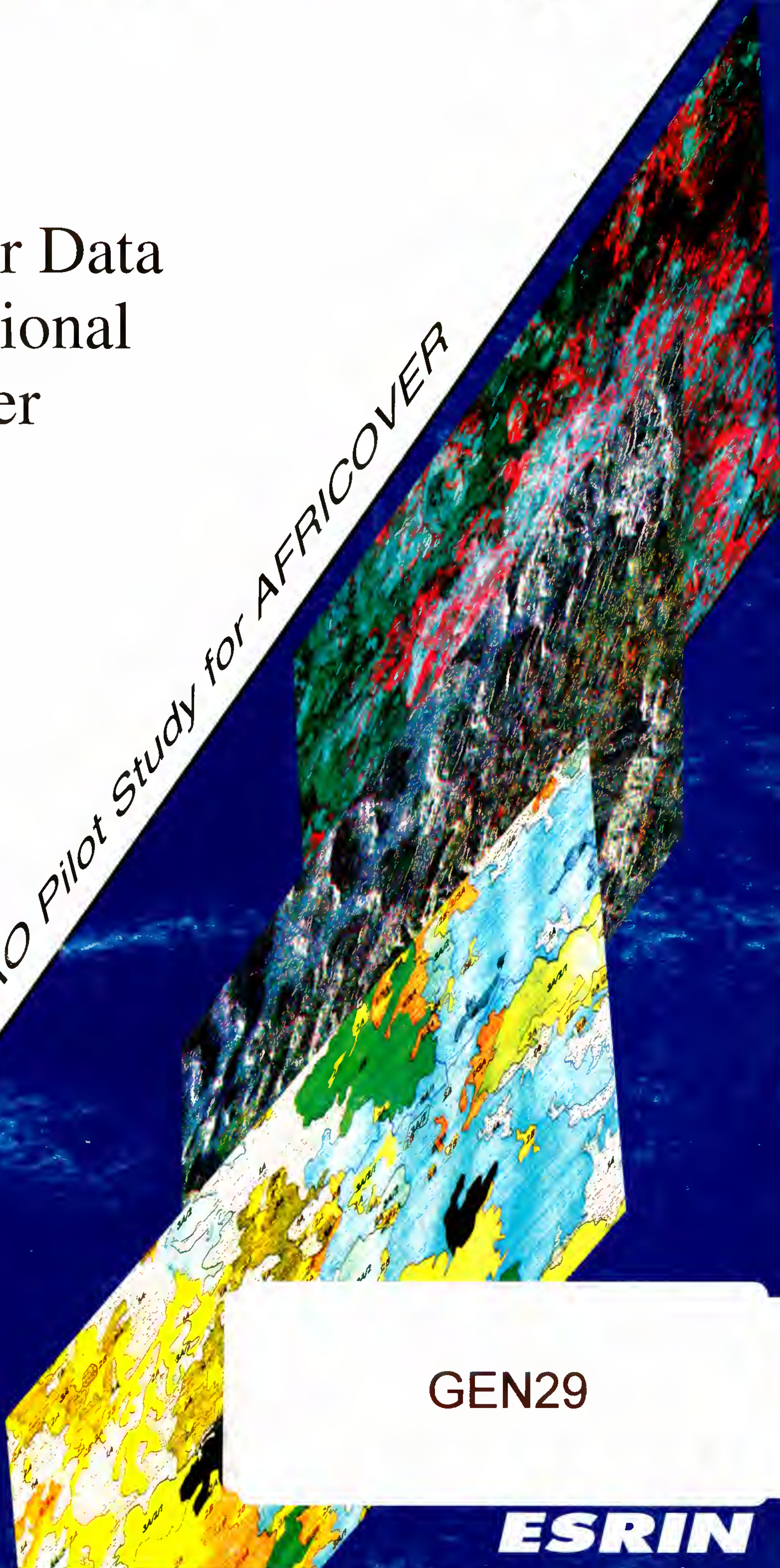
ERS Radar Data for Operational Land Cover Mapping

An ESA/ESRIN-FAO Pilot Study for AFRICOVER



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ERS Radar Data for Operational Land Cover Mapping

- An ESA/ESRIN-FAO Pilot Study for AFRICOVER -

September 1996

Authors

This Report illustrates the results obtained during the ESA-ESRIN/FAO Pilot Study conducted within the Remote Sensing Exploitation Department of ESA/ESRIN by Gianna Calabresi and Juerg Lichtenegger, with contributions from Jarkko Koskinen, presently with the Helsinki University of Technology, Finland.

The Report has been prepared with the help of Dominique Lantieri, Project Representative for FAO, and Antonio di Gregorio, an ESA/FAO Consultant, both of whom contributed significantly to the Pilot Study's execution and results.

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Table of Contents

1. Introduction

1.1. AFRICOVER
1.2. Implementation of AFRICOVER
1.3. Use of satellite remote sensing data for AFRICOVER

2. ESA/ESRIN-FAO Pilot Study "ERS Radar Data for Operational Land Cover Mapping in AFRICOVER"

2.1. Background and objectives
2.2. The ERS radar data experiment

3. Work Methodology

3.1. Land cover definition
3.1.2. Land cover identification versus mapping
3.2. Methodological approach
3.2.1. Principles
3.2.2. Preparation of optical data
3.2.3. Preparation of ERS radar data

4. Image Interpretation

5. Results

5.1. Test site area 1
5.1.1. Brief of the area description
5.1.2. Results and discussion
5.2. Test site area 2
5.2.1. Brief of the area description
5.2.2. Results and discussion
5.3. Test site areas 3 and 4
5.3.1. Brief description of the areas
5.3.2. Results and discussion

6. The Operational Use of ERS Radar Data in General, and for AFRICOVER in Particular

6.1. Operational use of ERS radar data in general
- Optimal scale
- Digital processing and/or type of product used
6.2. Use of ERS radar data in AFRICOVER
6.2.1. Use of ERS radar to replace optical data in equatorial zones
6.2.2. Use of ERS radar data to:
(a) update land cover information derived from old optical data
(b) complement the interpretation made with partially cloudy optical data in equatorial zones
6.2.3. Use of ERS radar data to increase the number of land cover classes mapped in equatorial zones and/or to improve their mapping accuracy
6.3. Final remarks
6.3.1. Data acquisition and programming
6.3.2. Technology transfer

APPENDIX - Material used
- Digitised maps of the test site areas

Summary

As a follow-up to the Technical Consultation Meeting on the AFRICOVER Project, hosted by the Economic Commission for Africa (ECA), in cooperation with FAO, in July 1994 in Addis Ababa, Ethiopia, ESA and ESRIN decided to support a Pilot Study by FAO based on the utilization of ERS radar data for land cover change issues. The aim of this Pilot Study was to assess ERS radar data's capabilities to assist in the land cover mapping activities foreseen in the FAO's AFRICOVER Project. The primary objective of AFRICOVER is to prepare a standardized, georeferenced topography and land cover database for all African countries, at an average scale of 1:200,000/250,000.-

This Report provides a detailed description of the joint ESA, ESRIN and FAO Pilot Study experience, including descriptions of the test sites selected, work methodology, image interpretation, results and final recommendations.

The four test sites selected to evaluate ERS Synthetic Aperture Radar (SAR) data are representative of different environments in Africa, one being located in a tropical humid zone (Fouta Djallon, Guinea), one in the Sahelian environment (Sokolo, Mali), and two in an equatorial region (Kananga and Kasai River, Zaire).

Before being analyzed using visual interpretation techniques, the ERS SAR data sets were preprocessed:

- radiometrically, first through the application of a low pass 3*3 pixel window filter to data rescaled to 30 m resolution, and then by applying a manual linear contrast stretch on data reduced to 8 bits;
- geometrically, by performing a first-order polynomial function transformation on the multidata channels of each scene, with subsequent application of nearest-neighbour interpolation to register the ERS radar data correctly with other optical satellite data.

The visual interpretation of the radar data has been performed using a multiphase approach specially developed for the AFRICOVER Project. For each of the test sites, the photo-interpretation results have been compared with the optical satellite image alone, with the radar image alone and with the combination of the two. The results show that the SAR data's accuracy for land cover mapping can vary depending on the ecological zoning:

- In equatorial areas, ERS SAR data were used to map the main land cover classes, such as forest/non-forest, fragmented forest, water and urban areas. It was not possible to discriminate open from dense forest. ERS radar information was employed either as an almost total replacement for optical data in permanently cloud covered areas, or as complement to the optical data when the scenes were not completely cloud free or the available optical data were too old to be reliable. Monotemporal radar data seemed to be adequate in most cases.

- In tropical and dry areas, ERS multitemporal data alone proved less accurate than optical data and could only be used to map a limited number of classes, usually mixed or general ones.

The Pilot Study demonstrated, however, that ERS SAR multitemporal colour composites remain a very interesting tool for mapping agricultural areas, as a complement to optical data.
The fact that ERS data can be acquired throughout the crop growing season, when there is often considerable cloud cover makes it possible to

discriminate phenological crop variations that occur when optical satellite data are unavailable. It is expected that ERS SAR data can be employed in many instances to discriminate active from non-active fields, crop types and irrigated fields in particular.

In summary then, the AFRICOVER Project can profit considerably from the use of ERS radar data to replace optical data, when the latter are unavailable in permanently cloud-covered equatorial areas, or to complement optical data in tropical and semi-arid areas, where it is difficult to discriminate between different types of agricultural areas.

It is suggested to programme the acquisition of ERS data for the AFRICOVER Project only after the beginning of the field activities, on the basis of two factors, ie, optical data availability and difficulty in mapping agriculture areas.
In order to apply ERS SAR data optimally for the AFRICOVER project in an operational context, further test exercises, specific training programmes and regular technical assistance need to be foreseen.

1. Introduction

1.1. AFRICOVER

The AFRICOVER Project proposal to produce a land cover and topographic database for Africa was initiated in 1992 by the FAO Remote Sensing Centre, in cooperation with the main African remote-sensing mapping and user entities. Since then, the Project proposal has been intensively discussed and progressively revised with the participation of all interested partners.

The overall objective of AFRICOVER is to strengthen the African Countries' capacity to produce and use reliable information on natural resources, with particular emphasis on food security and environmental protection.

The specific objectives are twofold:

- the production of a homogeneous land cover map, a digital database and a geographical reference (toponymy, roads, drainage) at 1:200,000 or 1:250,000, and 1:1,000,000 scale for all Countries on the African Continent, plus 1:100,000 scale for some specific areas and for a few small Countries (less than 30,000 square km), all of them based on existing datasets, remote-sensing and GIS techniques;

- the strengthening of national and regional capacities by the practical application of advanced geographic information technologies to land cover mapping, natural resources assessment and environmental monitoring.

It is intended that at the end of the Project, technicians and decision makers in charge of the management of natural resources will be able to make immediate use of the output data, and to prepare maps at larger scales, quickly and cost-effectively to serve local priorities.

AFRICOVER foresees the building up of local capacities of this type across the whole African Continent, through:

❒ preparation, in collaboration with African experts, of technical specifications standards to be applied in Africa for land cover mapping and for topographic database compilation;

❒ intensive hands-on and specialized training programme for hundreds of technicians;

❒ provision to the regional and national centres of the standardized GIS stations needed to build and operate the land cover databases and other future databases on renewable natural resources;

❒ national workshops/seminars on behalf of the potential users of such databases;

❒ provision to national and regional institutions of printed maps and digital geo-databases and manuals in CD ROM form.

1.2. Implementation of AFRICOVER

The Project will be split into several regional modules, defined in accordance with the aims of the participating Countries and Donors. Six regional modules have provisionally been identified:

(a) East Africa
(b) Sahelian Africa
(c) West Coastal Africa
(d) Central Africa
(e) South Africa
(f) North Africa.

Potential users of the AFRICOVER information include:

- Governmental Organizations (Ministries of Agriculture, Water, Forestry, Environment, Bureaus of Statistics, Research Centres, Universities);

- Intergovernmental entities (CILSS**, IGADD**, SADC**, OACT**, RCSSMRS**);

- International Bodies (Development Banks such as the World Bank, AFDB **, UN** Bodies and Agencies like ECA **, UNDP**, UNEP**, WMO**, FAO**, EU**);

- Bilateral aid Agencies (USAID**, CIDA**, JICA**, ODA**, GTZ**, Ministries of Cooperation of France, Belgium, Italy);

- Scientific and professional bodies;

- Non-governmental organizations involved in rural development (WWF**, WCMC**, IUCN**, etc.);

- Private sectors involved in the production and use of information on natural resources;

- Local organizations, farmer associations, cooperatives.

**

CILSS - Comite International de Lutte contre la Secheresse du Sahel
IGADD - Inter-Governmental Authority on Drought and Development
SADC - Southern Africa Development Conference
OACT - Organisation Africaine de Cartographie et de Télédétection
RCSSMRS - Regional Centre for Services in Surveying, Mapping and Remote Sensing
AFDB - African Development Bank
ECA - Economic Commission for Africa
UNDP - United Nations Development Programme
UNEP - United Nations Environment Programme
WMO - World Meteorological Organization
FAO - Food and Agriculture Organization
EU - European Union
USAID - United States Agency for International Development
CIDA - Canadian International Development Agency
JICA - Japanese International Cooperation Agency
ODA - Overseas Development Agency
GTZ - Gesellschaft fuer Technische Zusammenarbeit (German Technical Agency for Technical Cooperation)
WWF - World Wildlife Fund
WCMC - World Conservation Monitoring Center
IUCN - International Union for Conservation of Nature

1.3. Use of satellite remote sensing data for AFRICOVER

The Project will rely primarily on high-resolution satellite data. Particular efforts will be concentrated on the production and updating of reliable databases, homogeneous at continental level in terms of geometric and thematic accuracy, and standardized in terms of both, hierarchical land cover legend, and formats/products. These will have to be compatible with the systems in use at the African facilities.

A further application of such databases will be as a reference for land cover monitoring and for calibration of NOAA low-resolution Vegetation Index data.

Compared to traditional large-area ground and aerial surveys, satellite remote-sensing offers numerous advantages including:

❒ good potential for accelerated surveys and production of information;

❒ capability to obtain synoptic views and thus to understand phenomena not visible on small sites;

❒ availability of multispectral data information on vegetation state/greenness, hard to obtain by other means;

❒ repetitive coverage useful to analyze seasonal and long-term variations and to identify critical land changes in a reduced time frame;

❒ provision of good quality, homogeneous information for the whole of the African Continent;

❒ possibility to obtain data without local, political or administrative restrictions;

❒ availability of imagery with minimum distortion, thereby permitting direct measurement of parameters in order to generate acreage statistics at district, as well as national/regional level;

❒ provision, cost-effectively, of critical information that it would be far too expensive to gather using other types of survey.

2. ESA/ESRIN-FAO Pilot Study "ERS Radar Data for Operational Land Cover Mapping in AFRICOVER"

2.1. Background and objectives

Ever-increasing amounts of valuable environmental information are being collected by radar instrumentation, the main advantage of which lies in the day/night, all-weather imaging capability that it provides.

In late 1994, ESA and FAO decided to carry out a Pilot Study, with the technical support of ESRIN, aimed at evaluating the ERS radar's ability to map land cover features, roads, hydrography, human settlements, etc. for Africa. In view of the intended utilization of this type of remote sensing data for the AFRICOVER project, a particular study objective was to determine those land cover classes (and their relevant accuracy) that could be mapped with ERS SAR data used alone or in combination with electro-optical sensor data. Four test sites were therefore selected, representing as many land cover variations as possible. All are located in West and Central Africa (see Fig. 1):

1. Mali (Sokolo)
2. Guinea (Fouta Djallon)

3-4 Zaire (Kananga City and Kasai River)

The Pilot Study was also intended to define the best digital image-processing method with which to improve the separability/interpretability of specific features, in order to generate optimal analogue images for visual interpretation

Finally, the experience gained and the results obtained for the four test sites were to be used to examine the various scenarios for the wider application of ERS radar data in the AFRICOVER initiative.

2.2. The ERS radar data experiment

The decision to undertake the ERS radar data experiment was based on three main factors:

a) **Database requirements**

- Reliable natural-resources information for Africa is an important database to be incorporated into the Regional and National Geographic Information Systems (GIS), which have become an indispensable tool for development planning and land/water resources management.

- The development, effective usefulness and success of these techniques depend largely on the quality and reliability of the data itself. In the case of GIS, where the synergy from the combination of different information sources is basic to the system, all of the various datasets must satisfy special requirements in order to make their integration possible.

- Furthermore, since the complexity of data outputs is likely to increase, as the latter must satisfy a wide range of users, all having access to the common integrated database, but with different requirements as to type of processing and products, the data input needs to be standardized as much as possible.
  Pre-requisites for renewable-resources data at regional and sub-regional level are therefore:
  - *homogeneity of mapping accuracy;*
  - *common legend in hierarchical form, according to the level of detail needed;*
  - *homogeneity in age (dates of acquisition) of the remote-sensing data used for the interpretation.*

  The availability of up-to-date information is particularly critical. In some areas the rate of degradation and depletion of natural resources is very high (e.g. due to increasing population pressures, political or economic change, etc).

  The various AFRICOVER modules may require 3 to 5 years for completion and it is therefore essential that the data acquisition period not exceed a 3-4 years time span. In many regions of Africa (especially the equatorial ones), cloud free or optimized acquisitions on such time scales are extremely difficult and the use of radar data is therefore a pre-requisite.

b) Legend requirements

The international land cover classification work is still under development. It is aimed not only at the identification of a high number of classes, but also at the definition of a high number of properties for each class.

Radar data can contribute to the evaluation of particular properties in specific classes, such as crop development or soil moisture estimates.

c) Interpretation requirements

The discrimination of features in satellite imagery is of primary importance. The acquisition time periods and the digital post-processing are fundamental factors in its success.

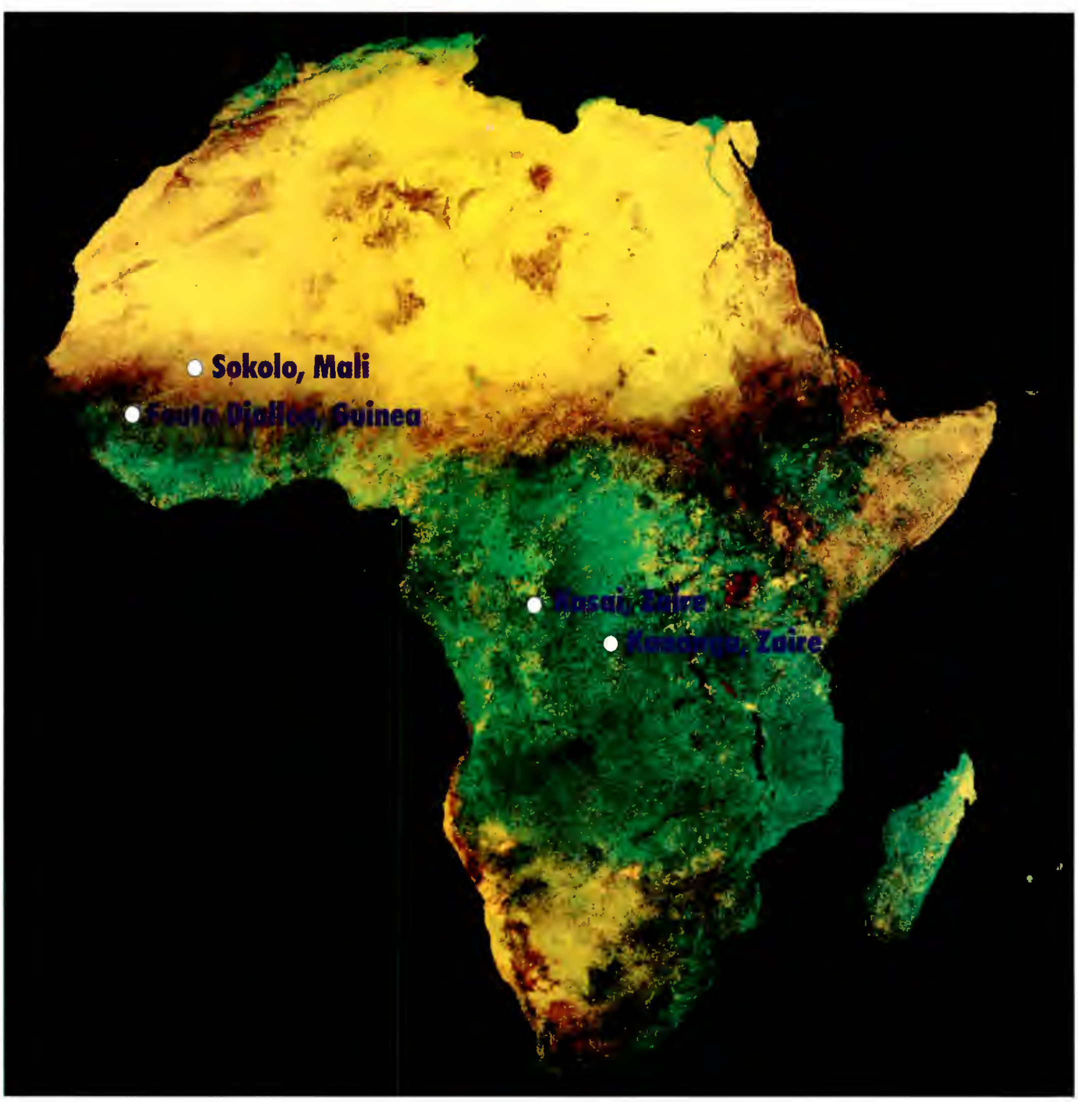


Fig. 1 - NOAA AVHRR image of Africa showing the approximate locations of the Pilot Study test sites. It is a composite of 1 month data set collected in April 1993 within the Global Land 1-km AVHRR Dataset Project (a cooperative endeavour by NASA, the US Geological Service - EROS Data Center, NOAA and ESA). Data processing by ESRIN, Frascati.

3. Work methodology

3.1 Land cover definition

The following are some of the most common definitions of land cover:

- ☐ "the biophysical state of the Earth's surface and its immediate subsurface (LUCC, 1994)"
- ☐ "the makeup of the land surface, whether it comprises arable land, trees or buildings, and so forth" (Countryside Survey 1990, Dept. of Environment, UK)
- ☐ "the vegetation (natural and cultivated) or man-made construction (buildings etc.) which occur on the Earth's surface. Water, ice, bare rock, sand and similar surfaces also count as land cover" (FAO, 1994).

3.1.2 Land cover identification versus mapping

The identification of land cover types is based on the ability to recognize particular features in remote-sensing images by georeferencing them in geographical coordinates. Land cover mapping is a more complex exercise, as it involves not only the identification of a particular feature, but also the correct delineation of its boundaries. In this case, the unit is georeferenced by a vector line or a set of grid cells., A mapping exercise, in addition, requires the ability to recognize and delineate a given class in the entire study area with the level of accuracy determined by the scale of the final output.

The present Pilot Study has evaluated the use, for mapping purposes, of ERS SAR data alone and when combined with LANDSAT optical data.

3.2 Methodological approach

3.2.1. Principles

The work has been carried out for four test site areas, selected based on such criteria as:

- availability of both optical and radar data
- availability of ancillary data (topographic and thematic maps)
- representativeness of land cover types in all agro-ecological zones covered by AFRICOVER between the Sahel and the Equator.

The work has been executed in three distinct phases:

- ❒ digital image post-processing including geometric correction, data filtering and enhancement, production of analogue images.
- ❒ visual interpretation of both optical and radar data
- ❒ critical evaluation of interpretation results.

3.2.2. Preparation of optical data

The optical data was prepared in two main steps:

- **Geometric correction**
  An image-to-map correction has been executed by using IGN topographic maps at 1:200,000 scale as a master. Due to the limited number of GCPs (Ground Control Points) and to their inconsistent distribution over the study areas, only a first order polynomial transformation has been used and a nearest-neighbour interpolation applied. Despite the less-performant transformation and interpolation method used, the RMS (Root Mean Square) error was satisfactory, not exceeding 1.5 pixels.

- **Image enhancement**
  The objective was to manipulate the grey-level tones in a monochromatic image to enhance the information that can be visually perceived. In our case, the goal was to optimize the possibility to discern and interpret land-cover features. A grey-level linear contrast stretch for the three selected bands has been executed. A False Colour Composite, combining two visible and one near-infrared band (band 4, red ; band 3, green; band 2, blue) has been obtained to generate a film output. From the latter, a photographic paper print on a scale of 1:100,000 has been produced.

3.2.3. Preparation of ERS radar data

In contrast to mono-date optical images, each of which consists of several spectral bands, ERS SAR has only one channel. However, different acquisition times can be combined to produce a multitemporal data set.

The following post-processing tasks have been performed:

- **Radiometric correction**

  Three categories of data manipulation have been executed, namely:

  - *Reduction of speckle effect.* Texture can be defined as the frequency of tonal changes in an image. Generally, radar images have a high frequency. However, most of the apparent texture in ERS SAR data is explained by the speckle. The overall result is an image with a "salt and pepper" aspect, affecting the interpretability. This image noise can be reduced by filtering.
    Different filters have been tested in order to enhance the information content. Specific filters such as LEE ADAPTIVE, FROST and GAMMA MAP were tried but most of them have caused undesirable new patterns in the image. The best result was achieved by applying a simple low-pass filter using a 3x3 pixel window, and by re-scaling the original pixel resolution to 30x30 m, equivalent to LANDSAT Thematic Mapper (TM) data. This method, which is fast in terms of computation time, is available in most post-processing software. It also reduces the speckle and still conserves the coarser texture.

  - *Radiometric scaling*. The ERS SAR data channel has a 16 bit resolution. To allow adapted contrast stretching and the integration with optical LANDSAT TM data, the radar data need to be down-scaled to 8 bits.
    Most of the digital image processing software has radiometric scaling functions such as linear, logarithmic or squared scaling of multi-byte image data. Because of the wide dynamic range of values in the original histogram, automatic scaling had to be avoided, especially when generating multitemporal data sets. The procedure chosen therefore was to determine a common highest threshold value and apply a fixed linear scaling.

  - *Grey-level contrast enhancement* has been applied to each individual channel of the data sets, in order to obtain an optimized FCC. Contrast stretching is more complex for radar than for optical data, because of the inherent multiplicative noise.

- **Geometric correction**

  Two different image registrations have been performed using a first order polynomial function and nearest-neighbour interpolation method. the former to ensure acceptable registration between radar data sets acquired over the same area but at different times, the latter to register ERS SAR data to LANDSAT TM data already referenced to a topographic map. The results proved acceptable, with an RMS error of 2-3 pixels. Given the rough terrain topography in some scenes, and the limited number of good GCPs, this error is considered satisfactory.

  A maximum of effort has been devoted to the enhancement of the main land-cover features. Finally, the best colour combination for each multitemporal data set has been selected. In the case of the two test site areas in Zaire, where only two acquisition dates were available, the FCC has been obtained by adding the first principal component to the enhanced scenes as the third artificial colour channel, which was found to improve the scene's interpretability.

4. Image Interpretation

The visual interpretation approach (Multiphase Visual Interpretation Method) selected for AFRICOVER involves the following steps:

- visual segmentation on remote-sensing images;
- stratified field campaign;
- identification of the land cover type according to a pre-determined classification scheme;
- final revision of the interpretation.

The Pilot Study has been conducted accordingly but, instead of undertaking a field campaign, the relevant ground-truth data have been extracted from existing topographic and thematic maps.

Three types of segmentation have been executed for each test site area:

- ☐ segmentation using optical data alone;
- ☐ segmentation using radar data alone;
- ☐ segmentation using a visual combination of optical and radar data

As remote sensing products, radar images differ completely from their optical counterparts as far as interpretation is concerned.
Grey-level, as well as colours, textures and patterns visible in hard copy images cannot be interpreted in the traditional way as radar utilizes coherent waves and operates in a totally different spectral range. The physical principles of the reflectance or backscatter from given objects are very different compared with optical sensors. In the case of radar, the reflectance is linked to surface roughness and humidity, as well as to type of structure and material of the objects imaged.

However, the final goal of the mapping exercise is the delineation of georeferenced thematic units. Such units must represent particular land cover features correctly, independent of the remote-sensing datasets from which they were originally extracted.

The parameters analyzed for each test site area were:

- correctly identified land cover classes;
- accuracy in the delineation of the boundaries of land cover classes;
- main criteria used to identify a given class (gray level, texture, multi-date effect).

5. Results

5.1 Test site area 1: Fouta Djallon

Country : Guinea

Approximate geographic location:
11° 42' N, 10° 37' E

Type of product used:

- paper print of LANDSAT TM - Path 201 row 53 - quadrant 1 - of 24 April 1994 - FCC of bands 4,3,2 -

  scale 1:100,000;

- paper print of ERS-1, FCC of three dates:

  Orbit/frame 15902/3392 of 31 July 1994 - red
  Orbit/frame 14556/3392 of 28 April 1994 - green
  Orbit/frame 6752/3393 of 30 October 1992 - blue

  scale 1:100,000;

- IGN topographic map (Dabola sheet) -

  scale 1:200,000;

- land cover map, scale 1:250,000 based on interpretation of B/W aerial photographs -
- scale 1:100,000.

5.1.1. Brief description of the area

The test site area is part of the Fouta Djallon massif, a broad plateau with an average altitude of 800 - 1000 m msl. It is a significant area, ecologically, and three of the most important rivers - the Niger, Senegal and Gambia - originate there. The study area has a mean yearly temperature of 23° and an annual rainfall of around 1600 mm. It is located approximately in the centre of the massif. Its broad land cover aspect is characterized by three main features:

❒ *Lateritic crust, locally called "Bowal".* It is a crust of over 5 m depth covered mostly by an open herbaceous layer. Due to the shortage of soil, the grass layer becomes dry immediately after the end of the rainy season. In general, it is used for grazing, but only when the grass is green. For this reason, the Bowal area is frequently burned, usually in the middle of the dry season (November, December) in order to eliminate dry plants and to help the new secondary growth favoured by the short rainfall period in December.

❒ *Natural vegetation.* Generally due to a high anthropological impact, its structural form ranges through all degrading aspects of the original primary forest layer, from high thicket scrubs(4-7 m high) to low scrubs (1-2 m high), from sparse/open to closed cover.

❒ *Agriculture fields.* These are often small patches in the vicinity of villages and can be subdivided into two main categories:

(i) permanent or semi-permanent fields
(ii) fields with a long fallow period

The first type of field includes a deep good soil and is located either in flooded plains, in which case it is cultivated with paddy during the rainy season and with tomatoes and other vegetables in the dry season, or almost a valley bottom, with only one harvest per year and a fallow period of 1-2 years every 5 or more years.

The second type of field is located in gentle sloping areas with medium deep or shallow soil. It is cultivated for 5-6 years, and then abandoned for grazing for an equivalent time period. The main crop type is fonio, a kind of wild millet.

All of these elements often form such a complex mosaic of features that it becomes very difficult, even on a rather large scale, to identify and map the land-cover types individually. Consequently, this type of land cover usually has to be mapped as mixed units.

The two main features emerging very distinctly from an examination of ERS radar data are:

(a) the lateritic crust
(b) the agricultural fields

Depending on how the ERS radar data were used (alone or in combination with optical data), different results were obtained, as is described more in detail below.

Figures 2 and 3 show the results of visual interpretation of optical data alone.

- *Results from the use of ERS radar data alone*

  The first feature is evidenced by the combined effect of texture and land form. In addition, the multi-season effect allows a further differentiation of recently burned Bowals.

  The second feature emerges mainly because of the multi-season effect. Less effective is the mapping of mixed areas due to the speckle and the smallness of the fields.

  The class 2b "fields and low scrub area" appears very clear in its general aspect (primarily due to the multi-season effect, probably a combination of crop phenology and fire action). However, it is not possible to discriminate every single element forming the mosaic-like pattern (as can be done with optical data). Consequently, it is impossible to differentiate subclasses. This imposes a greater level of generalization on the cartographic unit than obtained using optical data.

  In addition, the delineation of unit boundaries is less certain than in optical data. This problem is more consistent in the other two mixed classes mapped (3a, 3b). No discrimination is possible between low scrub and high scrub areas.

  The results from the use of radar data alone are shown in Figures 4 and 5.

- *Results from the combined use of ERS radar and optical data*

  The results obtained by optical data interpretation show a clear limitation in the discrimination of different types of fields. Their appearance is, in fact, uniform because of the data acquisition time. Due to the cloud cover problem, the time of acquisition is confined to the middle or end of the dry season, when harvesting is already complete and no differentiation can therefore be made between permanent/semi-permanent, long-fallow fields or prairies.

  The results of the interpretation executed visually by combining two data types are encouraging (see Fig. 6), giving an increase in the number of main land cover classes mapped, and at the same time a good level of generalization delineating the mixed classes.

Mapping a subclass of recently burned Bowals is considered to be of secondary importance, but the possibility to separate the fields into two classes (active or permanent/semipermanent and nonactive or a long-fallow period) is of fundamental significance in the context of AFRICOVER.

5.1.2. *Results and discussion*

Interpretation results are shown in Table 1.

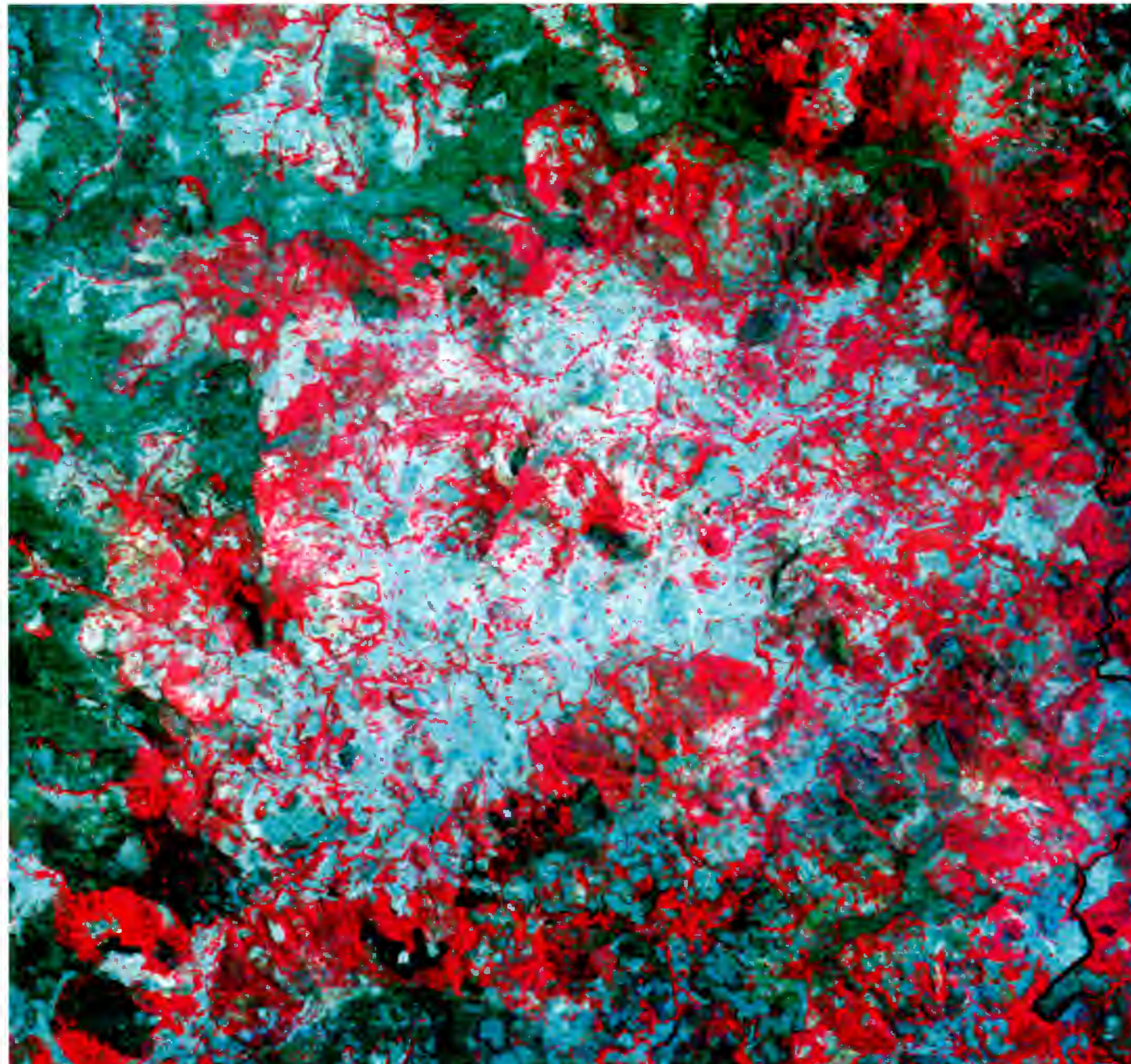


Fig. 2 - *Fouta Djallon, Guinea*
Approximate geographic location: 11°42' N, 10° 37' E

-
LANDSAT TM colour composite of bands 4,3,2 (red,green,blue) derived from the acquisition of 24 April, 1994 - Path 201 row 53.

Bowals are shown in green, shrubs in red and fields in bright blue. The only available images are related to the dry season, when most fields have been already harvested. For this reason no further separation could be made.

VISUAL INTERPRETATION OF OPTICAL DATA

Code	Unit Name
1	Lateritic crust (Bowal)
2	Agricultural fields (permanent or semi-permanent and long-fallow)
3A	Low scrubs from dense to open cover
3B	Thickets (high scrubs, open trees)
2/3A	Agriculture fields mixed with open low scrubs (not more than 25-30%)
3A/2	From dense to open low scrub layer mixed with small patches of agricultural fields (long-fallow)
3A/2/1	Open to sparse low scrub area with patches of agriculture fields and Bowals (last two not exceeding 40% of lateritic crust not more than 25-30%)
3A/1	From dense to open low scrub layer mixed with small patches of lateritic crust (not more than 25-30%)
3B/1	Dense thicket mixed with small patches of lateritic crust (not more than 25-30%)

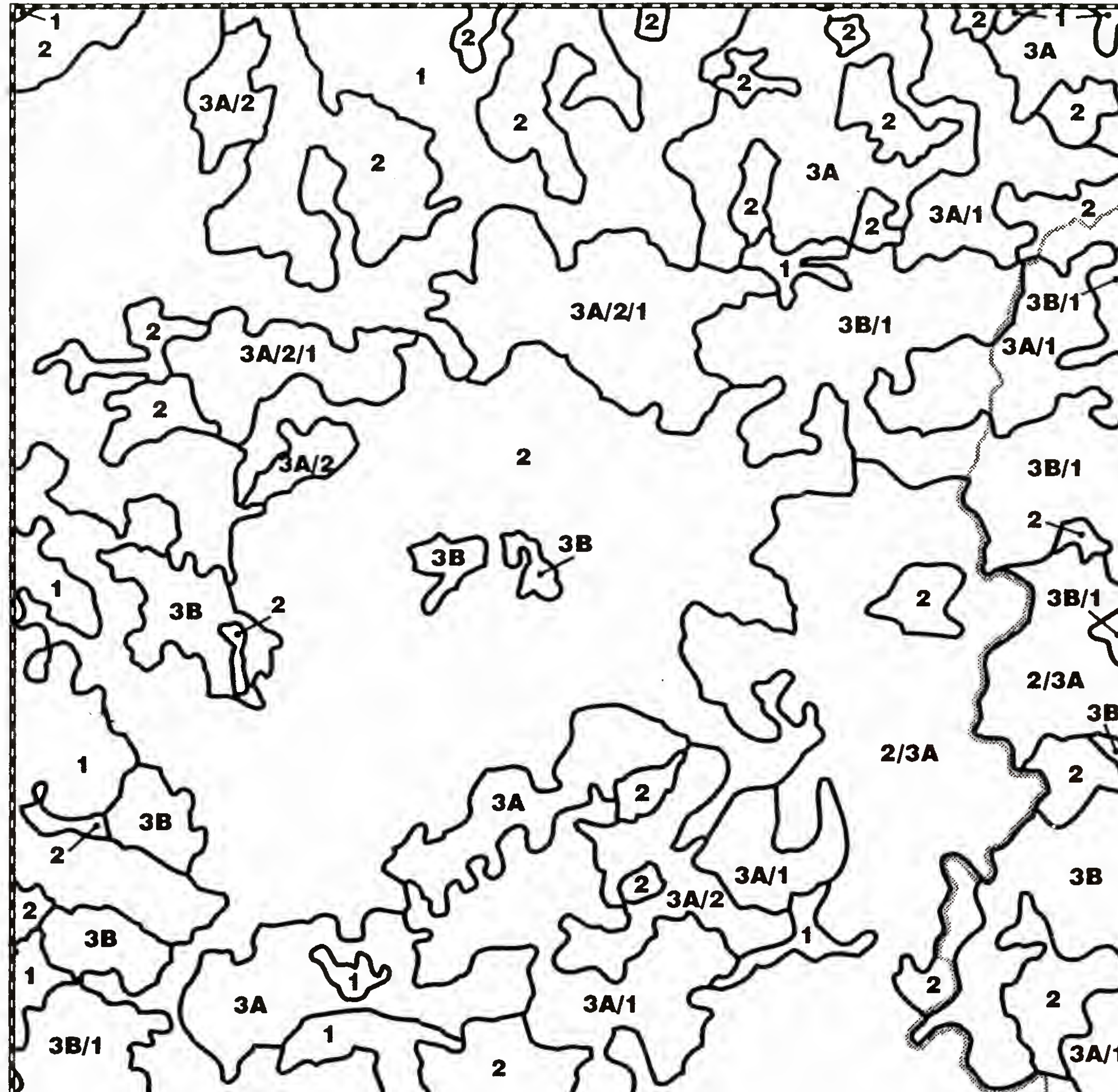


Fig. 3

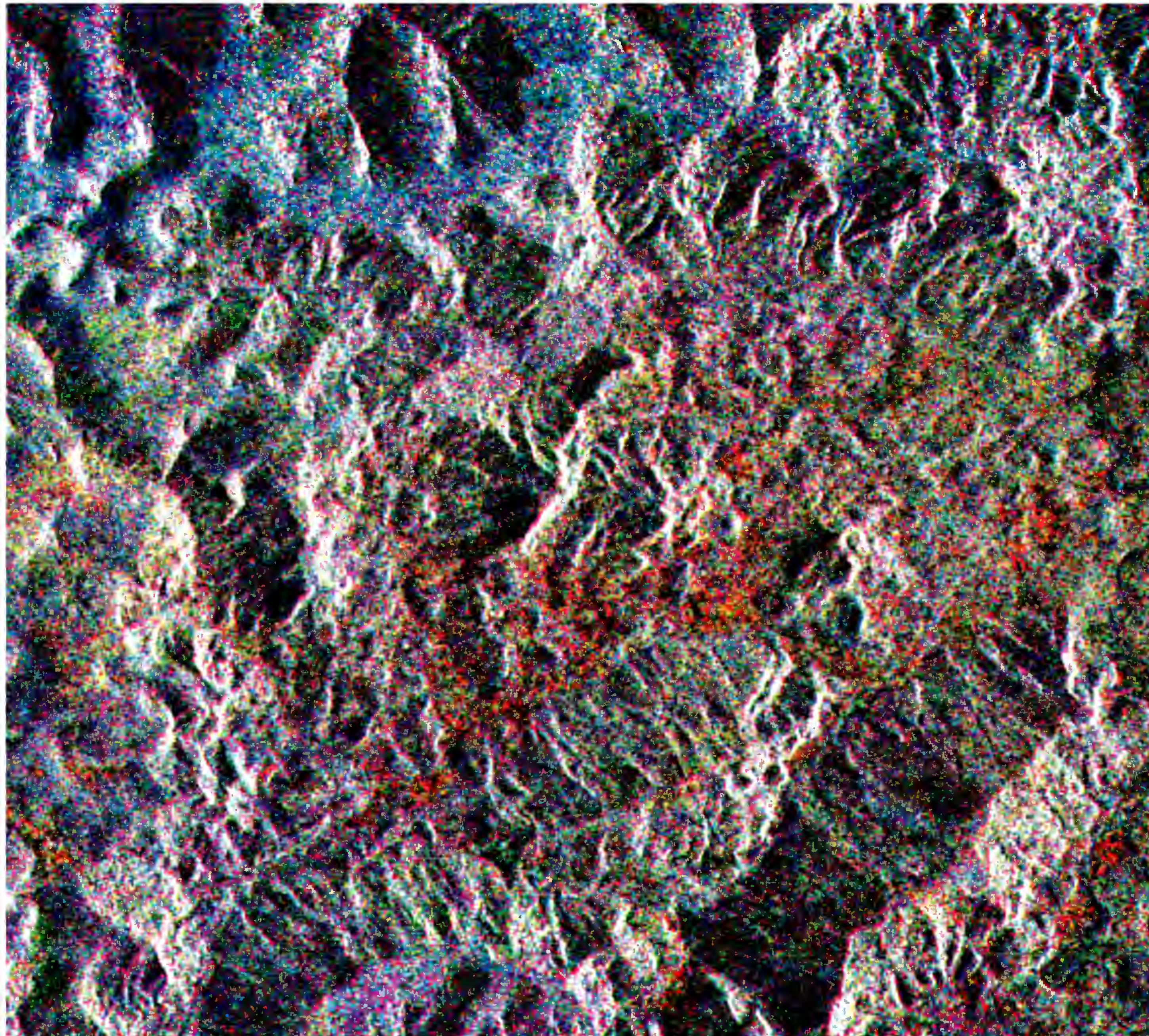


Fig. 4 - *Fouta Djallon, Guinea*
Approximate geographic location: 11°42' N, 10°37' E

ERS-1 SAR multitemporal image derived from three acquisition dates:

- *orbit/frame 15902/3393 of 31 July 1994 (red)*
- *orbit/frame 14556/3393 of 28 April 1994 (green)*
- *orbit/frame 6752/3393 of 30 October 1992 (blue)*

The SAR image provides a good idea of the area topography. Bowals, shown in blue, can be found on the higher plateaux in the upper part of the scene. Shrub is represented in green and fields under cultivation in brown, red or yellow.
Three main classes can be identified in the area :
- *Lateritic crust, locally called Bowals, an open herbaceous layer, used for grazing only;*
- *Natural vegetation consisting of high/ low shrub;*
- *Permanent/semi-permanent agricultural fields, or simply fields.*

The combined analysis of optical and radar data allows not only mapping of the main land use, but also to distinguish between fields permanently used and fields with long fallow periods. Moreover, it is possible to map the burned area in the Bowals.

VISUAL INTERPRETATION OF RADAR DATA

Code	Unit Name
1A	Lateritic crust (Bowal)
2A	Agricultural fields (permanent or semi-permanent)
2B	Mosaic of long fallow fields and low scrub areas (small patches of lateritic crust can be present)
3A	Mosaic of low scrub areas and patches of lateritic crust (small patches of long-fallow fields can be present)
3B	Prevalence of thicket (patches of lateritic crust or open low scrub areas can be present)

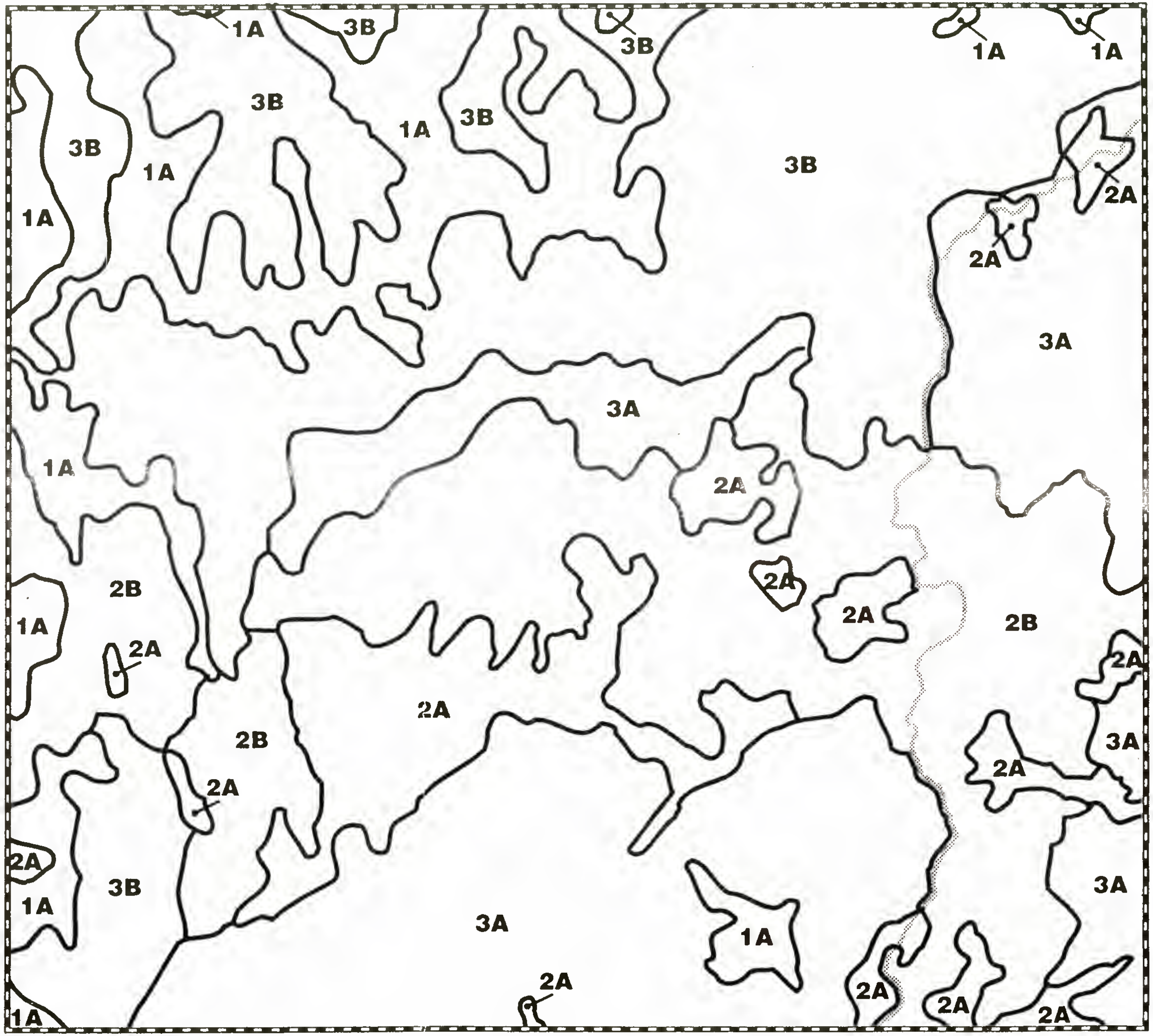


Fig. 5

Test Site Area 1:
FOUTA DJALLON (Guinea)

CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL INTERPRETATION OF OPTICAL DATA		CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL INTERPRETATION OF RADAR DATA				CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL COMPARISON OF OPTICAL AND RADAR DATA	
				Accuracy in the delineation of the boundaries of the land cover classes	**Main criteria used for the interpretation**		
Code	**Unit Name**	**Code**	**Unit Name**			**Code**	**Unit Name**
	Single Classes		**Single Classes**				**Single Classes**
1	Lateritic crust (Bowal)	1	Lateritic crust (Bowal)	Good	Texture, topographic effect	1a	Lateritic crust (Bowal)
		1a	Lateritic crust recently burned	Good	Topographic and multiseason effect	1b	Lateritic crust recently burned
2	Agricultural fields, permanent or semi-permanent and long fallow	2a	Agricultural fields, semi-permanent	Medium	Multiseason effect	2a	Agricultural fields with long fallow period
						2b	Agricultural fields, permanent or semi-permanent
3a	Low scrubs from dense to open cover	---	-----			3a	Low scrubs from dense to open cover
3b	Thickets (high scrubs, open trees)	---	-----			3b	Thicket (high scrubs, open trees)
	Mixed classes		**Mixed classes**				**Mixed classes**
1\3a.	Lateritic crust and open low scrub layer					1\3a.	Lateritic crust and open low scrub layer
2\3a	Agriculture fields mixed with open low scrubs (not more than 25-30%)			Low	Multiseason effect	2\3a.	Agriculture fields mixed with open low scrub (not more than 25-30%)
3a\2	From dense to open low scrub layer mixed with small patches of agricultural fields (long fallows)	2b	Mosaic of long fallow fields and low scrub areas (small patches of lateritic crust can be present)			3a\2.	From dense to open low scrub layer mixed with small patches of agricultural fields (long fallows)
3a\2\1	Open to sparse low scrub area with patches of agriculture fields and Bowals (last two not exceeding 40% of the total area)					3a\2\1	Open to sparse low scrub area with patches of agriculture fields and Bowals (last two not exceeding 40% of the total area)
3a\1	From dense to open low scrub layer mixed with small patches of lateritic crust (not more than 25-30%)	3a	Mosaic of low scrub areas and patches of lateritic crust (small patches of long fallow fields can be present)	Low	Topographic effect	3a\1	From dense to open low scrub layer mixed with small patches of lateritic crust (not more than 25-30%)
3b\1	Dense thicket mixed with small patches of lateritic crust (not more than 25-30%)	3b	Prevalence of thicket (patches of lateritic crust or open low scrub areas can be present)	Low	Texture, topographic effect	3b\1	Dense thicket mixed with small patches of lateritic crust (not more than 25-30%)
		4	Steep areas (no information available)				

TABLE 1

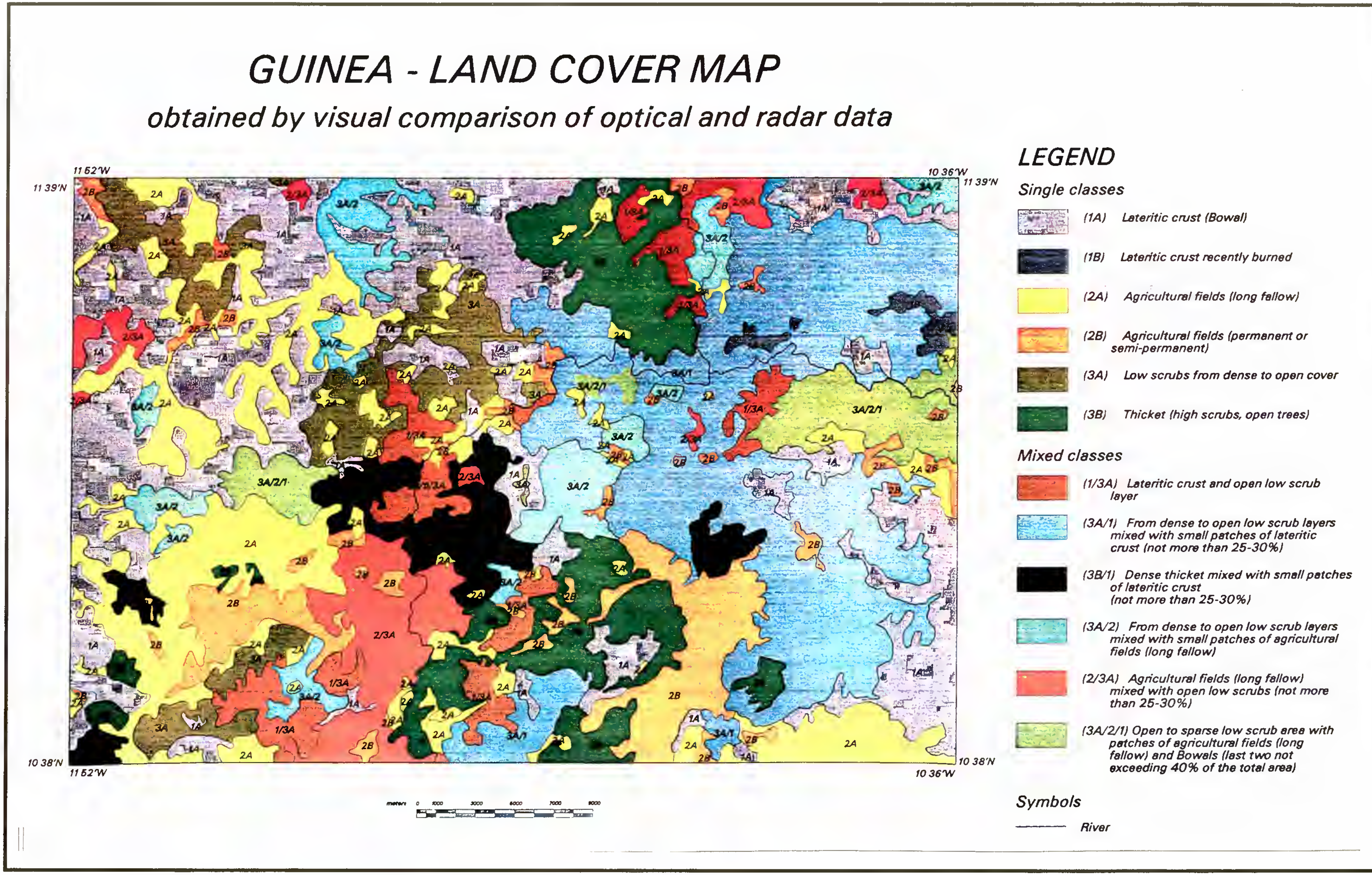

GUINEA - LAND COVER MAP
obtained by visual comparison of optical and radar data
11 52'W
10 36'W
11 39'N
10 38'N
LEGEND
Single classes
(1A) Lateritic crust (Bowal)
(1B) Lateritic crust recently burned
(2A) Agricultural fields (long fallow)
(2B) Agricultural fields (permanent or semi-permanent)
(3A) Low scrubs from dense to open cover
(3B) Thicket (high scrubs, open trees)
Mixed classes
(1/3A) Lateritic crust and open low scrub layer
(3A/1) From dense to open low scrub layers mixed with small patches of lateritic crust (not more than 25-30%)
(3B/1) Dense thicket mixed with small patches of lateritic crust (not more than 25-30%)
(3A/2) From dense to open low scrub layers mixed with small patches of agricultural fields (long fallow)
(2/3A) Agricultural fields (long fallow) mixed with open low scrubs (not more than 25-30%)
(3A/2/1) Open to sparse low scrub area with patches of agricultural fields (long fallow) and Bowals (last two not exceeding 40% of the total area)
Symbols
River

Fig. 6

5.2 Test site area 2: Sokolo

Country : Mali

Approximate geographic location:
15° 07' N, 5° 41' E

Type of product used:

- paper prints of Landsat TM - Paths 199/ /198, rows 49/50 of 4 and 11 December 1990 - full scenes FCC of bands 4, 3, 2 (two subscenes), scale 1:100,000;
- paper prints of ERS-1, FCC of three dates:

  Orbit/frame 5120/3303 of 8 July 1992 - red
  Orbit/frame 8627/3303 of 10 March 1993 - green
  Orbit/frame 7124/3303 of 25 November 1992 - blue
  (two subscenes) - scale 1:100,000;
- IGN topographic map (Sokolo Sheet) - scale 1:200,000;
- land cover map, scale 1:200,000, based on interpretation of SPOT images.

5.2.1. Brief description of the area

The area is located in the Central-Northern part of Mali, not far from the border with Mauritania. It is a complex landscape including very low hills and plateaus, sometimes with a lateritic crust, generally covered by a sand layer. Ergs formed mainly by longitudinal dunes are common. The average altitude is around 250 m. The area belongs to the "South Sahel" bioclimatic zone and has rainfall ranging between 400 and 650 mm, with a mean yearly temperature of 27°. As a consequence of these factors, the landscape is dominated by two main features:

❒ *Natural vegetation.* It is generally formed by an open scrub savanna or open herbaceous steppe. When dunes are present, the scrub/trees (mainly Pterocarpus spp, and Combretum spp) assume a particular pattern called "Brousse tigree". Small patches of scrub/trees can be found in interdune areas, also recognizable by their pattern. In addition, river or wadi marsh areas are present.

❒ *Agriculture areas.* They are generally of two types: dry cultures with long-fallow periods, and irrigated cultures in regularly flooded areas. In the first case, the main crops can be millet or winter wheat, in the latter case rice and, as a second harvest, other cereals or vegetables.

5.2.2. *Results and discussion*

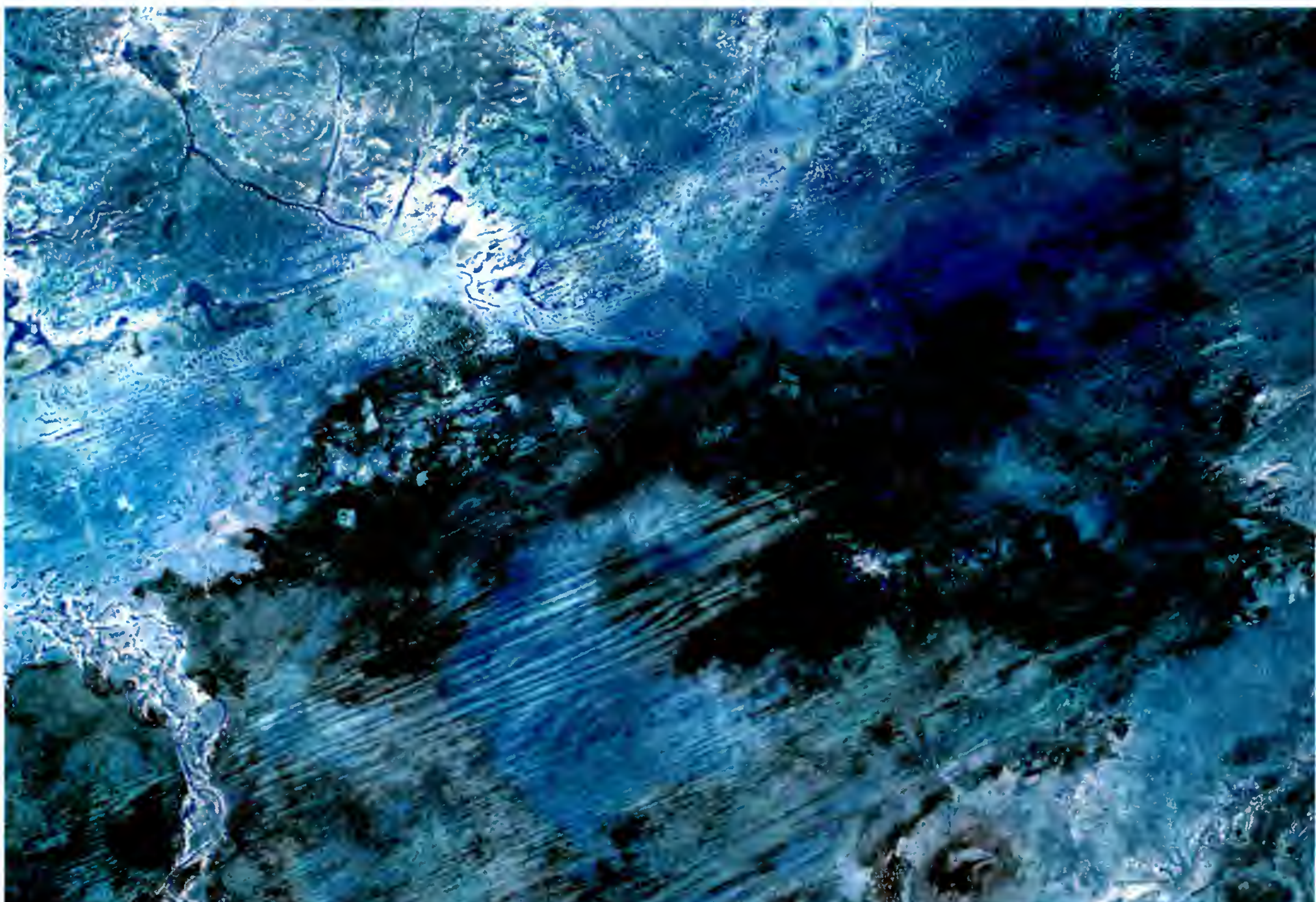
Interpretation results are shown in Table 2

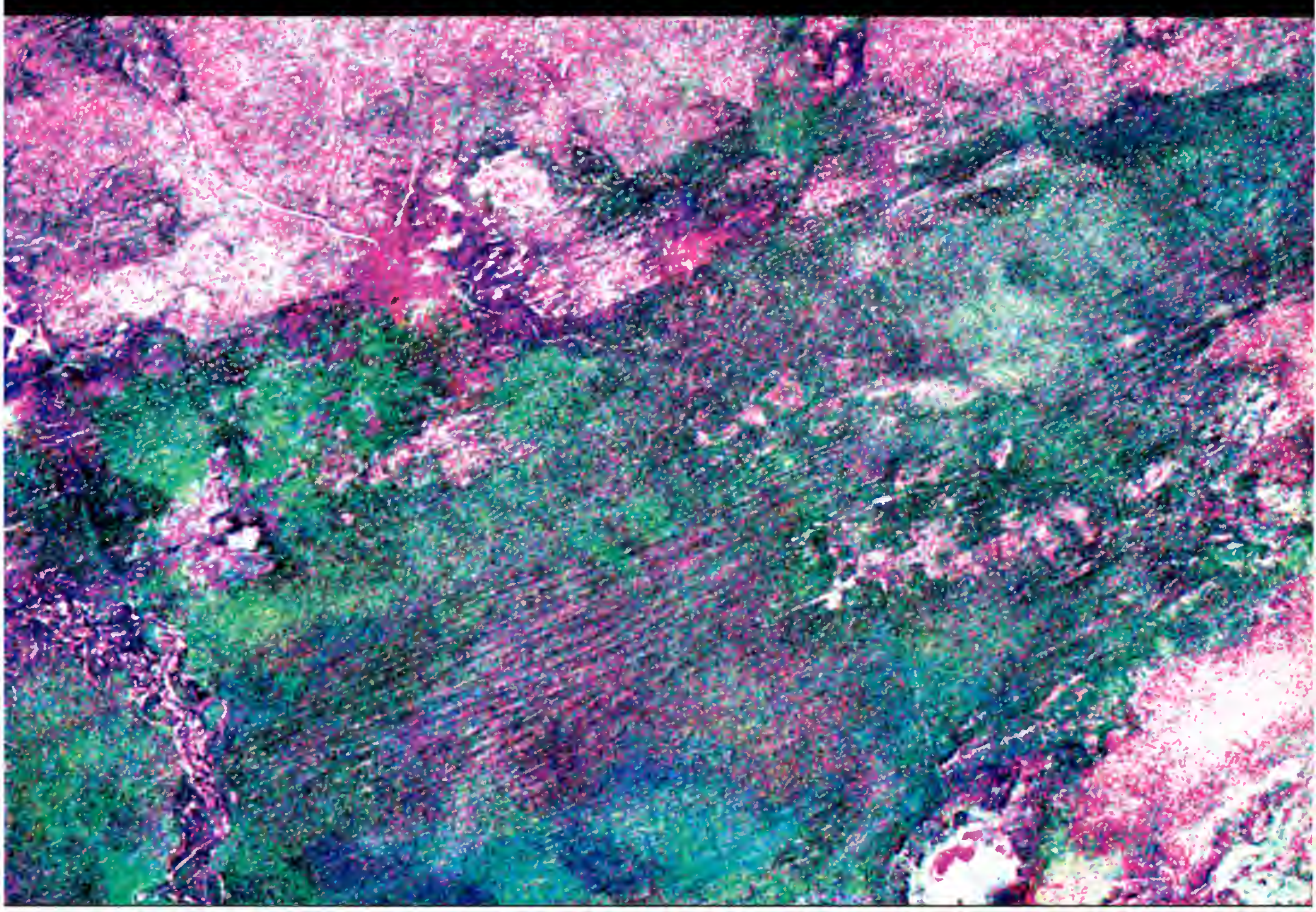
The results obtained in this area are poorer than those achieved in the other test site areas, mainly because it has not been possible to map the natural vegetation (dense scrub/trees and brousse tigree) on the radar images. It has been possible, instead, to discriminate marshes. Furthermore, dry and irrigated cultures have been mapped with a good accuracy. Still, this has not brought any substantial improvement in the final legend quality (classes obtained combining optical and Radar data), because the definition of those cultures is easier and more accurate with optical data.

An improvement of secondary importance in the legend can be considered to be the subdivision of the sandy plain class (as from the interpretation of optical data alone) into an additional subclass defined as "sandy plains with lateritic crust and a shallow sandy layer".

Fig. 7 shows the complementarity of the optical/radar data.

It is concluded that the use of radar information in this area is not essential for AFRICOVER, due to the good performance of optical data and the limited cloud-cover constraints. It may still be useful, however, to combine radar and optical images in order to differentiate rice fields from marshes in the flooded plains of the Niger. Unfortunately, this type of crop was not present in the particular study area chosen.





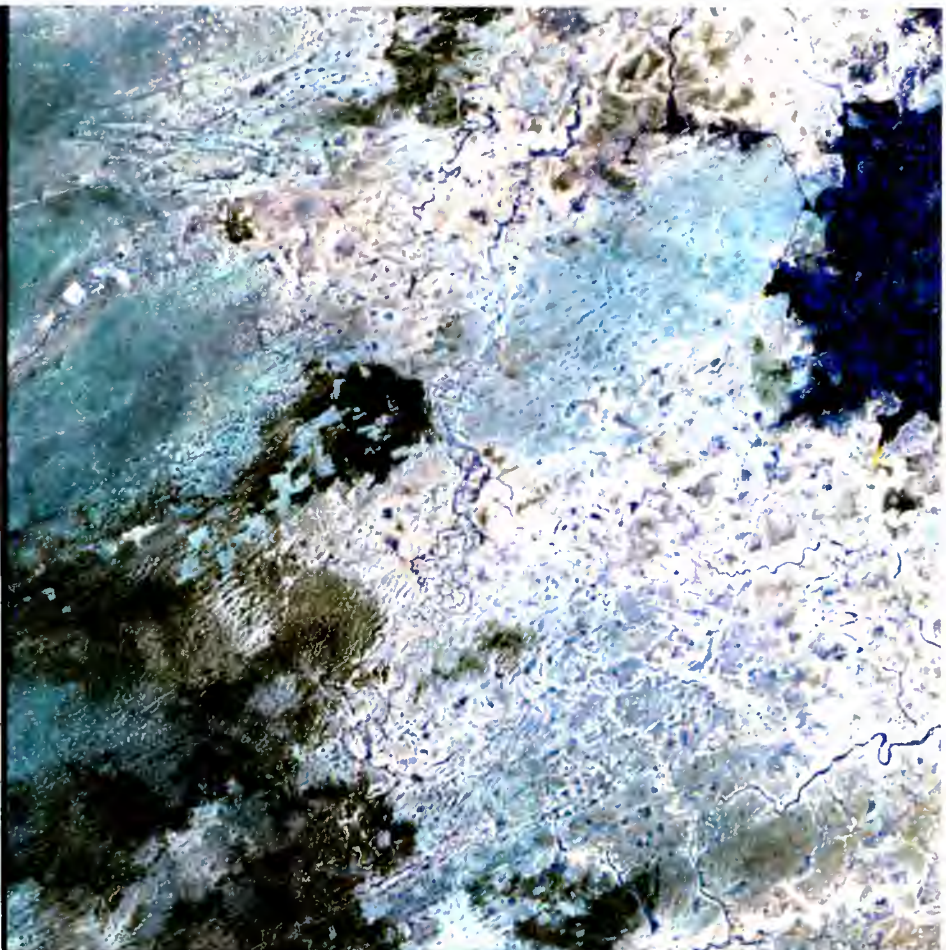


Fig. 7 - *Sokolo, Mali*
Approx. geographic location: 15°07' N, 5°41' E

Upper two images: *ERS-1 SAR multi-temporal image derived from three dates of acquisition:*
- *orbit/frame 5120/3303 of 8-7-1992 (red)*
- *orbit/frame 8627/3303 of 10-3-1993 (green)*
- *orbit/frame 7124/3303 of 25-11-1992 (blue)*

Lower two images: *LANDSAT TM colour composite derived from bands 4,3,2 (red,green,blue) of the following acquisitions :*
Path/rows 199/49-50 of 4 December 1990
Path/rows 198/49-50 of 11 December 1990

It is a complex landscape with very low hills and plateaux, covered sometimes by lateritic crust, but more often by sand layers. Ergs formed mainly by longitudinal dunes are common. Natural vegetation consists of open scrub savanna or open herbaceous steppe. When dunes are present, the scrub/trees assume a particular pattern called "brousse tigrée". River or wadi marsh areas can also be found. Agriculture areas include dry cultures with long fallow periods (millet or winter wheat), as well as irrigated fields (rice, cereals or vegetables).

The radar and the optical image are highly complementary. Colours in the radar image indicate primarily soil moisture changes that occurred during the observation period. It was not possible, instead, to map on the radar image natural vegetation like dense scrub/trees and "brousse tigrée", but it was easy to discriminate marshes. In spite of the good result obtained in mapping dry and irrigated areas, it has to be recognised that most of the agriculture areas were mapped more precisely using optical data.

Test Site Area 2:
SOKOLO (Mali)

CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL INTERPRETATION OF OPTICAL DATA	CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL INTERPRETATION OF RADAR DATA		
Unit Name	**Unit Name**	**Accuracy in the delineation of boundaries of the land cover classes**	**Main criteria used for the interpretation**
Single Classes	**Single Classes**		
Dry cultures	Dry cultures	Good	Texture, multi-season effect
Irrigated cultures	Irrigated cultures	Good	Multi-season effect
Marshland	Marshland	Good	Multi-season, textural effect
Brousse "tigrée"	-----		
Scrub/tree layer closed	-----		
Sandy plain	Sandy plain	Poor	Multi-season effect
Longitudinal dunes	Longitudinal dunes	Medium	Texture
-----	Lateritic crust with sandy layer	Good	Multi-season effect
Mixed Units	**Mixed Units**		
Wadis areas (sandy areas and marshes)	Wadis area (sandy areas and marshes)		
Sandy plain with scattered marshes	Sandy areas with scattered marshes	Good	Textural effect
		Medium/good	Textural effect

TABLE 2

5.3 Test site areas 3 and 4

The results achieved in these two areas are discussed together because of the high similarity of environmental conditions.

Area 3: City of Kananga

Country : Zaire

Approximate geographic location:
5° 47' S, 22° 12'I E

Area 4: Kasai River

Approximate geographic location:
4° 32' S, 19° 40' E

Country : Zaire

Type of product used:

- paper prints of LANDSAT MSS Path 177 row 64 of 5 June 1989 and LANDSAT TM Path 179 row 63 of 26 May 1986

  scale 1:250,000
  (interpretation executed in the framework of the Forestry Inventory Project "FRA90")

- paper prints of ERS-1, FCC of two dates:

  Orbit/frame 15229/3717 of 14 June 1994
  - red
  Orbit/frame 16291/3717 of 27 August 1994
  - green, plus
  - 1st principal component - blue

- scale 1:100,000

5.3.1. Brief description of the areas

The two areas are located approximately in the Centre of Zaire. The main land form is an undulating landscape, with elevation not exceeding 200 - 300 m. Annual rainfall is averages 1600 mm in the area of Kananga, and 1500 mm in the Kasai River area. The mean yearly temperatures in the two areas are 30° and 29°, respectively.

The main land cover feature is the moist forest, formed by different layers of deciduous and evergreen trees. The forest is represented in all aspects: from the untouched closed layer, through the different stages of its degradation. In areas where the anthropological pressure is strong, big patches of cut forest are present. Here, small patches of fields, mostly used for grazing, can be found.

Agriculture is fed by the rain but fields can be subdivided into short- or long-fallow types. Generally, short-fallow fields are located in areas where all trees have been cut, whilst long-fallow ones (shifting cultivations) are located in areas similar to a closed arboreal and scrub savanna. Very often, between this last zone and the closed forest, there is a separation zone of open forest. A hypothetical transection starting from untouched dense forest should, in fact, pass through an open forest and a dense savanna, before reaching the grassland and small agriculture patches.

In addition, in test site area 3, south of the city of Kananga, a natural savanna mixed with thin lines of gallery forest can be recognized.

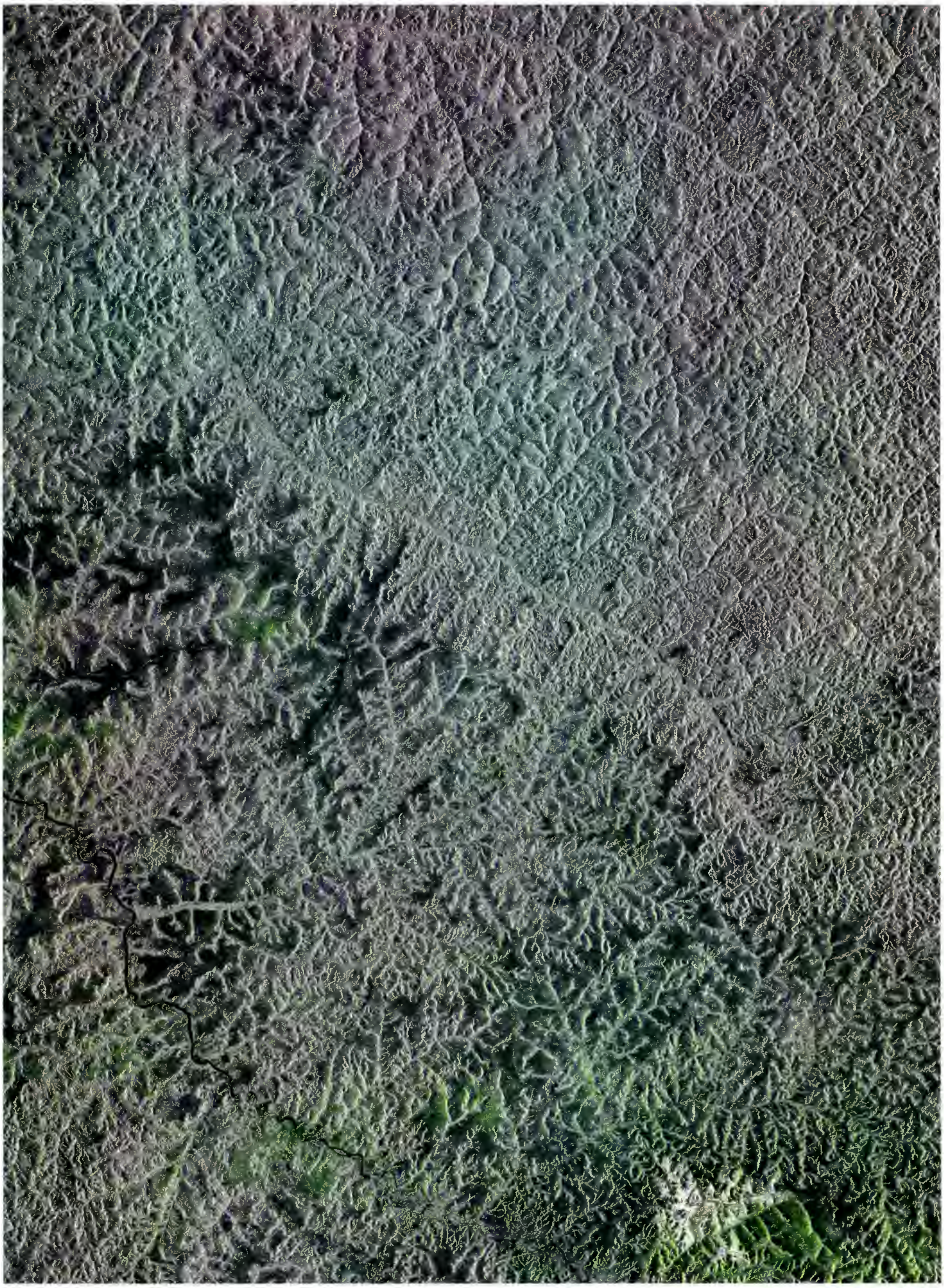
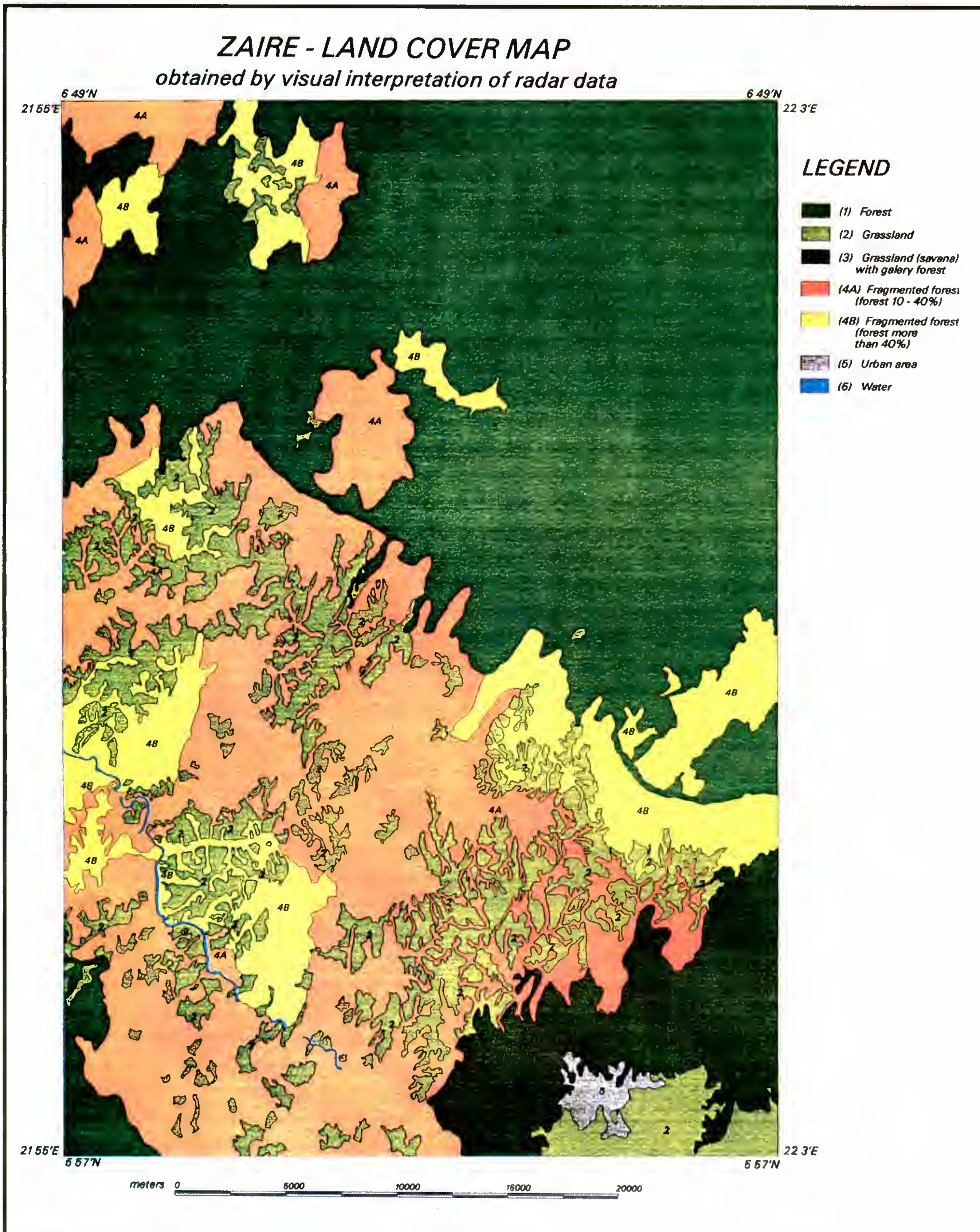


Fig. 8 - *Area of Kananga, Zaire*
Approximate geographic location: 5°47'S, 22°12'E.

ERS-1 SAR multi-temporal image derived from two dates of acquisition : orbit/frame 15229/3717 of 14 June 1994 (red); orbit/frame 16291/3717 of 27 Aug. 1994 (green) and 1st principal component of both dates (artificial channel) displayed in blue. The area topography is well outlined. The brightly imaged forest is restricted to the valleys, while the higher plateaus with low shrub or herbs appear dark. The river course, bottom left in the image, sometimes seems to be interrupted by the presence of rapids. Rough water is imaged in much brighter tones than smoothly flowing waters.



ZAIRE - LAND COVER MAP
obtained by visual interpretation of radar data
6 49'N
6 49'N
21 55'E
22 3'E
21 55'E
22 3'E
5 57'N
5 57'N
LEGEND
(1) Forest
(2) Grassland
(3) Grassland (savana) with galery forest
(4A) Fragmented forest (forest 10 - 40%)
(4B) Fragmented forest (forest more than 40%)
(5) Urban area
(6) Water
meters 0 5000 10000 15000 20000

Fig. 9

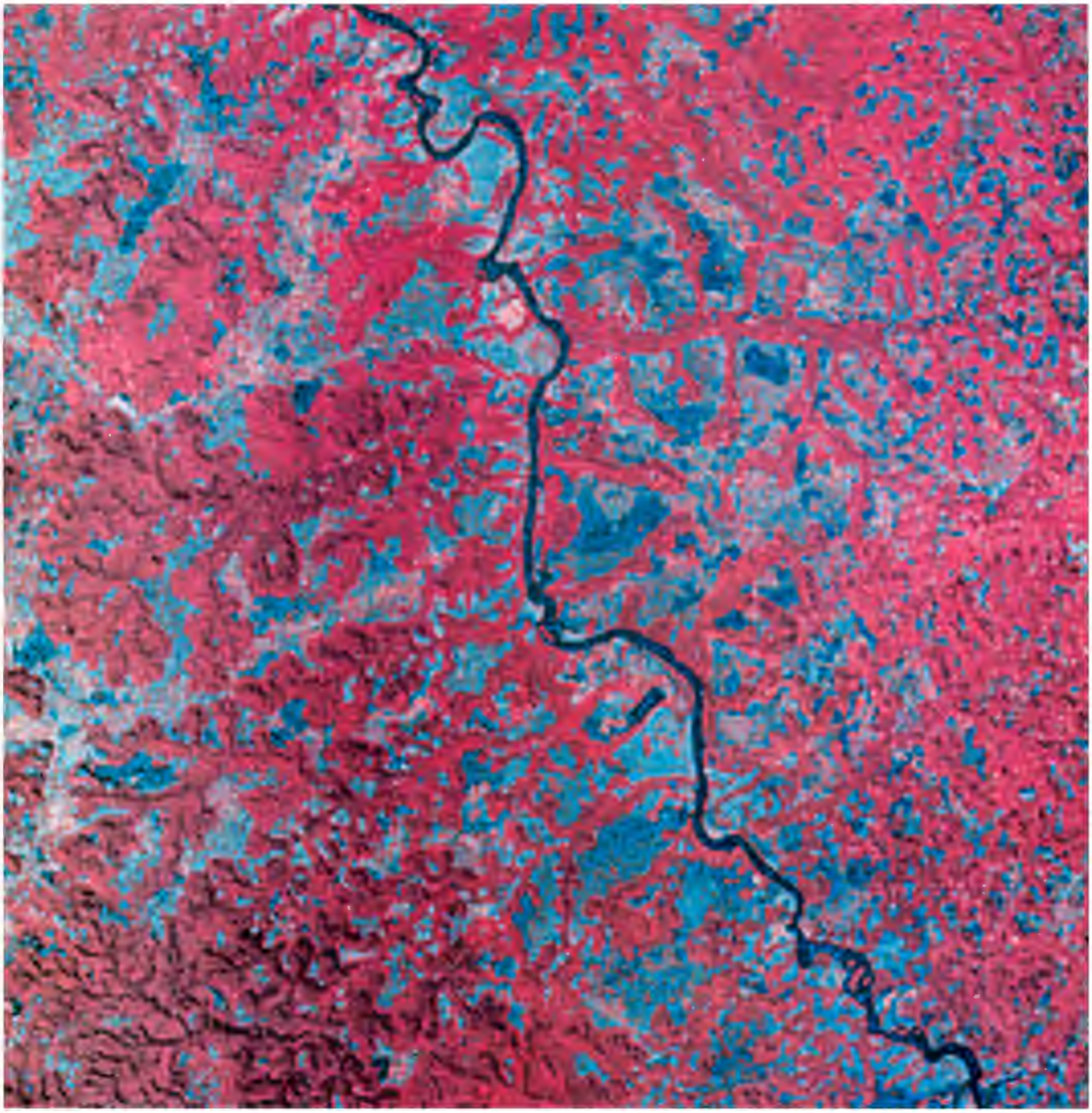


Fig.10 - *Area of Kananga, Zaire*
Approximate geographic location: 5°47'S, 22°12'E.

LANDSAT MSS colour composite of bands 4,3,2 (red,green,blue) derived from the acquisition of 5 June, 1989, Path 177 row 64

Forests are shown in red, open savanna in orange and bluish tones. Very minor changes can be detected when comparing the recent ERS-1 SAR image with this older LANDSAT MSS image taken five years earlier.

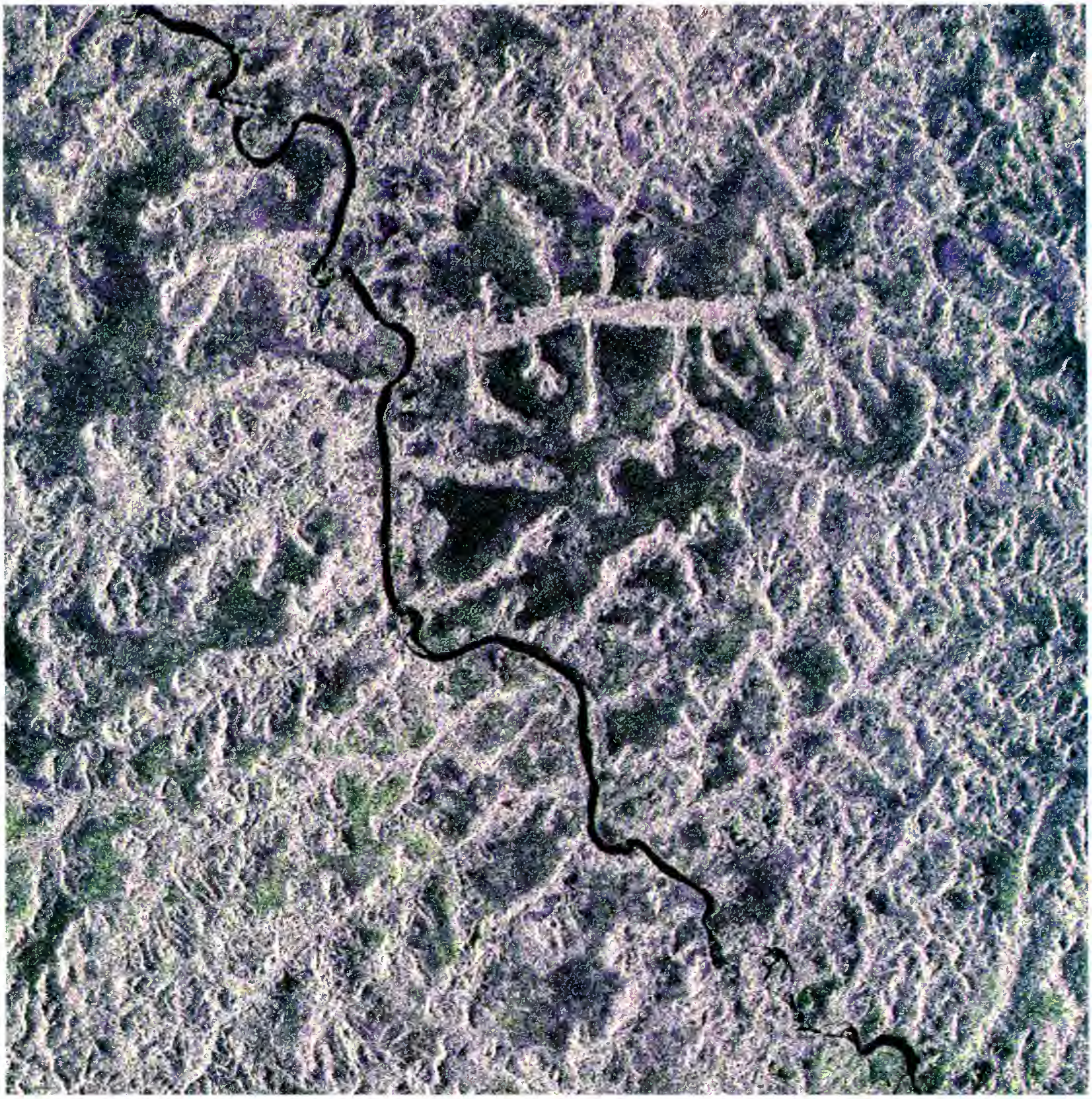


Fig.11 - *Area of Kananga, Zaire*
Approximate geographic location: 5°47'S, 22°12'E.

ERS-1 SAR multitemporal image (section of one full scene). From the interpretations of both, radar and optical images, it emerges that all land cover units mapped in optical images are also clearly visible in radar images, the only exception being the differentiation between closed and open forest. However, the forest cover degradation could be assessed by mapping the patches of cuttings, easily detectable in the radar image.

Fig.12 - *Area of Kasai River, Zaire*
Approximate geographic location: 4°32'S, 19°40'E.

ERS-1 SAR multi-temporal image of two dates of acquisition :
- orbit/frame 16736/3699 of 27 September 1994 (red) - orbit/frame 15134/3699 of 8 June 1994 (green) and
- 1st principal component of both dates (artificial channel) displayed in blue.
The area, located in the centre of Zaire, is similar to the ones shown in the previous figures. It consists of undulating landscapes, with elevations not exceeding 300 m. The average yearly rainfall is 2000 mm.- The main land cover is the moist forest, formed by different strata of deciduous and evergreen trees. The forest is represented in all aspects: from the untouched closed layer (bright), through different stages of its degradation. In areas where the anthropological pressure is strong, big patches of cut forest (dark green) are present. Here, small patches of fields, mostly used for grazing, can be found.

Test Site Areas 3 and 4:
KANANGA CITY and KASAI RIVER (Zaire)

CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL INTERPRETATION OF OPTICAL DATA		CARTOGRAPHIC UNITS IDENTIFIED BY VISUAL INTERPRETATION OF RADAR DATA			
				Accuracy in the delineation of the boundaries of the land cover classes	**Main criteria used for the interpretation**
Code	**Unit Name**	**Code**	**Unit Name**		
	Single Classes		**Single Classes**		
1a	Closed forest	**1**	Forest	Good	Texture
1b	Open forest				
2	Grassland	**2**	Grassland	Good	Texture
3	Grassland (savana) with gallery forest	**3**	Grassland (savana) with gallery forest	Good	Texture
	Mixed Classes		**Mixed Classes**		
4a	Fragmented forest (forest 10-40%)	**4a**	Fragmented forest (forest 10-40%)	Medium	Texture
4b	Fragmented forest (forest more 40%)	**4b**	Fragmented forest (forest more 40%)	Good	Texture
5	Urban area	**5**	Urban area	Good	Texture
6	Water	**6**	Water	Good	Texture - Shape

TABLE 3

5.3.2 Results and discussion

Interpretation results are shown in Table 3.

The following conclusions can be drawn from our studies:

- No differentiation between closed and open forest can be made using SAR data.
  The only way to evaluate the degradation of a forest cover seems to be the detection of patches in cut areas. These can be distinguished easily.
- With the exception of the above, all other units mapped in optical images were also clearly visible in SAR images.
- For the classes under consideration, there is no specific need for Radar multitemporal data sets as a monotemporal SAR image seems perfectly adequate.

Figures 8, 10 and 11 show ERS SAR and LANDSAT MSS images of the Kananga test site.
In Fig. 9 the Zaire land cover map is provided.
Fig. 12 is an ERS SAR multi-temporal image of the Kasai River test site.

6. The Operational Use of ERS Radar Data in General, and for AFRICOVER in particular

6.1. Operational use of ERS radar data in general

The use of ERS radar data was tested in four areas only, which cannot be considered fully representative of the wide range of land cover situations prevailing in Africa. Nethertheless, some clear conclusions can be drawn from the Pilot Study exercise, in terms of image scale, digital processing and product types.

Optimal scale

Aside from the "layover" and "shadowing" effects related to terrain topography, speckle is the main problem during a visual interpretation of a radar image. The "salt and pepper" effect has a strong impact on the interpretability of specific features. The texture is related both to the inherent characteristics of the area observed and to the scale of the interpreted image. Different land cover situations lead to very different textural effects, and consequently only broad indications can be given, but with reduced image scales, the texture gradually becomes finer and finally disappears.

As too small a scale impacts on the interpretability of the image, it is necessary to find a good balance.

From the observation of the four test site areas, the 1: 100,000 scale seems to be the lowest range of the optimal scale. The 1: 200.000 or 1: 250,000 scales seem to represent the highest limit.

In areas with a specific type of cover, such as in test site area 3, the optimal scale may be higher than the 1: 100,000 recommended above.

Digital processing and/or type of product used.

Processing

The best performing digital image processing has been discussed previously (see 3.2.3). It involves reduction of speckle effect, radiometric scaling, grey-level contrast enhancement and eventually geometric correction, all of which are normally performed with commercially available software packages for digital image processing.

However, it is important to recall that the method used here was aimed at the production of an analogue image for visual interpretation purposes. Further investigation should be carried out, especially in terms of the digital analysis of the texture (some PC software, for instance, has specific algorithms supporting different measures of the texture such as: homogeneity, contrast, dissimilarity, means, standard deviation, and entropy).

Output product type

As far as product type is concerned, the FCC of the three dates was recognized as a valuable informative product for land cover discrimination. However, in some cases like Zaire, the classes obtained using a FCC of two seasons are similar to those identified by means of a monotemporal SAR image. Consequently, the last product could have been used without affecting the results. It is therfore reccommended that for operational projects the cost/benefit ratio of land cover mapping of multidate versus single date images of a representative area be carefully assessed at the outset.

6.2. Use of ERS radar data in AFRICOVER

The following three scenarios for the operational use of ERS SAR information in the AFRICOVER Project should be considered (listed in increasing order of importance):

6.2.1. Use of ERS radar to replace optical data in equatorial zones

In equatorial areas in particular, the acquisition of both, SPOT and LANDSAT TM/ MSS data is very limited. As an example, despite the twenty attempts made, no cloud free-image was acquired over the Equatorial Guinea during a 4-year period. However, as demonstrated by the two tests in Zaire, SAR data can be used to map the main land cover classes such as forest, non-forest, fragmented forest, water and urban areas (see 5.3.) irrespective of the prevailing cloud-cover.

6.2.2. Use of ERS radar data to (a) update land cover information derived from old optical data, or (b) complement the interpretation made with partially cloudy optical data in equatorial zones

In equatorial, humid tropical and coastal areas cloud free optical data are often only available every several years. This can be a substantial constraint when a precise requirement such as that of ensuring map updates at regular time intervals has to be met.

ERS radar imagery offers the opportunity to complement old or partially cloud covered optical satellite data. As shown for the Zaire test sites, the main land cover classes obtained from optical satellite images can be mapped with ERS images to a similar level of accuracy (see 5.3.)

6.2.3 Use of ERS radar data to increase the number of land cover classes mapped in equatorial zones and/or to improve their mapping accuracy

The image interpretation methodology provisionally adopted for AFRICOVER is based primarily on the use of optical satellite data, processed in three distinct phases: preliminary segmentation, field verification, and final interpretation (see Par. 4).
During the field verification, particularly in agricultural areas where the phenological aspect of crops plays an important role, the field survey can reveal the presence of more than one land cover class in the preliminarily mapped unit (as in test site area 1).

As it is shown for the Guinea test site, ERS SAR acquired on a date with optimal crop differentiation can be used as a complementary data source to increase the number of classes mapped. For example, radar imagery could contribute to:

❒ identification of active/non-active fields in areas where fields with a long-fallow period are mixed with permanent cultivation;

❒ identification of a particular crop type;

❒ separation of a particular crop type (for instance, rice) from natural vegetation (marshes).

Radar data might be also very useful in particular environments (e.g. irrigated agricultural areas) for differentiating between subclasses on the basis of soil moisture or the presence of water.

6.3 Final remarks

6.3.1. Data acquisition and programming

Large operational mapping projects like AFRICOVER must be based on a standardized process of analysis of the optical satellite datasets acquired. However, this type of approach runs into difficulties whenever unforeseen situations are encountered during the mapping phase, e.g. differentiation of a new, important class identified during the ground survey, or difficulty in mapping a given class with the same accuracy in different environments.
Consequently, the inherent flexibility in the acquisition of radar data (all weathers, independent of cloud cover) and the possibility to perform a cost/benefit analysis of the radar-derived information as a complement to optical imagery, can only increase the operational efficiency of the Project.

6.3.2. Technology transfer

If the use of ERS radar data in the AFRICOVER project is indeed confirmed, careful attention needs to be devoted to the selection and training of the staff involved in the analysis and interpretation of those radar data, which is more complex than for optical data. In addition to good skills in photo-interpretation, specialised radar-interpretation training will be needed if a good quality output from the final image interpretation work is to be achieved.

APPENDIX

- Material Used

Sensor	Path	Row	Date	Product type
LANDSAT TM	201	53	94-04-24	digital floating quarter scene
	201	53	88-12-03	digital floating quarter scene
LANDSAT MSS	177	64	89-06-05	paper print - full scene
	179	63	86-05-26	" " scale 1:250.000
ERS-1	Orbit	Frame	Date	
	15905	3393	94-07-31	digital
	14556	3393	94-04-28	"
	6752	3393	92-10-30	"
	5120	3303	92-07-08	"
	8627	3303	93-03-10	"
	7124	3303	92-11-25	"
	15229	3717	94-06-14	"
	16291	3717	94-08-27	"
	15143	3699	94-06-08	"
	16736	3699	94-09-27	"

- **Digitized Maps**
  (see enclosure)

LEGEND

(1) *Lateritic crust (Bowal)*

(1A) *Lateritic crust recently burned*

(2A) *Agricultural fields semi-permanent*

(2B) *Mosaic of long fallow fields and low scrubs areas (small patches of lateritic crusts can be present)*

(3A) *Mosaic of low scrubs areas and patches of lateritic crusts (small patches of long fallow fields can be present)*

(3B) *Prevalence of thicket (patches of lateritic crusts or open low scrub areas can be present)*

(4) *Steep areas (no information available)*

Symbols

——— *River*

ʼ data

LEGEND

Single classes

(1A) Lateritic crust (Bowal)

(1B) Lateritic crust recently burned

(2A) Agricultural fields (long fallow)

(2B) Agricultural fields (permanent or semi-permanent)

(3A) Low scrubs from dense to open cover

(3B) Thicket (high scrubs, open trees)

Mixed classes

(1/3A) Lateritic crust and open low scrub layer

(3A/1) From dense to open low scrub layers mixed with small patches of lateritic crust (not more than 25-30%)

(3B/1) Dense thicket mixed with small patches of lateritic crust (not more than 25-30%)

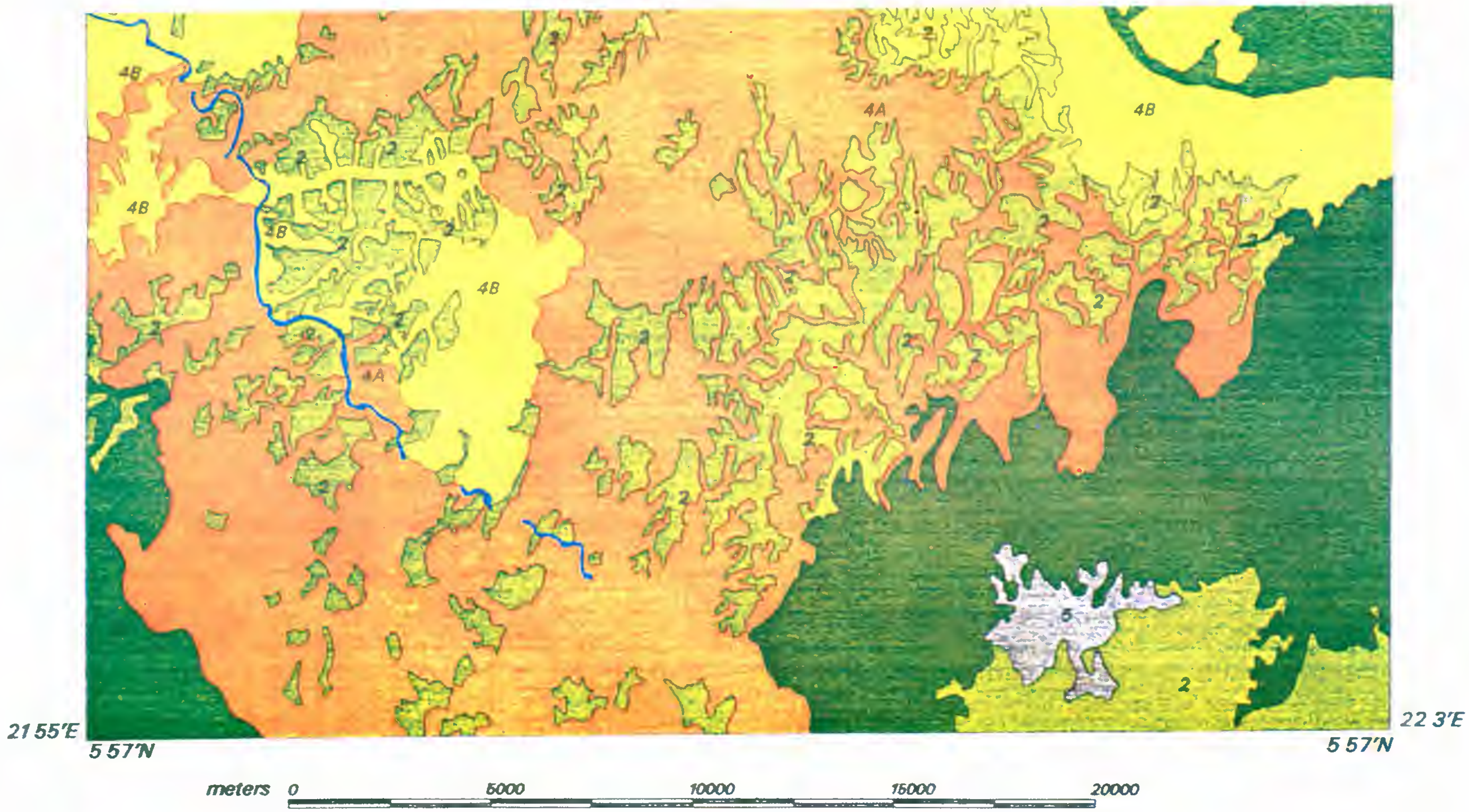
(3A/2) From dense to open low scrub layers mixed with small patches of agricultural fields (long fallow)

(2/3A) Agricultural fields (long fallow) mixed with open low scrubs (not more than 25-30%)

(3A/2/1) Open to sparse low scrub area with patches of agricultural fields (long fallow) and Bowals (last two not exceeding 40% of the total area)

Symbols

River


4B
4A
2
5
21 55'E
5 57'N
22 3'E
5 57'N
meters
0
5000
10000
15000
20000

LEGEND

Single classes

(1) Lateritic crust (Bowal)

(2) Agricultural fields (long fallow / permanent or semi-permanent)

(3A) Low scrubs from dense to open cover

(3B) Thicket (high scrubs, open trees)

Mixed classes

(1/3A) Lateritic crust and open low scrub layer

(3A/1) From dense to open low scrub layers mixed with small patches of lateritic crust (not more than 25-30%)

(3B/1) Dense thicket mixed with small patches of lateritic crust (not more than 25-30%)

(3A/2) From dense to open low scrub layers mixed with small patches of agricultural fields

(2/3A) Agricultural fields mixed with open low scrubs (not more than 25-30%)

(3A/2/1) Open to sparse low scrub area with patches of agricultural fields and Bowals (last two not exceeding 40% of the total area)

Symbols

River