and slump block which moves down a curved slippery surface with rotation on a horizontal axis.

# 2. BASIC CONCEPTS OF PEDOLOGY OR SOIL SCIENCE

## 2.1. WHAT IS SOIL?

A soil is a natural body having both depth and surface area. It is a complex mixture of inorganic minerals (mostly clay, silt and sand), decaying organic matter, living organisms, air and water. Soil is a product of nature resulting from both destructive and synthetic forces.

Each type of soil can be analysed in terms of:
i) colour,
ii) texture or porosity based on the percentage of sand, silt and clay particles in the soil,
iii) structure, which refers to the grade size of soil particles and the soil consistency,
iv) ratio (organic matter/inorganic minerals),
v) acidity and alkalinity,
vi) chemical composition of the soil solution, the part of the soil which is composed of air and water.

## 2.2. BASIC PEDOGENIC PROCESSES

Three main pedogenic processes can be identified:

i) addition of material to the soil body,
ii) translocation of material within the soil body,
iii) transformation of material within the soil body.

### 2.1.1. Addition of material

This process is usually called *"soil enrichment"*. Four types of soil enrichment can be identified:

i) the organic enrichment of the soil surface by decomposition of the organic litter from the vegetable biomass growing on the soil;

ii) the inorganic enrichment of the soil surface by colluvium, sediments brought by running water;

iii) the inorganic enrichment of the soil surface by sediments transported by the wind (volcanic ash for example);

iv) the inorganic enrichment by weathering and alteration of the deeper part of the soil at the contact of the bed rock.

### 2.1.2. Translocation of material

Translocation of material can be divided into two big movements:
i) the downward transport of soluble elements or colloids under the influence of infiltration and percolation;

ii) the upward movement of soluble elements, fine particles and colloids caused by the evaporation of soil water.

Translocation movements cause internal enrichment or loss of organic and inorganic material in the soil.

Eluvation and illuvation are two simultaneous downward translocations of fine particles in the upper part of the soil (figure 38).

i) Elluvation occurs just under the soil surface. It causes a removal of colloids in this zone and leaves behind coarse skeletal mineral grains.
ii) Illuvation is the accumulation of material carried out of an upper soil zone by elluviation mostly clay particles, humus (organic particles), iron and aluminium.

The translocation of calcium and salt through the reverse processes of (decalcification - calcification) and (desalinisation - salinisation) are also very important.

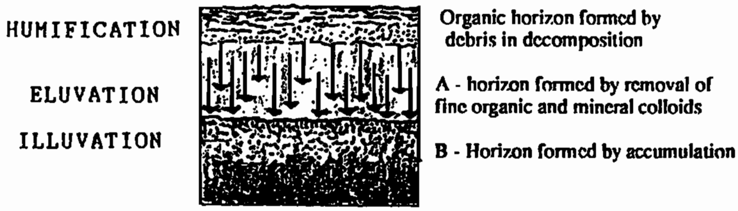


Figure 38. Humification, eluvation and illuvation

2.1.3. Transformation of material

Oxidation and hydrolysis are the main chemical processes affecting the inorganic material. They transform by decomposition primary mine-minerals such as feldspars to secondary minerals such as bauxite; new minerals can be synthesised from the products of decomposition. Humification is the transformation process affecting organic material. By humification plant tissues are transformed into humus.

## 2.2. HORIZONATION

### 2.2.1. The soil horizons

Pedogenic process cause the stratification of soil into horizons. Five horizons are commonly identified (figure 39).

a) The first horizon is an organic horizon, called 0 horizon. In fact two 0 horizons are usually identified:
   i) 01 horizon, which is formed of loose leaves and organic debris, largely undecomposed,
   ii) 02 horizon, which consists largely of humus.

b) The second horizon is the first material horizon, called A horizon. This horizon is often divided into two subhorizons called A1 and A2:
   i) the A1 horizon is a dark coloured horizon of mixed minerals and organic matter, it is rich in humus with much biological activity;
   ii) the A2 horizon is characterised by a maximum of elluvation.

c) The third horizon is still a mineral horizon called E horizon; it is a transition horizon between horizons A and B. The E horizon is characterised by a low concentration of organic and inorganic matter.

d) The B horizon is the third mineral horizon. It is characterised by a high illuvation of mineral matter which is accompanied by a maximum accumulation of silicate clay minerals or of sesquioxides and organic matter.

e) The last horizon, called C horizon, is a mineral layer of regolith or sediment with poor biological activity.

The fertility of the soil is concentrated in 0, A1 and B horizons.

### 2.2.2. Horizons and soil fertility in tropical forests

In tropical forest countries, the most common types of soil are "*oxisols*". They are characterised by the extreme weathering of most minerals to sesquioxides of aluminium and iron and to kaolinite.

Usually oxisol horizons are not very distinct except for the dark surface layers, 0 horizons, in which most of the fertility of the soil is concentrated. A2 and E horizons with very poor nutrient contents are very large and only the roots of the big forest trees can reach B horizon where they pump minerals accumulate by illuvation (figure 40).

## 2.3. SOIL AS A SYSTEM

From a cybernetic point of view, soil can be seen as a black box in contact with two types of flux:

i) soil forming factors acting as input flux in a process called pedogenesis;
ii) soil erosion factors acting as output flux in a process called morphogenesis.

### 2.3.1. Pedogenesis

Pedogenesis is the result of six soil forming factors: climate, vegetation, animal organisms, parent material rock, relief (topography) and time. At each period of its

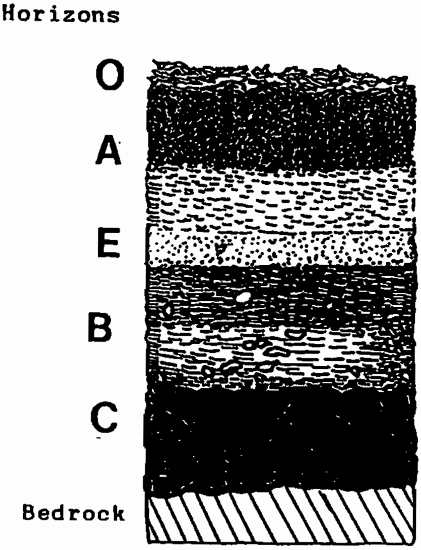


Figure 39 -

The soil horizons

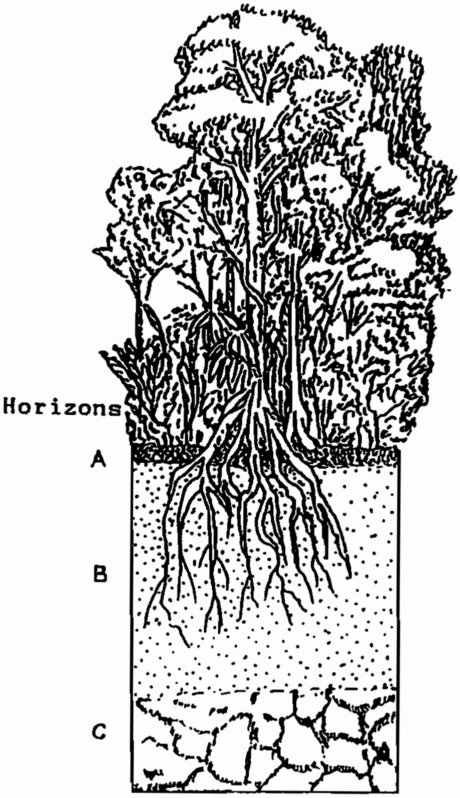


Figure 40 -

Horizons and soil fertility in tropical forests evolution a soil results from the interactions of these six variables as shown in the following equation:

$$S = f(C, V, O, P, R)\, t0$$

Where 0: animal organisms, C: climate, V: vegetation, P: post material, R: relief, t0: relative age.

### 2.3.2. Equilibrium between pedogenesis and morphogenesis

If soil is a function of pedogenesis as the last equation shows, soil is also a function of morphogenesis. If this morphogenesis is more dynamic than pedogenesis, a soil disappear in several weeks, months or years by erosion.

The concept of equilibrium between pedogenesis and morphogenesis leads to the typology of soils into three groups:

I) Mature soils where pedogenesis equals morphogenesis. In using EHRART's (1956) theory of biorhexistasy, we call mature soils "*soil in biostasy*".

II) Immature soils, still in formation, where pedogenesis is more intensive than morphogenesis. According *to EHRART's classification, immature soils are* "soils in positive rhexistasy".

III) Eroded soils, where pedogenesis is less intensive than morphogenesis, these soils can be called "*soils in negative rhexistasy*" according to EHRART's theory of biorhexistasy.

Figure 41 gives a summary of the soil system.

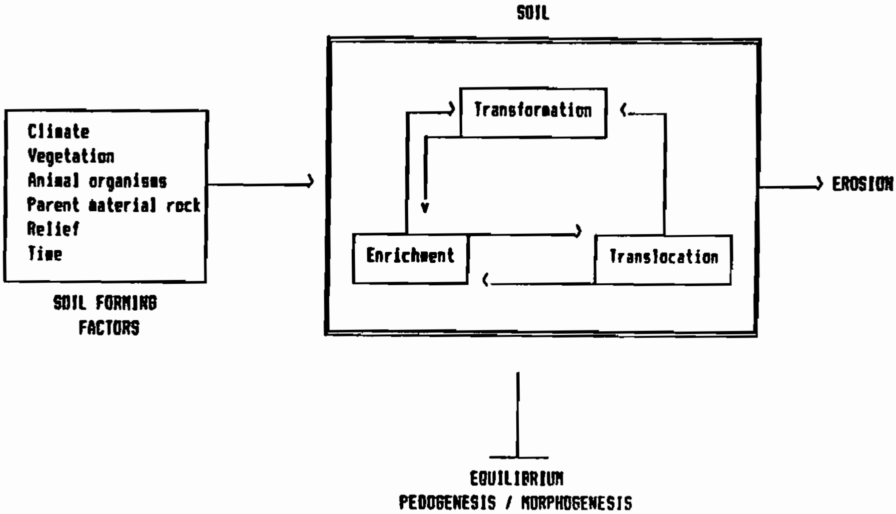


Figure 41 - The Soil System

To conclude this talk, we must keep in mind that the morphology and soils are essential parameters to explain vegetation distribution in the high islands of the Pacific. Both are very sensitive to any natural and anthropic (man made) disturbance which might cause erosion and a complete loss of soil fertility.

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## ACKNOWLEDGMENTS

I wish to thank Miss Alfreda MABONLALA for the drawings.

# CLIMATE AND VEGETATION IN MELANESIA

*by Gilbert DAVID*
*ORSTOM - PORT VILA*

## 1.THE CLIMATE: A MAJOR ENVIRONMENTAL FACTOR FOR VEGETATION

### 1.1. THERMAL CYCLES AND ZONES

#### 1.1.1. Latitudinal variations and thermal amplitude

Except in the heart of Papua New Guinea, all Melanesian islands are the tropical west coastal zone. This climatic zone is characterised by a weak annual cycle of temperatures and no extreme heat. In the tropical west coastal zone, the daily thermal amplitude (the difference of mean temperature between the hottest and the coolest hours of the day) is greater than the seasonal thermal amplitude.

Table 7 deals with the situation in Vanuatu, seen as an example of the tropical west coast zone of temperature. This data was collected from the six meteorological stations of Vanuatu over the last 30 years. The table shows:

i) the average yearly minimum temperatures (T min),
ii) the average yearly maximum temperatures (T max),
iii) the yearly average temperatures, AT = (T min + T max) / 2),
iv) the thermal amplitude (T max - T min).

Table 7. The yearly mean temperatures in Vanuatu (1961-1983), from STUBER and AUTONES (1985)

| | Tmin | AT | Tmax | Tmax-Tmin |
|---|---|---|---|---|
| Vanua Lava | 23.3 | 26.1 | 28.8 | 5.5 |
| Santo | 22 | 25.2 | 28 | 6 |
| Malakula | 22.8 | 25.9 | 29 | 6.2 |
| Efate | 21.4 | 24.8 | 28.1 | 6.7 |
| Tanna | 20.2 | 23.8 | 27.4 | 7.4 |
| Aneityum | 20 | 23.5 | 26.8 | 6.8 |

According to table 7, temperatures decrease with the latitude when we move from the north of the country to the south. Thermal amplitude increases.

Table 8 shows the seasonal thermal amplitude in Vanuatu. Four periods "seasons" are considered: Winter, from July to September; Summer, from December to April; and two transitional seasons, May - June and October - November.

Table 8 - Seasonal temperature variation in Vanuatu (1961-183), from DAVID (1990a)

| | May-June | July-Sept | Oct-Nov | Dec-April |
|---|---|---|---|---|
| Vanua Lava | 26.1 | 25.4 | 26.0 | 27.7 |
| Santo | 24.8 | 24.2 | 25.1 | 26.0 |
| Malekula | 25.5 | 24.5 | 25.8 | 26.8 |
| Vila | 24.0 | 22.8 | 24.6 | 26.3 |
| Efate | 23.0 | 21.4 | 23.6 | 25.6 |
| Aneityum | 22.5 | 21.0 | 23.0 | 25.2 |

### 1.1.2. Altitude variations and ground effect

Temperature decreases with altitude from 0,5$^{0}$ to 0,6$^{0}$c each 100 meters. Example: if the temperature at sea level is 25$^{0}$c, snow would be found between 4,500 and 5,500m altitude.

At the same altitude (eg. 1,000 m) the thermal amplitude is less above the open sea than on the ground, this is called the "*ground effect*".

## 1.2. THE WINDS

Four main features characterise the wind regime patterns in the Melanesian islands.

a) The trade winds are the prevailing winds. They blow from the east-south east from April to August-September.

b) Winter is the calm season.

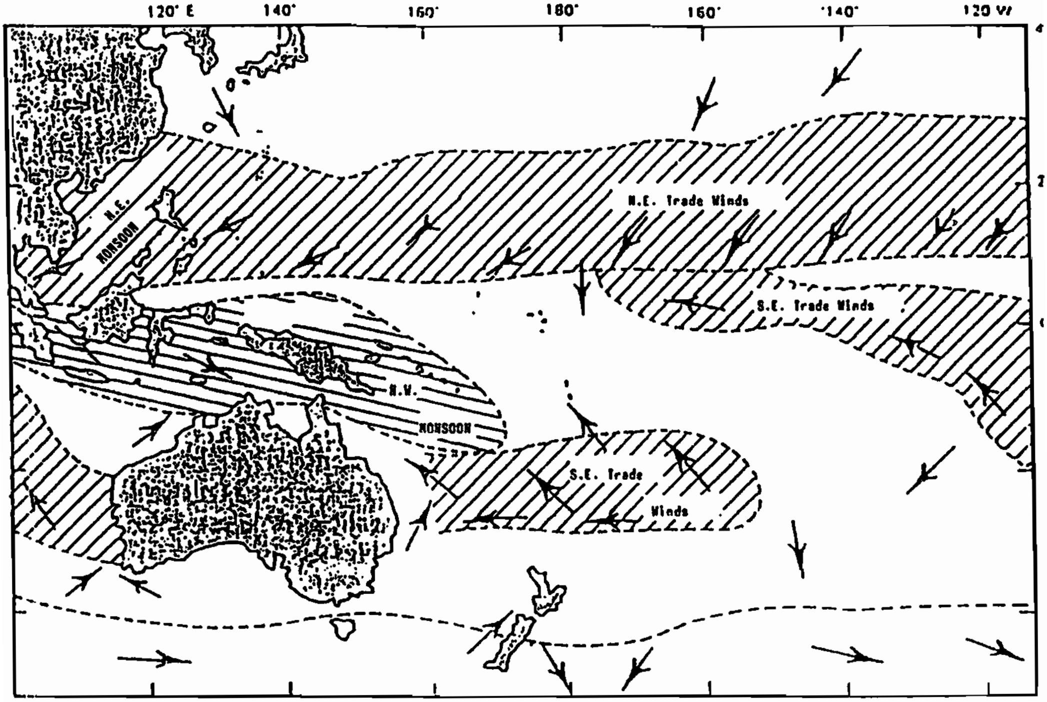



Figure 42. Monsoon and trade winds in the South West Pacific
(After SHOM, 1984)

c) Winter is the Monsoon season close to the Equator. In Melanesia, the North West Monsoon affects all the Solomon Islands and can reach the North of Vanuatu (figure 42).

d) Winter is the cyclone season.

Cyclones need a sea temperature higher than 27 degrees C and a high instability in the troposphere (9,000 m of altitude). Cyclones are not common in the Solomon Islands which are too close to the Equator. A cruel exception to the rule was cyclone "Namu" in 1986.

In theory, cyclones can affect any equatorial and tropical place located at $5^{o}$ - $10^{o}$ latitude minimum. Figure 43 shows the number of tropical cyclones that crossed each $5^{o}$ square of the South pacific region from November 1039 to April 1969. In fact, most of the zones affected by cyclones and tropical depressions lie between $15^{o}$ and $25^{o}$ latitude, the latitude of the Vanuatu archipelago. From 1940 to 1985, 58 cyclones and tropical depressions crossed the archipelago of Vanuatu (DAVID, 1990 b)

Figure 44 shows the origin and movements of cyclones in the South Pacific. All of them appear between $5^{o}$ and $15^{o}$ latitude. Three zones of cyclone formation may be identified:

i) North of Fiji and West of Wallis and Futuna between Tuvalu and Rotuma Island;

ii) West of the Solomon Islands;

iii) North West of the Coral Sea, to the South of PNG.

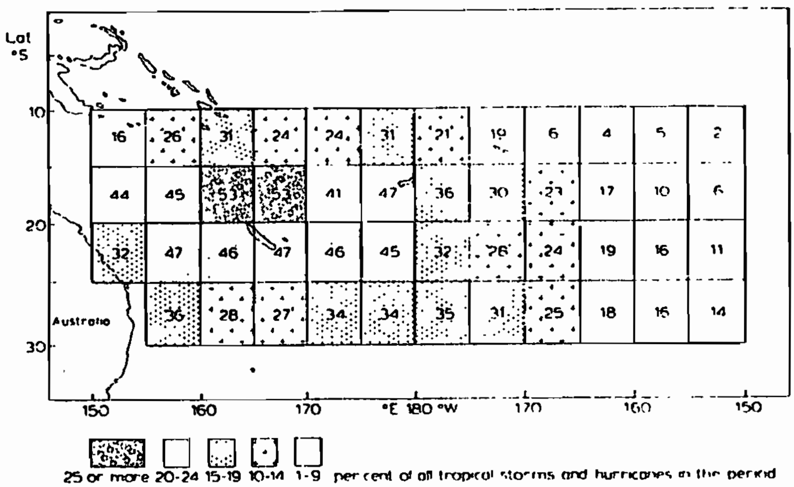



Figure 43. Number of tropical cyclones that ccrossed each 5-degree square in the 30 "seasons" November 1939 to April 1969. Shading shows percentage of total storms (After Kerr, 1976).

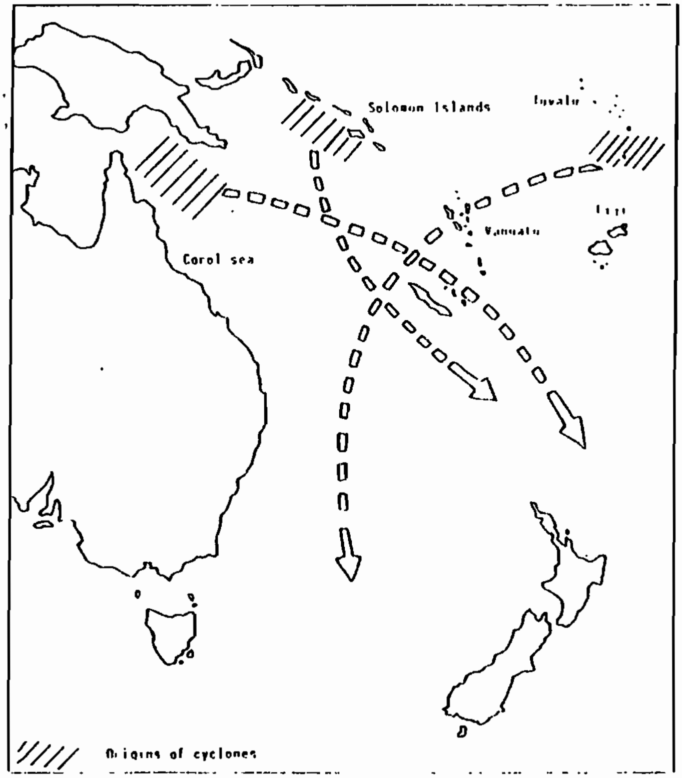



Figure 44. Origins and movements of cyclones in the South-West Pacific

## 1.3. PRECIPITATION

A maximum of precipitation, more than 5,000mm of rainfall as a yearly average, occurs in the south-east of the Solomon Isl. (Figure 45). Table 9 shows the seasonal precipitations in Vanuatu.

In all meteorological stations, the summertime from December to April is the wet season. Wintertime, July to September, is the dry season.

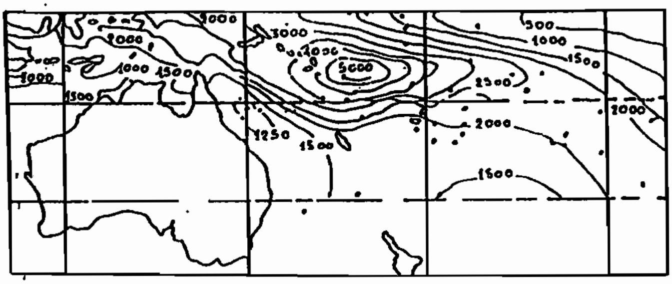



Figure 45. Means of Rainfall all the year round in the South West Pacific
(After Taylor, 1973)

Table 9 - Seasonal precipitations in Vanuatu from Stuber and Autones (1985)

| | Dec-Apr | May-Jun | Jul-Sep | Oct-Nov | Yr Rd |
|---|---|---|---|---|---|
| Vanua Lava | 403 | 355 | 245 | 376 | 4,215 |
| Santo | 317 | 203 | 140 | 209 | 2,832 |
| Malekula | 241 | 149 | 92 | 152 | 2,080 |
| Efate | 276 | 151 | 106 | 141 | 2,281 |
| Tanna | 183 | 103 | 76 | 69 | 1,486 |
| Aneityum | 259 | 158 | 122 | 139 | 2,254 |

## 1.4. THE HYPER HUMIDITY OF HIGH ISLANDS

The tropical islands affected by trade winds are characterised by an inversion layer around 3,000m altitude which borders a dry air subsidence above and convection and evaporation of wet air underneath (figure 46).

The intensity and frequency of precipitations changes according to the altitude.

a) In High Islands a maximum of rainfall occurs between 1,000 and 1,200m (figure 47).

b) Up to the level of maximum rainfall is a zone of continuous rainfall from 1,200-1,400m to 1,600-1,800m. With the altitude the drops become smaller and smaller. From 1,600-1,800m to 2,200 to 2,400m a very thin rainfall level is reached. The zone of continuous rainfall and the zone of very thin rainfall are characteristic of the rainfall forest.

c) The "mist zone" also called "the cloud sea" stands between the inversion layer and the thin precipitation level from 2,200-2,400 to 3,000-3,500m. In botanical terms this zone is characteristic of moss forest.

d) In a low unsaturated atmosphere a process of evaporation causes a decreasing of the drop sizes. The evaporation is so high that the drops di$appear before reaching the soil (CABAUSSEL, 1984).

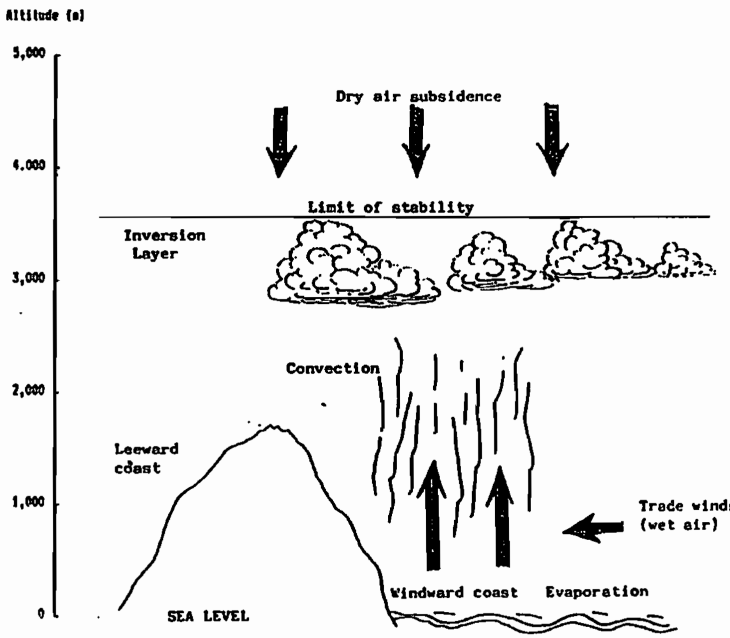



Figure 46. Air movements in a South Pacific Island

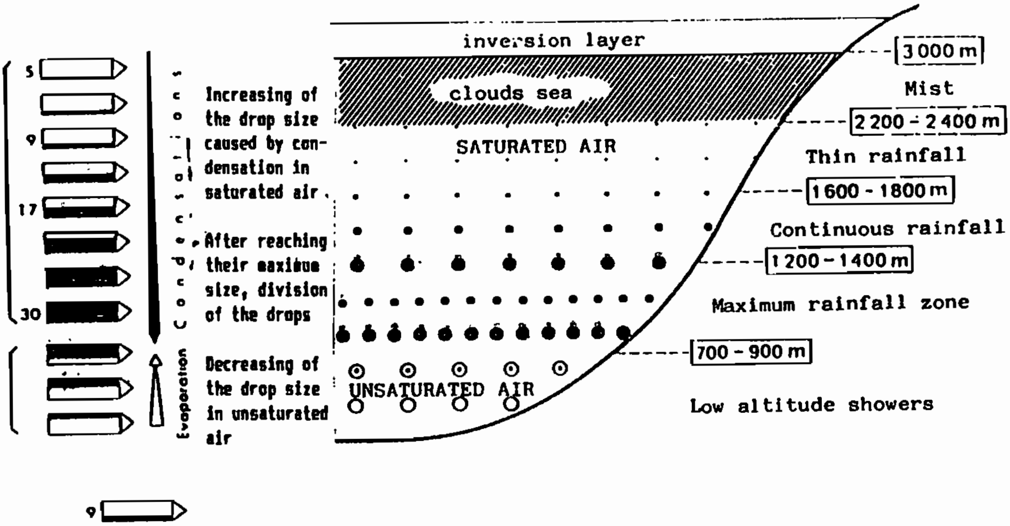



Figure 47. A model of rainfall related to altitude in tropical islands (After Cabaussel, 1984)

## 2. VEGETATION AND CLIMATE

Vegetation distribution is closely linked to climatic factors.

### 2.1. THE INFLUENCE OF ALTITUDE AND HUMIDITY ON VEGETATION

a) Coastal vegetation grows in sunny conditions. Coconut trees, yams and cassavas are three typical coastal plants. Coconut trees rarely grow above 600m altitude in Vanuatu.

b) Rain forest grows in cloudy and wet conditions where taro is also grown.

c) Moss and high altitude shrubs grow at "cloud sea" level which is characterised by a permanent mist and cool temperatures of less than 15$^{o}$ C, up to 5$^{o}$ - 10$^{o}$ C, around 3,000m.

### 2.2. THE CONTRAST BETWEEN WINDWARD AND LEEWARD COASTS

The leeward coast of high islands is drier than the windward coast and slopes covered by rainfall forest.

On the leeward coast of many islands some xeromorphic adaptation such as savanna called white grass and dry forest may be noted.

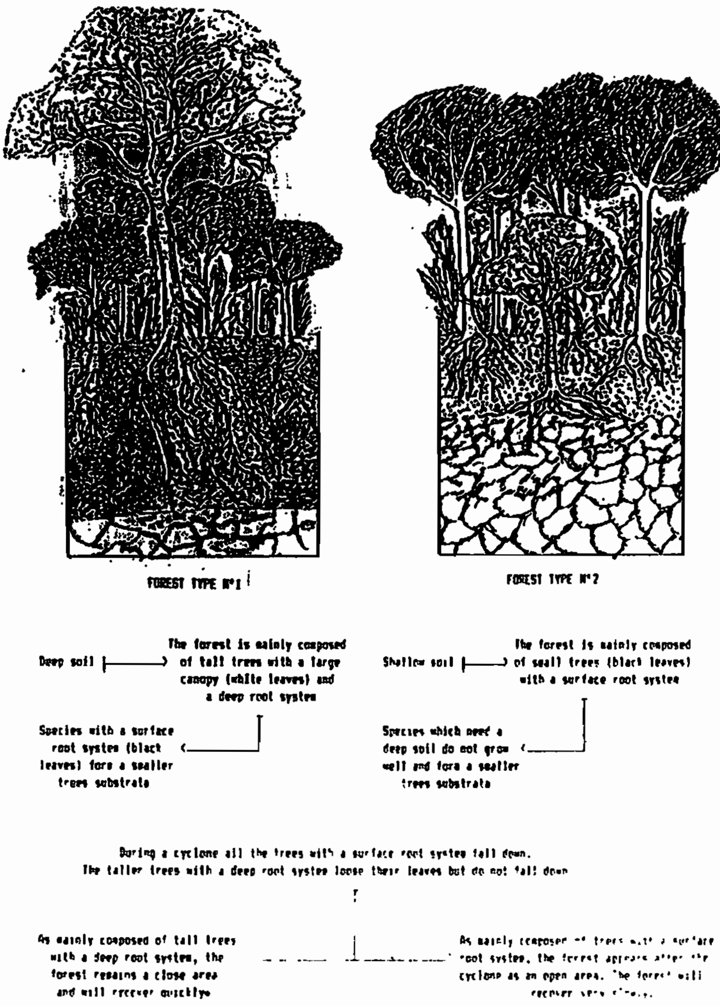
On the leeward plain of Guadalcanal Themeda australis is a good example of a white grass area component.

On the leeward coast of Efate the dry forest grows to 300m altitude. Legumenous trees such as *Acacia spirorbis*, *Leucaena glauca* or *Leucaena leucocephala* and *Acacia forneslana* are the main shrubs which characterise dry forest and grass land savanna.

## 2.3. THE INFLUENCE OF CYCLONES

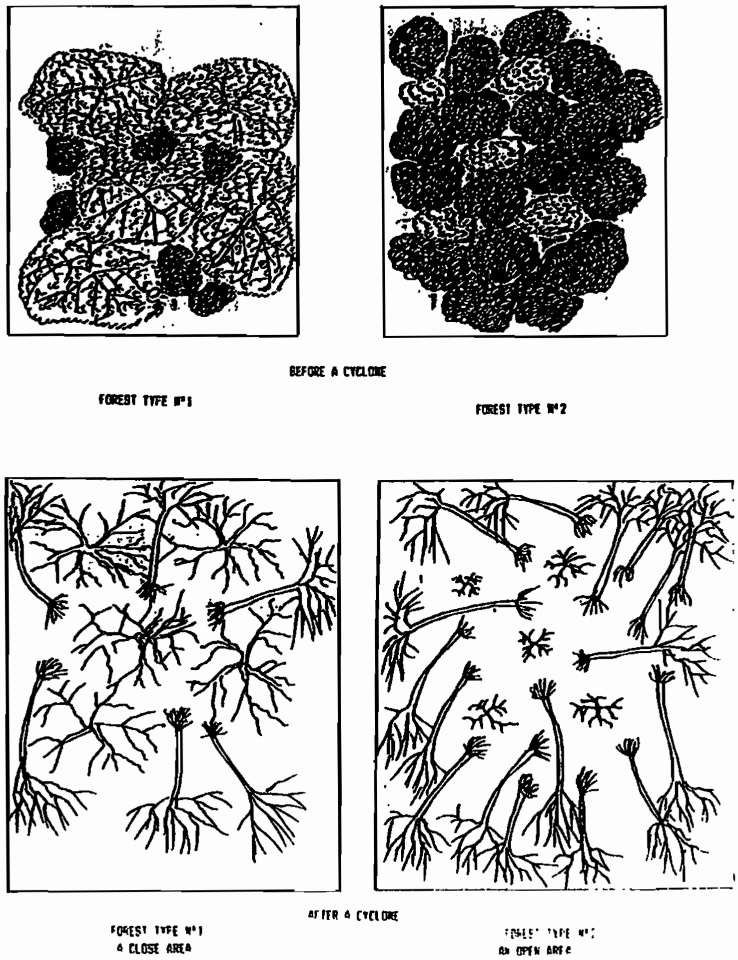
Cyclones are a disaster for food crops, especially fruit trees such as bananas, citrus and mango, but also for the forest, especially if the deeper horizon of the soil is too compact. In this case, the three roots are concentrated on the solum and this constraint cause a heavy selection among the trees. Trees which grow faster with superficial roots are advantaged but these trees are very sensitive to wind blow. Figure 48 shows the relationships between the structure of the soil, the resistance of the trees to cyclones and the composition of the vegetation.

Two cases are presented, a soft soil with deeper horizons which allow the growth of tall trees and a shallow soil where fast-growing trees with superficial roots, a small canopy and low resistance to cyclones effect are in the majority. The combination of superficial roots, quick growth and low resistance to cyclones could explain the low density of big trees in Efate and the low economical value of the forest which is mainly composed of small trees.




a) Lateral side view

Figure 47. Relatations between the depth of the soil, the forest vegetation's composition and the resistance of the trees to cyclones




b) aerial view

Figure 47. Relatations between the depth of the soil, the forest vegetation's composition and the resistance of the trees to cyclones

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# ENERGY FLOW AND MATERIAL CYCLES IN TROPICAL FORESTS

*by Gilbert DAVID*
*ORSTOM - PORT VILA*

## 1. GLOBAL RADIATION BALANCE

Two types of energy acting as input in the forest ecosystem may be identified : gravitation and solar energy. Figure 48 shows a schematic diagram of the global radiation balance.

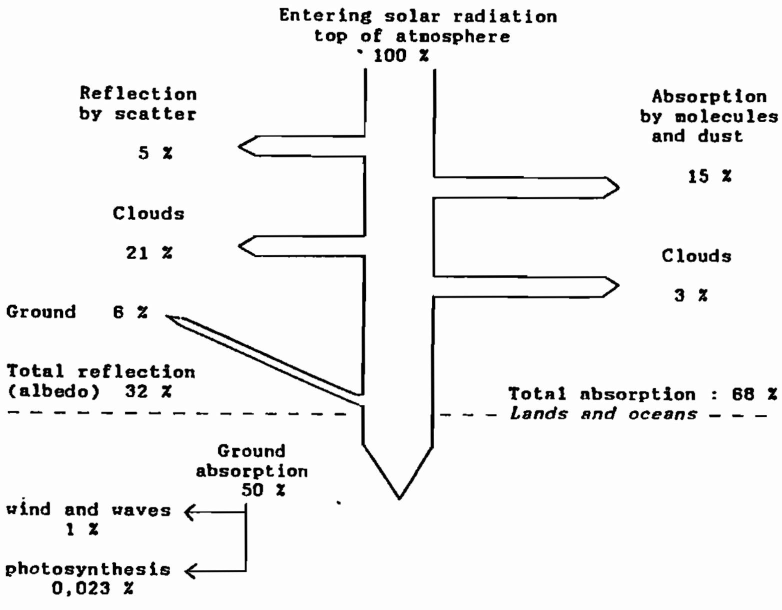


Figure 48 The global radiation balance

## 2. THE ROLE OF PLANTS IN ENERGY FLOW AND MATERIAL CYCLES

Vegetation lies at the interface between the ground and the atmosphere. Plants are the first component of the terrestrial ecosystem to receive solar radiation composed of shortwave radiation (ultra violet and visible).

## Lecture notes

i) Plants use the shortwaves of solar energy for the photosynthesis of carbon hydrate molecules which are used for cell respiration and for the building of vegetal tissues. Only 0,023 % of the total solar energy radiation entering the atmosphere is used for photosynthesis (figure 48).

ii) Plants absorb infra-red radiation (longwave) which increases the temperature of their tissue surface. Without regulation this temperature increase could destroy the leaves. Plant transpiration is the thermal regulation which avoids this threat.

Figure 49 shows plants as a "black box" system where :

i) inputs are solar shortwave radiation, longwave radiation and air oxygen,
ii) outputs are carbon material coming from photosynthesis,
iii) transpiration acts as a feed back regulation of the system to avoid disturbance caused by temperature increase and allow a maximum of efficiency to photosynthesis.

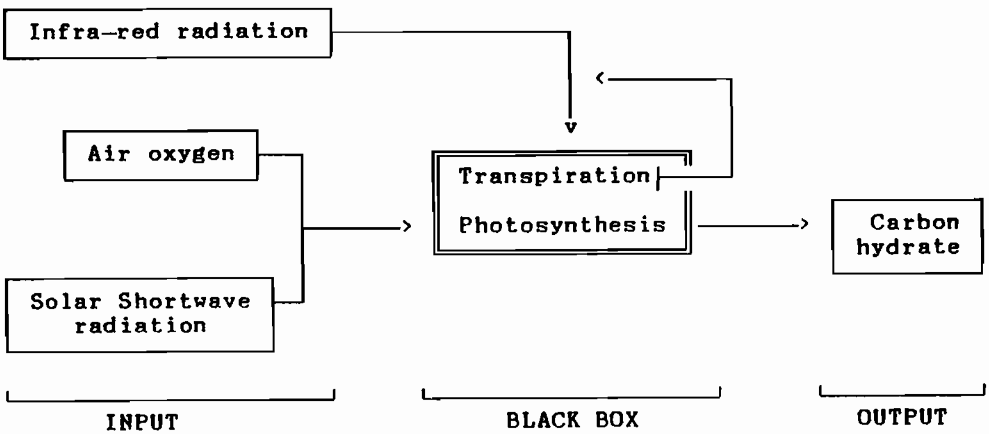


Figure 49 - Solar energy flow in the Plant system

If by photosynthesis, the plants change the solar energy flux reaching the ground, plants also play a key role in the water cycle and nutrients cycle in the soil through the hydric flux caused by transpiration. With their roots, plants pump water and soluble nutrients into the soil by osmotic pressure. Under the form of sap, water moves in the plants from the roots to the leaves where under the form of water vapour it evaporates into the atmosphere by transpiration.

Plant Tissues are composed of water, minerals, carbon and energy. Energy is stored in the joints between small molecules. The more complex the molecules are, the richer in energy they are.

Each year, each square kilometre of tropical forest produces an abundant biomass of living organic matter and an abundant waste composed of dead organic matter. With this waste, vegetation plays a key role in pedogenesis and soil fertility. Dead leaves are mainly composed of glucides (starch, hemicelluloses, celluloses); lignite (10 to 30%) and small quantities of proteins. The decomposition of this dead organic matter is the result of decomposers. Decomposers are microconsumers such as bacteria, fungi, insects and worms, which break down complex molecules to obtain energy. There are two methods of waste decomposition.

a) The first one is a mechanical decomposition. Eaten by a multitude of small animals such as slugs, snails, ants, arthropods and worms, plant tissues are transformed into small pellets of faeces, dead animals, shells,.

b) The second one is a chemical decomposition of plant tissues, mainly membranes and parenchymes. Sugar, starch, hemicelluloses and proteins are easily decomposed by bacteria and fungi. Pectines and celluloses are not so easily decomposed. Decomposition of lignine is very slow and difficult to accomplish. All these products are transformed into simpler chemicals to be finally evaporized into carbonic gas ($CO_2$), hydrogen ($H_2$) and methan ($CH_4$) or mineralised into nitrogen (N), phosphorus (P) and potassium (K).

Decomposition of litter produces humus (organic material) and minerals whose migration by leaching in the soil cause horizonation. The formation of humus and horizonation are the main components of pedogenesis.

Figure 50 shows the organic matter cycle in a tropical forest.

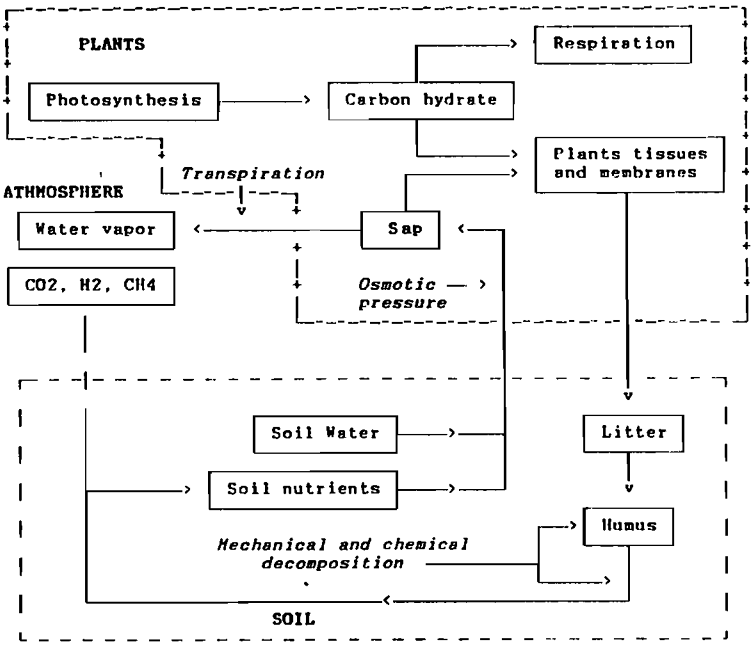


Fig. 50. The organic matter cycle in a tropical forest.

## 3. THE WATER CYCLE

### 3.1. GENERAL OVERVIEW

Figure 51 shows an overview of the water cycle mainly based on seven processes:

i) precipitations (rainfalls and mist in tropical countries)
ii) evaporation from soil, from vegetation, from streams and ponds;
iii) transpiration;
iv) surface run off;
v) infiltration;
vi) lateral movement of water in soil;
vii) percolation.

The complete water cycle may be briefly summarised in the following equation:

$$P = E + G + R$$ Where

P: precipitation,
R: water surplus, E: evapotranspiration, G: change in soil water storage

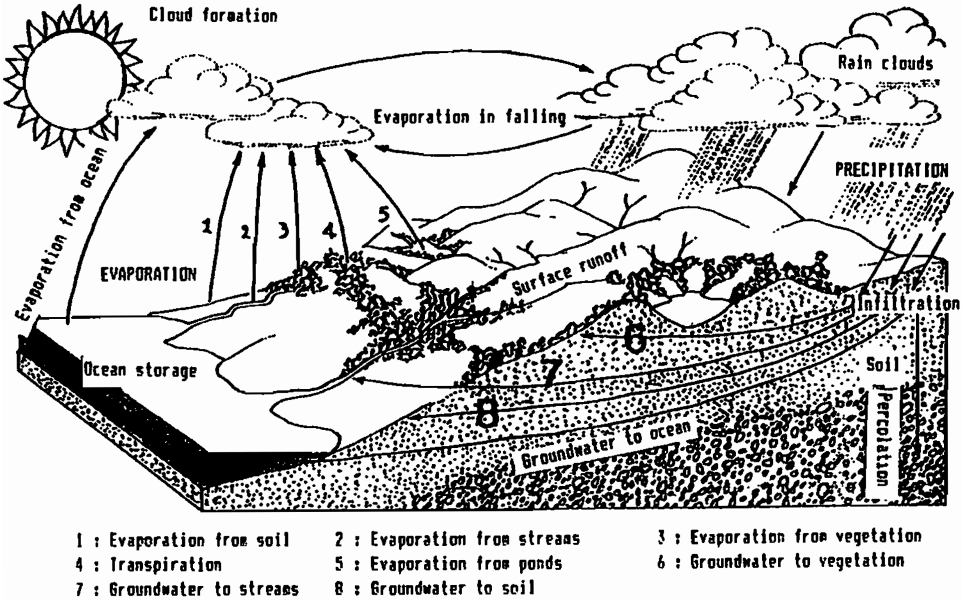


Figure 52 - The water cycle (After Tyller Miller, 1988)

In evapotranspiration two processes are combined: the transpiration of plant tissues, the evaporation of water on plant leaves and in the soil.

## 3.2. THE RAINFALL

Rainfall play a key role in soil erosion by the impact of raindrops. This impact is caused by the kinetic energy of raindrops. Kinetic energy of raindrops is a function of three parameters:

i) the distance between the clouds and the soil, the further the distance is, the more energetic and destructive is the impact of the drop on the soil;
ii) the air resistance, a big air resistance reduces the kinetic energy of drops;
iii) the size and the mass of drops.

When a raindrop reaches the soil, it causes a geyserlike splashing. Soil particles are lifted and then dropped into new positions. This process is called splash erosion. Particles shifted by raindrop splash tend to seal the natural soil opening, reducing the infiltration of rainwater in the soil and increasing the sheet wash and soil removal.

## Lecture notes

On bare ground, splash erosion is a function of three parameters:

i) the kinetic energy of raindrops;
ii) the duration of the shower;
iii) the soil resistance to erosion which heavily depends on the texture and the structure of the soil.

Lying at the interface between atmosphere and ground, vegetation plays a key role in reducing splash erosion. The main effect is the interception of raindrops by tree canopy. The kinetic energy of raindrops acts on leaves and branches without direct effect on the ground surface.

i) In total, 35% of the rainfall reaching the canopy will evaporate and will never reach the soil.
ii) The rain water washes along the branch any removing obstacles and causing a concentration of running water which flows down into gutters, to the next branch or to the leaves underneath.
iii) By guttering from 5% to 10% of the total rainfall reaching the canopy runs along the branches to the trunk. The water washes along the trunk and disappear at its base by infiltration.
iv) By guttering from 55% to 60% of the total rainfall reaching the canopy runs along the branch to the apex of the leaves and reaches the soil after a fall of several meters during which drops concentrate kinetic energy.
v) The size and the mass of these guttering drops is bigger than the raindrop size. However their kinetic energy is less, the distance of impact being incomparably smaller.

As in the case of raindrops, the effect of guttering drops on the soil is heavily influenced by the soil resistance to erosion. In tropical forests this resistance is very high. A layer of dead leaves of several centimenters thick covers the soil, breaking the kinetic energy of guttering drops and avoiding splash erosion. The decomposition of this layer and humification is the first step of pedogenesis. So waste has a direct influence on the texture and the structure of the soil. In fact, the resistance of soil to erosion is a direct function of the status of the neighbouring vegetation and the agricultural practice when logged areas in the forest are used for shifting cultivation or cash crops.

A good example of the importance of agricultural practice to avoid splash erosion is given by coffee plantations. Soil resistance to erosion in coffee plantations depends on the density of the tree cover. Because of the shape of their leaves, coffee shrubs have heavy guttering. This is the reason why the soil underneath and in the surroundings is sensitive to splash erosion and needs tree cover, also useful for the coffee which likes shady areas.

Forest trees which provide an abundant litter of leaves seem better able to grow coffee underneath than coconut trees which give poor protection against splash erosion. A good litter means also a better soil permeability and a better nitrification, in fact a better soil fertility and indirectly better yield.

## 4. CONCLUSION

To conclude figure 53 shows a synthesis on the function of climate in the environmental processes of the life layer.

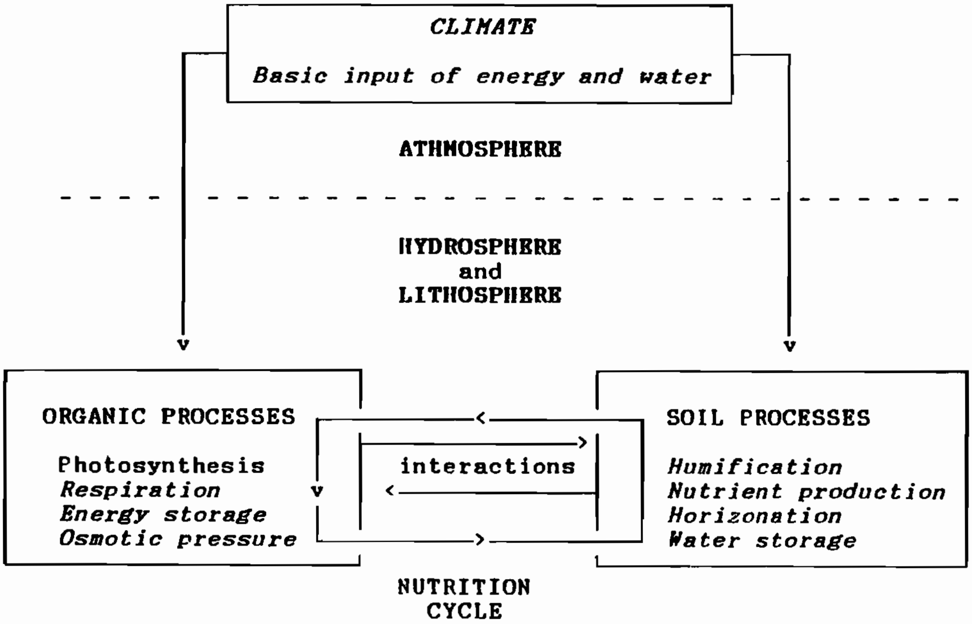


Figure 53 - Climate, plant organic processes and soil processes

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Philippine Sea
FEDERATED STATES OF MICRONESIA
PALAU
MARSHALL ISLANDS
NAURU
KIRIBATI
(IRIAN JAYA)
PAPUA NEW GUINEA
SOLOMON ISLANDS
TUVALU
CORAL SEA
VANUATU
FIJI
NEW CALEDONIA
AUSTRALIA
Tasman Sea
NEW ZEALA