APPLICATIONS OF SPACE IMAGERY IN THE DEVELOPING COUNTRIES

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ABSTRACT

The paper describes a number of mapping projects based on satellite images that the Swedish Space Corporation and its subsidiary SSC Satellitbild have been involved in since 1987. The first large vegetation mapping project, considered a major breakthrough in the earth observation business, was a land use mapping of the Philippines finalised within one year. A land use mapping, followed by a forest suitability study on South Sumatra, Indonesia, was carried out in the early 1990's. During 1992 and 1993 a land use, forestry and biomass mapping of Malawi was carried out. A forestry mapping project of Northern Namibia started in late 1992 and is beeing finalised now.

In Ethiopia SPOT panchromatic stereo images were used to derive a DEM, contour lines with 20 metre intervals and orthophotos for mapping at 1:50,000. Twenty-seven 1:50,000 topographic map sheets of the islands of Cebu and Bohol in the Philippines were produced based on existing old topographic maps and SPOT images. As a part of the National Population Census of Nigeria, 177 planimetric maps at 1:50,000 were produced in early 1990. This mapping led to an updating of the regular 1:50,000 series by the Federal Survey Department of Nigeria of 350 more map sheets. In the Baltic States ongoing projects are producing a new series of topographic maps based on orthocorrected SPOT Satellite Image Maps.

Earth Observation technology is a fully operational tool for land use and vegetation mapping and revision of topographic maps in developing countries. Major issues are related to availability, where cloudiness is one major problem and the programming and distribution system another. Strict handling of geometrical problems is essential in all applications. The trade-off between spectral, spatial and temporal resolution is treated. A typical land cover project design is described. Conclusions are made.

1 INTRODUCTION

The Swedish Space Corporation (SSC) and its subsidiary SSC Satellitbild have since 1987 been involved in a number of mapping projects in developing countries using satellite data. The first large vegetation mapping project, considered a major breakthrough in the earth observation business, was a land use mapping of the Philippines finalised within one year. The project was carried out at a time when remote sensing was seen more as a tool for researchers, using scenes or parts of scenes, than for practical use in larger areas. Since then thematic mapping and topographic mapping projects have been carried out by SSC on all continents.

2 PURPOSE

The purpose of this paper is to share the experiences from SSC's international mapping projects and point out the important issues in mapping from space in developing countries.

3 PROJECT DESCRIPTIONS

3.1 Land Cover Mapping of the Philippines

During one year's execution time, between 1987 and 1988, a full Land Cover Mapping at 1:250,000 of the Philippines was carried out using SPOT scenes (Rasch et al, 1988, Rasch, 1994). The primary goal of the project was to establish land cover statistics for project planning at the World Bank. The choice of SPOT was primarily based on the programming and tape recorder capabilities in combination with the flexibility and repeatability due to the side-viewing capabilities. In the beginning of the project almost no useful images existed and at that time it was practically more or less impossible to get a coverage with Landsat. A sufficiently cloud-free coverage was achieved during the project period, partly due to the fact that there were more cloud-free periods than usual during the year. The mapping was performed by interpretation of precision corrected scenes at a scale of 1:100,000. 24 land cover classes were interpreted on the 187 scenes used, 43 map sheets at 1:250,000 were produced and land use statistics by region were computed. To obtain ground truth and give the interpreters an understanding of the area 19 air reconnaissance and 7 ground surveys were carried out.

Twelve months was, especially in 1987-1988. a short time for a project of this size. It was possible due to the characteristics of the SPOT system and the enthusiasm of the team. The accuracy of the classification was good - the only frequent problem was two forest classes that were mixed up - especially taking into account that the number of actual classes was twice as much as stipulated by the contract. The project has since then got many followers internationally.

3.2 Forest Suitability Mapping on South Sumatra

As part of a study on management plans for industrial forest plantations of parts of the Musi River watershed, South Sumatra, two sequential studies of the same area were carried out jointly by SSC Satellitbild and Swedforest International. This is a part of Indonesia with intensive land use and rapid changes. A land use mapping in 20 classes was followed by a forest suitability mapping based on the land use information. Forest Suitability Maps are powerful instruments for land use planning and decision makers (Fig. 1). Satellite Image Maps of multispectral SPOT Images, complemented with Landsat TM scenes were used. The initial study was of pilot character and was carried out on twelve map sheets at a scale of 1:50,000. The project was carried out jointly by SSC and Swedforest International and was finalised in 1991. Sumatra is, like most of Indonesia, extremely cloud covered. The areas were selected at that time based on existing satellite data.

The results were considered very satisfactory and have led to an ongoing full scale project covering 109 1:50,000 map sheets on East Kalimantan (Borneo) and Sumatra.

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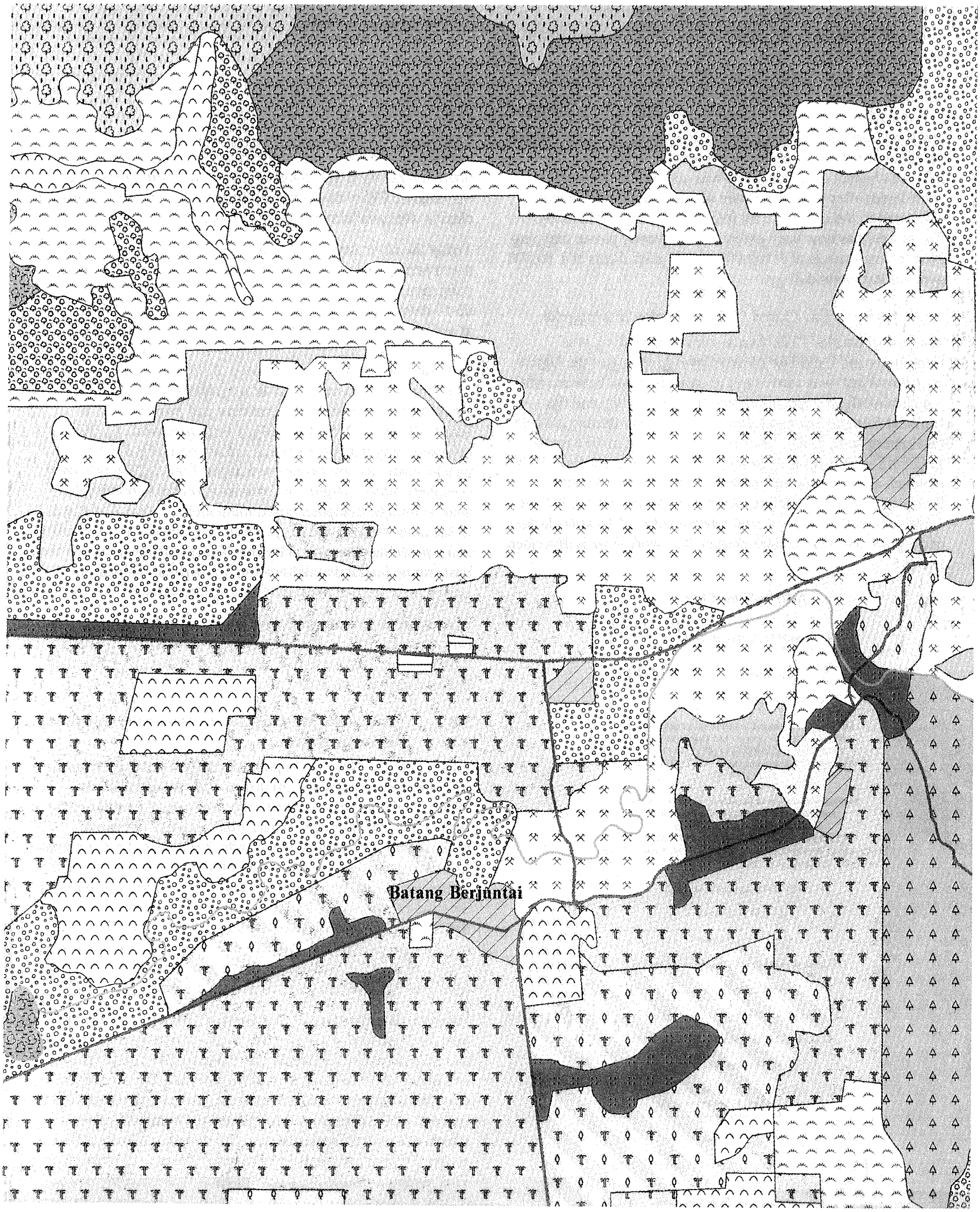

Figure 3 Part of Land Cover Map, Malaysia.

3.5 Forestry Mapping of Northern Namibia

A forestry mapping project made in co-operation between SSC and the Directorate of Forestry under the Ministry of Environment and Tourism of Namibia of the forestry areas of Northern Namibia started in late 1992 and finished in late 1994. Forestry Maps based on 46 Satellite Image Maps at 1:100,000 based on Landsat TM and 158 Satellite Image Maps at 1:50,000 based on SPOT multispectral were produced. The middle infrared channel of Landsat TM was not used as it was not considered, after tests, to contain any additional information compared to the conventional infrared colour combinations. The project has now been extended to a second phase, mapping 24 more map sheets at 1:100,000 and 92 map sheets at 1:50,000 with similar methodology.

3.6 Land Use / Land Cover Mapping in Mongolia

The project entitled "The Assessment of Environmental Conditions and Land Use / Land Cover Mapping of the Ugtaal-Jargalant Area" was carried out as a co-operation between SSC Satellitbild, the Research Institute for Land Policy and the National Remote Sensing Centre in Ulanbaatar during 1994-95 (Malmberg et al, 1995). The project was based on one set of SPOT XS scenes from 1994 and one provisional set from 1986, in which a gap was complemented with Landsat TM data. Precision corrected Satellite Orthophoto Maps at 1:50,000 and 1:150,000 were used for visual interpretation of 16 area classes and 7 point and land feature classes. The work flow is described in Fig 5.

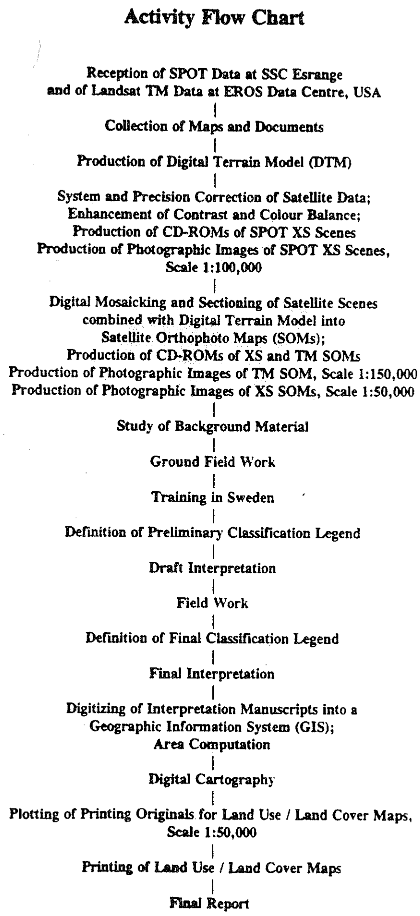

Figure 5. Activity Flow Chart for the Assessment of Environmental Conditions and Land Use / Land Cover Mapping of the Ugtaal-Jargalant Area.

3.7 Forest Inventory in Chile (A Pilot Project)

The aim of the project was to (i) evaluate whether the use of satellite images can fulfil, completely or partly, the demand for up-to-date forest information on both plantations and native forests; (ii) evaluate feasible data sources to be used and (iii) evaluate technology to be used - digital or analog. The goal of the project was to test the feasibility and learn how to use satellite data in forest inventory. It was carried out as a co-operation between SSC Satellitbild and Instituto Forestal in Santiago de Chile. Seven natural forest types and five plantation classes were available within the project area.

Today the inventory of the plantation forests is done using aerial photographs for later transfer into GIS - the scale corresponding to 1:50,000. Concerning natural forests overall up-to-date information is mainly lacking, but is now carried out at scales corresponding to 1:250,000. Three test areas were inventoried - each covering four different map sheets at 1:50,000, and including one sheet at 1:25,000 - one coastal area, dominated by pine plantations, and two mountainous areas, consisting mainly of secondary and primary natural forests. Satellite Orthophoto Maps were produced for the corresponding map sheets based mainly on merged SPOT panchromatic and multispectral images. Landsat TM was used complementarily. Digital interpretation on hard copies and semi-automatic computer based methodology were compared. In the latter method, the images were segmented automatically and a predelineation was achieved. This predelineation was the basis for an interactive delineation. In the final delineated image, an on-screen interpretation was performed.

The results were in most regards negative for the computerised methodology. It gave lower accuracy, and was slower and more monotonous. Satellite data was found to be useful, but needed to be combined with other information sources.

3.8 Planimetric Mapping for the National Population Census in Nigeria.

As a part of the National Population Census of Nigeria, in all 177 planimetric maps at 1:50,000 were produced (Atilola, 1990). The areas to be mapped were not earlier covered with sufficient 1:50,000 maps. Where maps existed they were produced by approximate means which included direct tracing from aerial photographs and acquisition of control points by slotted templates. For five out of seven blocks SSC produced Satellite Image Maps (not orthocorrected) from multispectral SPOT-images. The choice of the multispectral mode was based upon image availability. The Satellite Image Maps were produced in UTM, while most of the existing material was in Modified Transverse Mercator in imperial units.

From the Satellite Image Maps cartographic information was extracted and later verified in the field - primarily settlements and road network. The results were presented as combined line and image maps in black and white. For the relatively limited selection of objects to be detected the project was considered a success. SPOT data existed for almost the complete areas, which was in itself a success as some mountainous areas had earlier defied all attempts to be mapped because of cloudiness. This mapping resulted in a continuation with updating of the regular 1:50,000 series by the Federal Survey Department of Nigeria of further 350 map sheets, this time using panchromatic images (Allo, 1993).

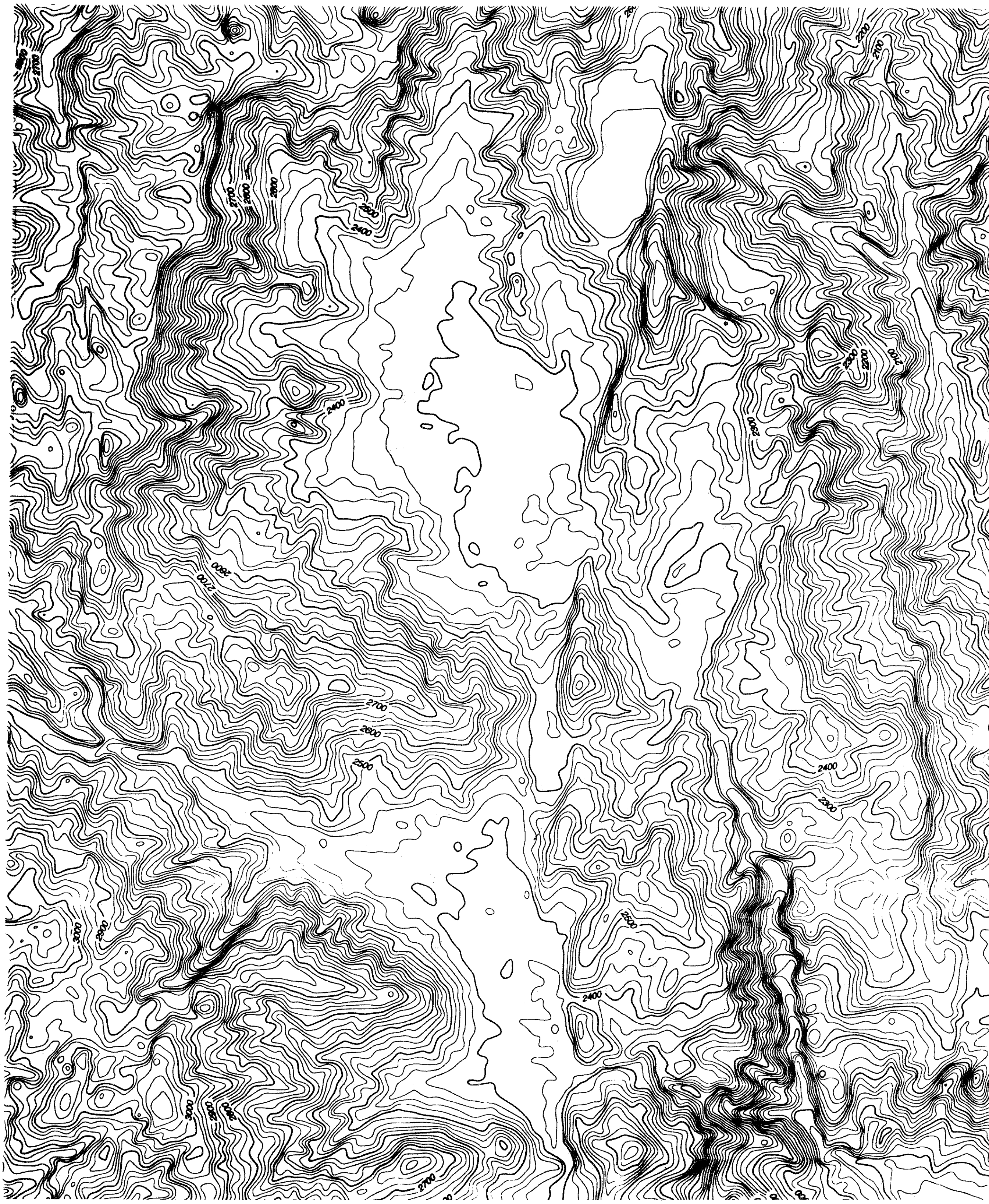

Figure 6. A part of a 20 meter equidistance height contour original extracted automatically from stereo SPOT Images (1:50,000).

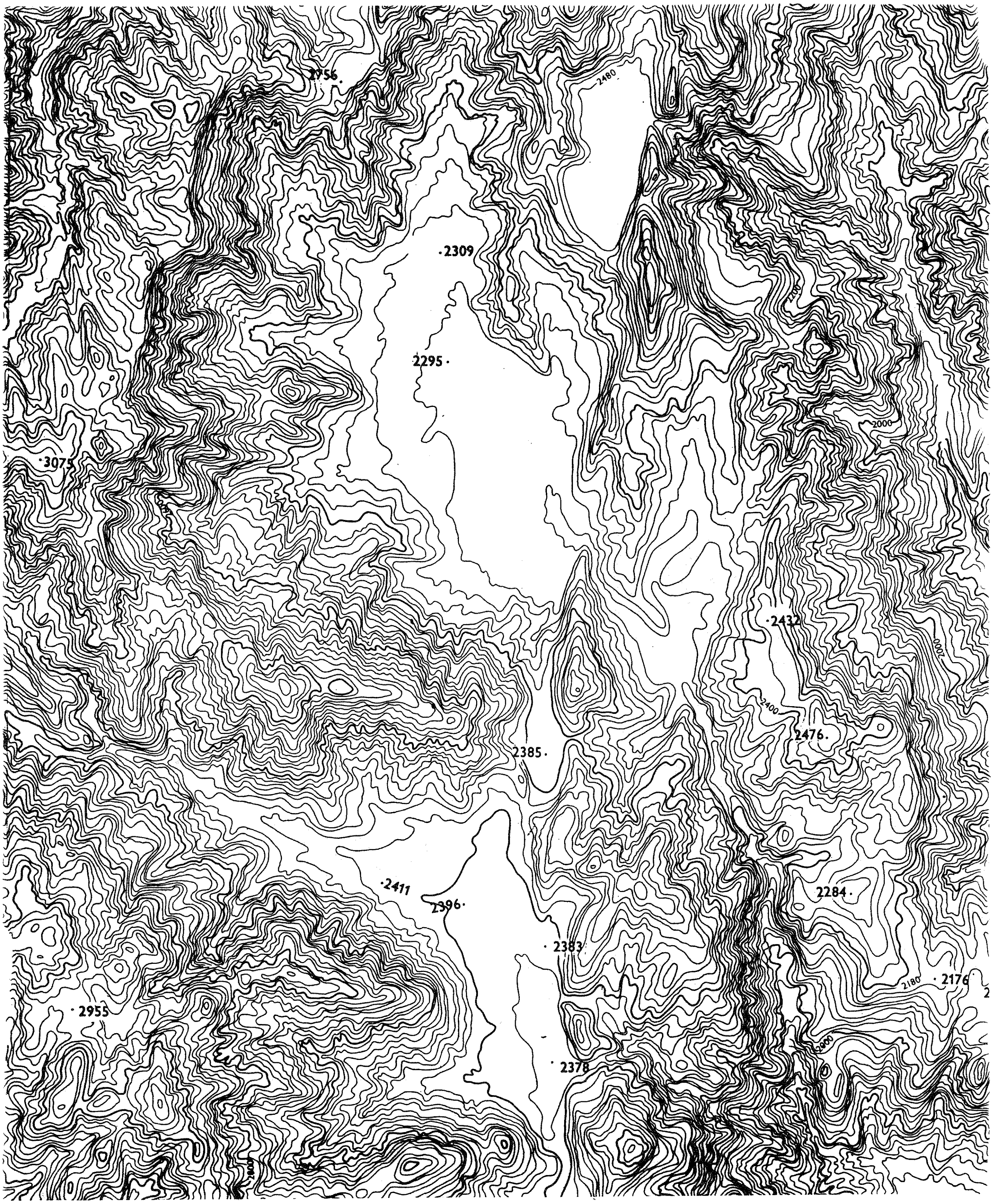

Figure 7. The corresponding part with contours extracted from aerial photographs.

3.9 Topographic Mapping of Asela in Ethiopia - a pilot study

A topographic map sheet at a scale of 1:50,000 was produced in 1988 over a map sheet in central Ethiopia (Westin et al, 1988). The area had very high relief, with elevations varying between 1700 and 3800 m. SPOT panchromatic stereo images were used to derive the DEM and contour lines with 20 metre intervals. Orthophotos from both panchromatic and multispectral SPOT images were also produced. Two more map sheets were later produced for the Ethiopian Mapping Authority (EMA) in an area newly mapped with conventional technology based on aerial photographs. These two sheets were produced as a blind test. In Fig. 6 a part of the contours extracted from SPOT is shown and in Fig. 7 the corresponding part produced with conventional technology is shown.

The results were considered very satisfactory. The planimetric accuracy of orthophotos extracted from SPOT is fully sufficient for 1:50,000 mapping. Compared to aerial photographs the image resolution of SPOT limits the possibilities of mapping details - and thus increases the need for field completion. The height accuracy was better than 10 meters r.m.s., compared to a few ground check points. The similarity in appearance between the contours extracted from SPOT and from aerial photographs was good. This was possible because of the short time differences, only a few days between the scenes in the pairs, and the good base-to-height ratios.

3.10 Topographic Map Revision in Bhutan

For map revision purposes Bhutan was in the end of the 1980's covered with totally 79 satellite image maps at a scale of 1:50,000 from panchromatic SPOT data (Brook, 1991). Where height contours already existed, the data was orthocorrected, while satellite image maps had to be produced without height correction in large parts of the country. The existing 1:50,000 topographic map series was outdated, especially the infrastructural changes had been major. By combining the satellite image maps with the feature separations of the existing height contours, the road network from visual interpretation of the satellite data (including field work) and the place names, an intermediate mapping series was produced.

3.11 Topographic Mapping of Cebu and Bohol in the Philippines

In co-operation with the National Mapping and Resource Information Authority (NAMRIA), SSC produced 27 1:50,000 topographic map sheets of the islands of Cebu and Bohol and some neighbouring smaller islands based on existing old topographic maps and SPOT images. The map sheet delineation and the sheet size were changed from 10 x 15 geodetic minutes to 15 x 15 geodetic minutes. Panchromatic orthoimages were produced for all map sheets. For all map sheets except one, the contours from the existing maps were digitised and transferred into the new system. Due to cloud cover it was possible to obtain stereo data for only one map sheet, covering the island of Siguiohor. Also in this pair the panchromatic stereo pair had to be complemented with one multispectral SPOT image due to a cloud covered mountain top.

Extracting height information from SPOT stereo images did not give any major advantages compared to digitising existing contours. The reasons were all related to cloudiness such as partial cloud cover, varying b/h-ratios and large differences in acquisition times. For revision of area and line objects SPOT was excellent, except where large side-looking angles made identification of roads difficult in areas with high vegetation (coconut palmtrees). For most point objects, such as single houses, the 10-meter resolution of SPOT was not sufficient.

3.12 Topographic Mapping of an area in Malaysia

Satellite Orthophoto Maps based on SPOT Panchromatic scenes were produced for 14 map sheets at 1:50 000 in co-operation with the Department of Survey and Mapping (DSSM) of Malaysia and used for revision of existing topographic maps. For 5 more map sheets DEMs and 20 meter contours were also produced. No formal accuracy evaluation was made although the SPOT produced DEMs were merged with DEMs extracted from existing topographic maps without specific border problems. Thirteen land cover classes, related to topographic maps were interpreted. Changes concerning roads, powerlines and built-up areas were detected. To extract changes of all map details used in Malaysia was not possible with SPOT data.

3.13 Topographic Base Mapping in the Baltic States

In the Baltic States ongoing projects are producing a new series of topographic maps based on orthocorrected SPOT Satellite Image Maps (Klang, 1995) . They are carried out in co-operation with the national mapping authorities in Estonia, Latvia and Lithuania respectively.

From existing maps, produced in the old Soviet cartographic system, existing cartographic information., including height contours, was digitised. The information was transformed to the new Baltic Geodetic datum. DEMs were extracted from the contours. Depending on the quality of the existing data versus the SPOT images three methods for production of databases are used; (i) when the need for revision is fairly limited the existing data base is updated using the SPOT image maps; (ii) the information is directly acquired by interpretation of the SPOT image maps, sometimes supported by existing maps; (iii) when information is impossible to acquire from satellite data the digitised data is used directly, typical examples being contours and administrative boundaries. Infrastructural elements and six area classes are delineated according to a priority scheme. The final map is produced as an orthophotomap with line information (Fig 8).

The project has given broad basic experience in how satellite images - and their excellent geometry - can be used for correction and revision of existing maps, conversion and production of new maps.

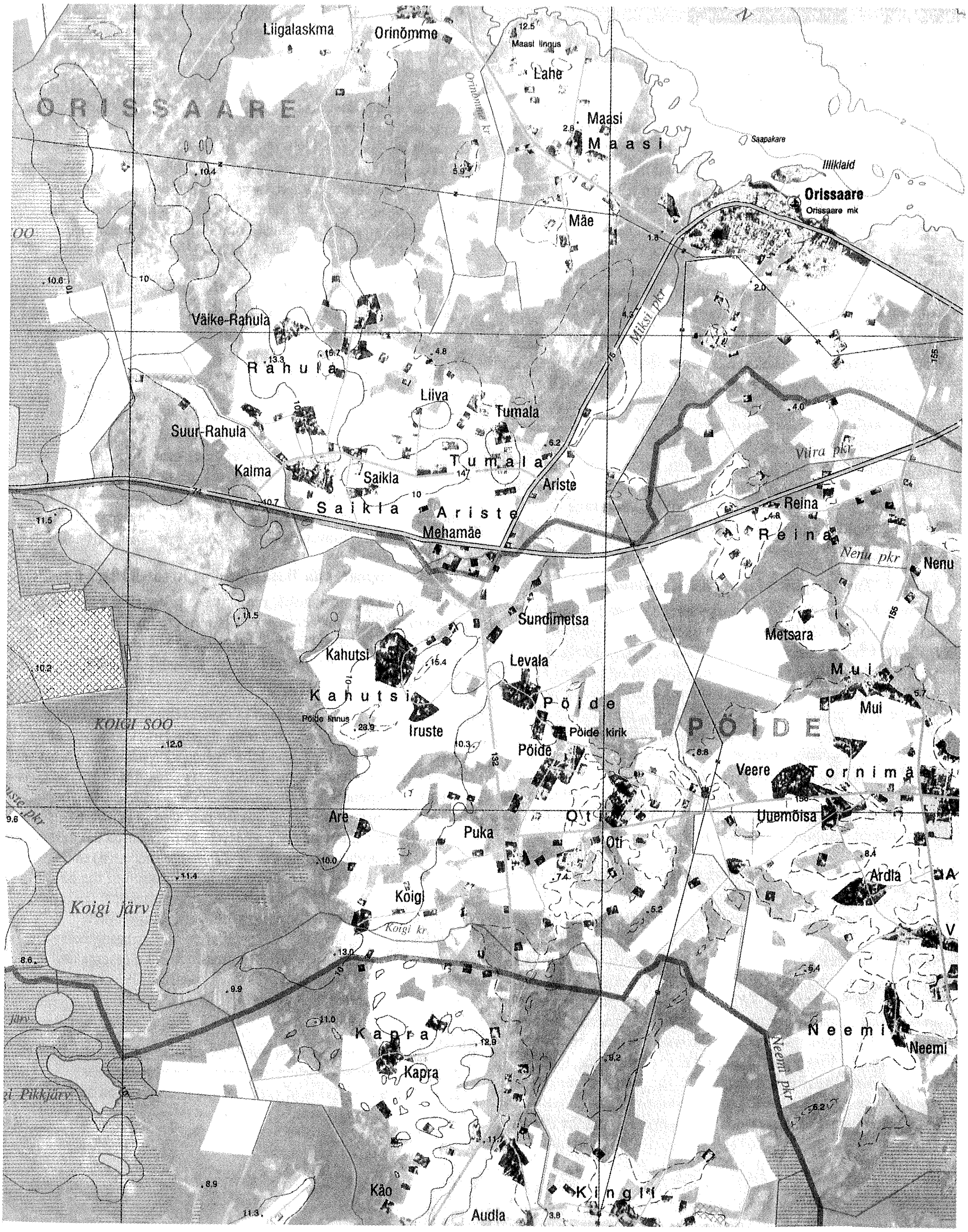

Figure 8 Part of a newly produced orthophotobased map sheet in Estonia.

4 DISCUSSION

4.1 Geometric Corrections and Image Maps

In almost all the projects described above satellite image maps of some kind were used. Contrary to image map prodution from aerial photographs orthocorrection is not always necessary using satellite images. The viewing angle is sometimes insignificant, compared to the scale and accuracy requirements.

The advantages of image maps are many. The existing information in maps, etc. can be interpreted simultaneously and be directly compared with the images. The results of an interpretation are already in a known and correct system. The distribution, visualisation and cartographyic production of the information can be done directly. Projects using uncorrected satellite images usually get messy when trying to handle the geometrical problems, combining information sources and making cartography. When visual interpretation on hard copies is done the possibility of working with the same image geometry as in the end products is an immense advantage. In digital systems geometric correction is necessary, although a division into image maps is not always needed.

In general, excellent orthophoto maps can be produced very efficiently from satellite data. A geometric accuracy around half a pixel can be obtained routinely. The large size of the original images admits homogeneous radiometry in large areas.

4.2 Availability and Clouds, Clouds and Availability

A common theme in the description of the above projects is dependence on the availability of image data. The choice of data type, acquisition period of the year and even project areas has often been a function of availability. The limiting factor is primarily cloudiness, in combination with the programming capabilities of the system. Especially in systems with neither side-looking capability nor tape recorder, such as Landsat, image access has been the major limitation.

Availability is not only one of many limitations. It is even likely that the single most important problem for the utilisation of today's satellite image technoloy is the unreliability of the access to data.

Availability has to be considered at the earliest possible stage in preparing a project. In the more favourable cases data exist but are too old. In the worst cases a complete coverage is not possible during the project execution time. To combine different data sources is commonly the solution. In many of the projects in equatorial countries this has been solved by combining a high resolution data set (SPOT) with a lower resolution complementary data set (Landsat). Another solution in areas where cloud-free images hardly exist is to include acquisition of extra images in the budget and in the project plan - to be used for cloud mosaicking.

4.3 Analog or digital mapping?

In all the thematic mapping projects described here the interpretation was done on overlays of photographically produced transparent satellite images. Afterwards the results were digitised and transferred into a GIS system.

As an alternative method the mapping can be done directly on the screen - with the raster image as the background for the vector mapping. Why did we not use such methods? There are many reasons: (i) this was not feasible technology at the time many of these projects were carried out; (ii) there would have been an increased risk of delays in the projects because of technical problems, insufficient training, etc; (iii) the projects might become more concentrated on technology instead of obtaining results; (iv) the purchase of the hardware would increase the cost of the project - connected with this is the problem of obtaining future funding for maintenance of the equipment; (v) all experience points towards the fact that interpretation on photographic hard copies is faster to do than on-screen mapping.

On the other hand, it appears that revision of data bases can be done very efficiently digitally. It is easy to compare and detect changes and edit them with the vector data overlaid on the images. It is also possible to semi-automate revision - in a way almost impossible for mapping without any previous knowledge.

4.4 Use Auxiliary Data!

To carry out an operational project is not the same as doing research! In research projects a basic methodology is tested on a specific material. In fully operational projects it is necessary to use all available data sources - it is one of the clues to effectiveness, accuracy and success. The two most obvious sources are existing maps and supplementary sets of satellite images or aerial photographs. In existing maps thematic areas, object and height information are available. Supplementary image sets can be used to identify features and classes not visible in the base data set. They can be used for overlapping cloudy areas and for identifying changes. The geometric problems of aerial photographs and of not corrected satellite images are usually not relevant when used together with image maps. An inventory of existing relevant maps should be made at an early stage of a project. Usually topographic maps have the most important information, but various thematic information usually exists at different ministries. Any kind of existing files from earlier inventories are also useful.

4.5 Which Image Material to Use - Stereo, Mono, B/W, Colour, Resolution, etc?

The use of aerial photographs creates naturally, through the acquisition schemes, availability to stereo images. However as individual photographs they are complicated to use and handle. Satellite images can relatively easily be corrected into orthophotomaps, as can aerial photographs with somewhat more time consuming methodology. What is the situation with satellite data? To get stereo coverage with satellite is twice as expensive as mono coverage. It can only be done with SPOT operationally and is anyhow practically more or less impossible except in arid areas.

The question is, which is more important for a good interpretation result, stereo coverage or the easy and reliable handling based on orthophoto maps?

A similar question is whether the texture in higher resolution images (such as SPOT P) is more important than the spectral information in, for instance, Landsat TM. When there are differences in interpretability, are they worth trading against other factors as operationality, price, etc.

Such questions are totally impossible to answer generally. Stereo can be more important than, for instance, colour images - that was part of the conclusion of the forest inventory project in Chile. The texture of SPOT panchromatic data would have been preferred against the spectral information of Landsat TM in the forest and biomass mapping of Malawi. In the forestry mapping of Northern Namibia the advantages of the middle infrared channel were considered negligible, despite the fact that this was a vegetation mapping. In the land cover mapping of the

Philippines the only operational way of carrying out the project was by using SPOT, any other considerations about data sources could be disregarded. The mapping project for the National Population Census in Nigeria used SPOT multispectral instead of the technically more feasible panchromatic images, as this was the only available data and the time was limited. The point behind this is that all these things have to be considered for each project, a general answer does not exist. It also means that these issues have to be considered concisely and can not be neglected.

4.6 Production of DEMs and Contours

It is possible and feasible to produce Digital Elevation Models and contours from stereo SPOT images. It is, however, for many reasons problematic in all areas except the most arid. As the stereo is not obtained on the same track the same day, both the images used have to be observed under cloud-free conditions. This limitation allows only a few choices of images. The consequences are; (i) the base-to-height ratios vary, giving inconsistent and unpredictable results, (ii) the time differences between the scenes vary, not only giving variations in precision but, even worse, also resulting in low reliability, (iii) any time planning is very difficult if data does not exist in an archive and programming is required - systematic coverage of an area by archived stereo data is rare; (iv) to cover partly cloudy stereo pairs the number of images has to be significantly increased.

When the image material is sufficiently good (only a few days between the image observations and a base-to-height ratio better than 0,5) the reliability and overall accuracy is sufficient for many purposes. An r.m.s. accuracy of 7-10 metres is routinely obtainable from SPOT stereo. This is sufficient for many purposes. It is sufficient for production of Digital Elevation Models for certain applications, such as planning of cellular networks. It is sufficient for production of 20 metre height contours at 1:50,000 (and corresponding elevation data bases) for areas where maps do not exist and the budget is limited. However, in general the limitations of today's stereo satellite data are too large for most general mapping purposes.

4.7 Topographic Map Revision

Revision of topographic maps can be, and has already been, carried out to a large extent using high resolution satellite images such as SPOT. However the feasibility varies for different types of objects. For revision of detectable objects it is a fully operational technology, as was the case in the mapping projects in Nigeria. When the requirements are tuned to the possibilities, as in the Baltic projects, even completely new map series can be established very successfully. If very detailed information is needed, as was the case in Malaysia, only aerial photographs, or orthophotomaps based on aerial photographs have sufficient resolution.

The resolution of SPOT has been sufficient for identification of area and most line objects in topographic maps at 1:50,000. Infrastructural elements - roads, tracks, waterways - are usually well detectable. Powerlines in open terrain and old railroads might not be detectable, but that is more a problem of contrast than resolution. The area classes of ordinary topographic maps are usually very well detectable both with multispectral and panchromatic SPOT images. Most point objects, such as single houses, are not detectable in SPOT or Landsat images. A significantly higher resolution is needed for detection of point objects.

4.8 A Typical Land Cover Mapping Project

How shall a typical land cover mapping project be carried out. A description of such a project is made in Fig 5. This description puts very much emphasis on the production of image maps. A more general description of how a work flow could look is:

Step 1. Acquisition of low cost information for planning of the project. The information is typically found in existing maps, NOAA-images and quick-looks of satellite images. It will give an increased understanding of the main features of the study area.

Step 2. A visit to the project area by the leading staff to get an overview of the distribution of the different classes. If possible photographs and/or video films should be obtained, from ground and air. Inventory of available information sources is essential. A preliminary classification schedule should be made.

Step 3. Test and selection of image data, product types, spectral channels, etc. Ordering and/or production of image material.

Step 4. Preliminary interpretation. Test of classification system. Identification of areas for field investigation.

Step 5. Field investigation in areas selected as typical and in ambiguous areas. The field trips should give the interpreters detailed knowledge about the area and the classes.

Step 6. Final interpretation based on the preliminary interpretation and refined by the knowledge acquired through the field work.

Step 7. Digitising, check and editing of the interpretation result.

Step 8. Cartographic processing and production of printing originals. Printing of maps. Production of final report.

Formal training should be performed early in the project, making on-the-job training possible to carry out throughout the entire project.

5 CONCLUSIONS

The following conclusions can be made from the projects:

Satellite remote sensing is a reliable and fully operational tool for thematic mapping of vegetation and land cover at scales between 1:50,000 - 1:250,000. In applications covering large areas it is actually the only realistic alternative.

Satellite images are fully operational for topographic map revision of detectable objects. When the requirements are tuned to the possibilities even completely new map series can be established very successfully. However today's satellites do not fulfill the same requirements as aerial photographs.

Only geometrically corrected images should be used in mapping projects. Normally Orthophotomaps should be used unless accuracy requirement and data allows the use of non-orthocorrected image maps. Satellite data is an excellent material for production of image maps. For digital mapping geometrically corrected scenes can be considered an alternative to image maps.

Image availability is a major problem for data acquired in the visible and infrared bands. The major factor limiting availability is cloudiness. Operationality of the data acquisition and distribution are major factors to consider for data choice.

Interpretation on photographic hard copies is preferable to direct interpretation on computer screen in most applications where new maps are produced. For revision purposes, however, editing existing data bases on raster image background can be time-efficient and reliable.

All available information, not only the basic image material, should be used for mapping. Existing maps, old aerial photographs, complementing satellite images, old files and tabular data are all most useful during interpretation.

Take all aspects into account for choice of images. Operationality and availability, spectral versus spatial resolution, stereo or mono data, effect on total cost and time consumption. Simple answers do not exist.

Digital Elevation Models and height contours can with today's satellite technology only be produced in areas with favourable cloud conditions and for specific purposes. Height contour mapping from space requires on-track stereo and higher accuracy.

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