Comparative tests of small-scale aerial photographs and Spot satellite images for topographic mapping and map revision in eastern, central and southern Africa

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ABSTRACT

A survey of the topographic map coverage of eastern, central and southern Africa showed that this is very extensive—indeed it is complete for several countries in the region. However, because of rapid changes in the landscapes, many of the existing maps are now out-of-date and urgently require revision. This paper considers the possibilities of doing so from Spot satellite images, with an emphasis on their interpretational qualities, since preceding tests have shown that the planimetric accuracy requirements for 1:50,000 and 1:100,000 scale topographic mapping can be met from such images. A series of interpretational tests were carried out in a number of different landscapes in Kenya, Tanzania, Zambia and Botswana for which maps were available. Comparative tests were also carried out in two of these areas using small-scale aerial photographs taken with super-wide-angle cameras. The results of all tests are given for five main feature classes: lines of communication, cultural features, vegetation and land cover, hydrology and geomorphic features. In general terms, the deficiencies in the Spot images were found to be in the communication features (eg, minor roads, tracks, railways), cultural features (eg, villages, buildings) and water-storage features (eg, tanks, ponds). Extensive and systematic field completion would be needed to rectify these deficiencies. Similar tests undertaken in Australia are described, in addition to results achieved in mapping and map-revision programmes in east Africa based on the use of Spot images. A further discussion addresses the future possibilities of carrying out topographic mapping and map revision from both satellite images and aerial photographs.

A number of projects and surveys conducted by University of Glasgow graduate students from eastern, central and southern Africa have provided a detailed picture of the current situation regarding topographic mapping in the countries of this vast region. These include the projects carried out by Kajumbula [10] for Uganda; Murimi [17] for Kenya; Liwa [13] for Tanzania; Buka [1] for Zimbabwe; and Ferrao [3] for Mozambique. These reports have been supplemented by information collected by Petrie [21] on visits to national mapping organizations in the area and by additional information supplied by OS International, the successor to the UK Directorate of Overseas Surveys (DOS), which has undertaken much of the basic topographic mapping in the region [15]. An outline of the information derived from these sources has been published elsewhere [21].

In summary, it can be said that the existing topographic map coverage of eastern Africa is very extensive, amounting to nearly 100 percent in Uganda, 85 percent in Kenya and 75 percent in Tanzania (see Figure 1). A similar situation prevails in central Africa. The coverage is 100 percent complete in Malawi, 90 percent in Mozambique and 95 percent in Zambia. Finally, in southern Africa the coverage is 100 percent for Zimbabwe, Lesotho and Swaziland and 50 percent for Botswana. Those areas which have not yet been mapped are either the most remote and inaccessible mountainous areas of these countries or arid or semiarid areas with little population or economic activity, *eg*, the north and northeastern regions of Kenya, the west-central area of Tanzania, the far western part of Zambia and that part of the Kalahari Desert occupying the southern and western parts of Botswana.

Most of this topographic mapping was carried out over the period 1946-1985, mainly by the UK [15], but

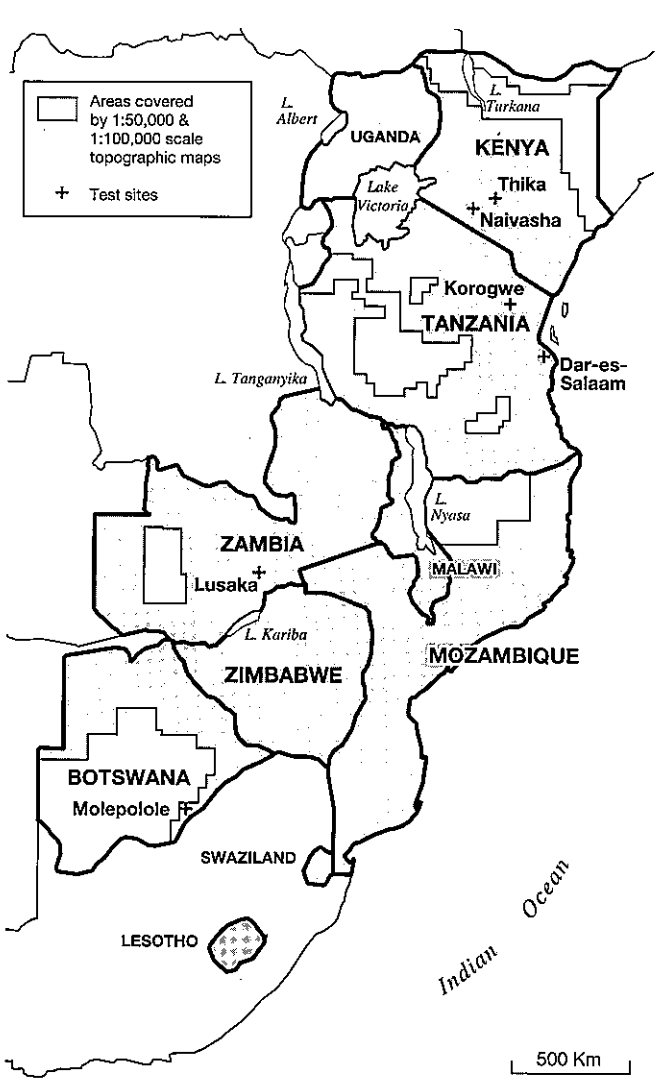

FIGURE 1..Topographic map coverage of eastren, central and southern Africa and locations of test sites

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also by Portugal in Mozambique. Other much smaller aid programmes carried out by Canada (in Zimbabwe and Tanzania), Japan (in Kenya and Tanzania) and Finland (in Zambia and Tanzania) have provided valuable additional coverage. In Zimbabwe, the original complete map coverage was achieved through the efforts of its own national surveying and mapping agency, supplemented later, after independence, by a Canadian aid programme [27]—the so-called "Zimbabwe air survey project" (ZASP).

Since the withdrawal of the colonial powers and the achievement of independence, however, there have been substantial and widespread changes in the landscapes of these countries. These have resulted from the effects of (1) civil wars (*eg*, in Uganda, Zimbabwe and Mozambique); (2) famine arising from these civil wars and from drought and other natural disasters; (3) political policies, *eg*, the break-up of plantations and large European-style farms into smallholdings in certain countries or the policy of forced "villagization" in Tanzania; and (4) large-scale agricultural and other development projects. The impact of all these major events or developments has been large shifts in population, resulting in considerable changes in the rural landscape and the rapid and often uncontrolled growth of many towns and cities. In many areas, when travelling through the rural landscape, it is immediately apparent that, while the basic topography (as represented by the relief, elevations, contours and hydrology shown on the maps) has not changed, the man-made cultural landscape in the form of settlements, communication networks, cultivated land, etc, has altered drastically as (in many cases) has the natural environment, in particular the vegetation and forest cover. Thus for most countries in the region, the most pressing problem in the field of topographic mapping is not that of acquiring basic map coverage, but revising and bringing up-to-date the planimetric detail of very large numbers of existing topographic maps in the more developed areas of each country. Even if an acceptable solution to this problem can be achieved, there will be a continuing demand to keep the topographic map coverage up-to-date, since it seems likely that rapid changes in the landscape will continue for the foreseeable future.

The sheer magnitude of the map revision problem in eastern, central and southern Africa can be appreciated when the number of sheets required for full coverage of each country is considered. For example, at the standard 1:50,000 scale, this amounts to 1294 sheets for Tanzania, 1207 for Mozambique, 587 for Zimbabwe, 310 for Uganda and 170 for Malawi. The large numbers of sheets that are involved in all of these countries can be compared with the corresponding number of sheets at 1:50,000 scale required to cover certain developed countries, *eg*, 204 for Great Britain and 108 for the Netherlands. In Kenya, 1:50,000 has been adopted as the basic scale only for the mapping of the more populated, fertile and developed southern, central and western parts of the country, with 1:100,000 used for the remaining arid and semiarid areas in the north and northeast bordering Ethiopia and Somalia (which so far are largely unmapped). A similar strategy has been adopted by Zambia, with the more settled and developed parts of the country being mapped at 1:50,000 scale and the remote and little developed parts at 1:100,000 scale. In Botswana, the same policy has again been followed, though with the use of 1:125,000 as the map scale in the less developed areas. However, even with the adoption of these smaller scales (1:100,000 and 1:125,000), there are still several hundred sheets to be revised in each country.

When considering how to tackle the problem of revising large numbers of sheets, it must be remembered that all countries in the region have pressing economic problems and, in most instances, the national survey and mapping agencies are working under very severe budgetary constraints which limit their operational effectiveness and their ability to invest in new technology. Furthermore, revising large numbers of map sheets using normal aerial photogrammetric procedures is quite heavily resource-intensive. In these circumstances, it is natural to consider whether satellite images can be used effectively and economically to satisfy the urgent need for the revision of their basic topographic map series.

TOPOGRAPHIC MAPPING REQUIREMENTS

TOPOGRAPHIC MAP SPECIFICATIONS

The typical basic map accuracy specifications for topographic mapping at 1:50,000 and 1:100,000 scales are shown in Table 1. These apply to all maps at these scales whether they are compiled from aerial photographs or satellite images.

TABLE 1 Topographic map specifications

Scale	*Plan resolution (at 0.1 mm)*	*Plan accuracy (± 0.3 mm)*	*Spot height accuracy*	*Contour interval (m)*
1:50,000	5 m	± 15 m	3 m	10 to 20 m
1:100,000	10 m	± 30 m	6 m	20 m +

RESULTS OF ACCURACY TESTS

The results of a number of accuracy tests of space images carried out in the context of topographic mapping were published by Jacobsen [6, 7]. These tests were carried out in areas in Germany where test fields with good quality-control points and high-class maps already existed. Corresponding tests carried out in an African landscape, *eg*, by Petrie and El Niweiri [22, 23] in Sudan, and in North Yemen by OS International [18, 19] gave somewhat less good results. A representative sample of these for Landsat TM and Spot pan scanner images and for photographs taken with the ESA metric camera (MC), the NASA large format camera (LFC) and the Russian KFA-1000 camera are listed in Table 2.

From these figures, it can be seen that there is little or no difficulty about the detail extracted from satellite

TABLE 2 Results of accuracy tests

Sensor	*Plan mx(m)*	*my(m)*	*mpl(m)*	*Height mz(m)*	*CI(m)*	*Source*
TM	14	13	20	-	-	[22, 23]
Spot	11	11	15/18	10/12	? 30	[18]
MC	17	19	25	25	? 50	[22, 23]
LFC	14	12	18	18/20	? 50	[22, 23]
KFA-1000	7	7	10	36	? 100	[6, 7]

images reaching the required planimetric accuracy standards. The main shortcoming in purely measurement/accuracy terms lies in the area of heighting, where there is a real shortfall, in both the spot height accuracy and possible contour interval (CI). In general terms, these are incompatible with standard topographic map specifications.

INTERPRETATIONAL REQUIREMENTS

The other major problem which affects the use of satellite images for topographic mapping lies in the shortfall in the resolution of the satellite images (and therefore in the information content of the resulting maps). A general discussion of this problem was conducted some years ago by Konecny, Schuhr and Wu [12]. Progressing from that study to discuss the ground resolution of the Spot images available since then, the 10 and 20 m pixel sizes of the Spot pan and XS images translate to larger values—perhaps 15 to 20 m and 30 to 35 m, respectively—in terms of ground resolution. Indeed, Naithani [20] of the Survey of India assessed the ground resolution of Spot pan and XS images as being 28 m and 56 m, respectively—figures which some may regard as overly pessimistic. In practice, even the more optimistic values for the Spot pan images of 15 to 20 m quoted above are not too substantially different from the ground resolution values of the MC (16 to 20 m) and LFC (10 to 14 m) photographs. Obviously these values result in difficulties in the detection of the smaller objects on the ground, especially isolated or individual buildings, groups of huts, narrow unsurfaced roads and motorable tracks, footpaths, streams and other drainage features, etc. These objects often have dimensions (<5 to 10 m) smaller than the figures quoted above for ground resolution and they may exhibit poor contrast with the surrounding terrain, especially in arid and semi-arid areas. This inability to detect such smaller objects means that the map detail compiled from satellite images would then be substantially deficient or incomplete. This is particularly serious over large parts of eastern, central and southern Africa, where such small features predominate in the mainly rural landscapes and are frequently objects (landmarks) of great local importance. Thus they need to be included on the topographic maps of these areas.

In turn, this deficiency will result in the need for a thorough and systematic field completion procedure to locate missing features, *eg*, roads beneath trees, motorable tracks, buildings, wells, bridges, etc, and to incorporate local knowledge, *eg*, names, building classification, etc. This intensive type of operation has been carried out quite successfully for 1:50,000 scale map revision in Canada [4] using hard-copy Spot ortho-images to help identify and position these smaller missing features in the field. However, there is no doubt that the implementation of such a comprehensive field completion procedure leads to a substantial additional expense, especially when it has to be carried out for very large numbers of map sheets, as in the countries of eastern, central and southern Africa, which, unlike Canada, do not have well-funded mapping agencies.

There is, of course, an emphasis in topographic map compilation and revision on the detection, interpretation, measurement and plotting of point and line features. This requires high resolution and the need for good contrast in the images used for mapping. Also, since automatic feature extraction is still in the research stage, the extraction of the required information will have to be carried out visually and manually by an operator—in contrast to the extraction of land use/land cover types and areas from satellite images for thematic mapping, often carried out using automated or semi-automated classification techniques. In the particular context of topographic map revision, since the planimetric accuracy of the measured data is not a real issue, the main problem lies instead with the detection, interpretation and depiction of those point and line features that have changed since the compilation and publication of the original edition of each map.

RESULTS OF PRECEDING INTERPRETATIONAL TESTS

A very detailed series of interpretational tests covering the information for topographic mapping that can be extracted from MSS, TM, MOMS-01, RBV, MC and LFC images over the Red Sea Hills and Khartoum areas in Sudan have been carried out at the University of Glasgow [22, 23]. These showed the superiority of the MC and LFC photographic images to the other (scanner) images in terms of the detection and interpretation of the required features. However, much of the communications network and many smaller settlements could not be detected in this arid region, even with the LFC photographs. Again this pointed to the need for comprehensive field completion if space images are to be used for either the compilation of original topographic maps or the revision of existing ones.

NEW SERIES OF INTERPRETATION TESTS

Since this original work, a further series of interpretational tests were carried out in Glasgow for a number of countries in eastern, central and southern Africa, with emphasis on the map content that can be extracted from Spot pan and XS images (which had not been available for the Sudanese test areas). The results of these tests are reported here. These tests cover a variety of landscapes in the region, ranging from semiarid to heavily vegetated and from urban and suburban areas to heavily cultivated and densely settled rural areas. Since the use of small-scale (1:60,000 to 1:80,000 scale) aerial photography flown with super-wide-angle cameras is the method currently employed for 1:50,000 scale topographic mapping and map revision in the region, a parallel set of tests using aerial photographs was carried out over some of the same areas for comparative purposes. It will be apparent immediately that the ground resolution of these aerial photographic images is very high—at 40 lp/mm, it will range between 1.5 m (at 1:60,000 scale) and 2 m (at 1:80,000 scale). Thus in terms of ground resolution, the aerial photographs used in the tests are an order of magnitude better than the Spot images.

TEST AREAS AND MATERIALS

The areas in eastern Africa over which the tests were conducted (see Figure 1) included two in Kenya. These were the Naivasha area on the west side of the Aberdare mountains and dropping down to Lake Naivasha on the floor of the Rift Valley, and the area around the town of Thika in the Kakuzi Hills at the foot of the eastern slopes of the Aberdares, northeast of Nairobi. Two areas in Tanzania were also included in the tests: the Korogwe area, partly agricultural land and partly forested mountains in northeast Tanzania, and the expanding suburban/periurban area of Kimara just west of the capital, Dar-es-Salaam. In central and southern Africa, the areas around Lusaka, the capital of Zambia, and Molepolole, a mainly semiarid area northwest of Gabarone, the capital of Botswana, were selected for the tests. Taken together, they covered a wide variety of landscapes which are reasonably representative of those found in the region.

The materials used in the tests are listed in Table 3. All Spot satellite images were produced originally by Spot Image in France, with the exception of the Molepolole image which was produced as an orthoimage by SSC Satellitbild in Sweden. All images were available in hard-copy form for interpretation at the various scales indicated in Table 3, since it was found that these were much easier to handle and interpret than the alternative method of displaying them on the monitor of an image processing system. This experience is similar to that reported by Rosenholm [25] in his account of SSC Satellitbild's experience of mapping with satellite images in developing countries. For the Spot multispectral (XS) images—although all individual bands were available for interpretation as black-and-white (monochrome) images as well as false-colour (FC) composite images—a selection of those images which appeared to be best suited to a particular area was made rather than attempting to interpret all individual band images. Thus the XS band 3 (XS3) images were used in the tests carried out for the Korogwe, Thika and Naivasha areas, the XS2 image was used over the Korogwe area, and false-colour (FC) composites were tested for both Korogwe and Naivasha. All four pan images tested were of course monochromatic.

In this context, it is worth noting that the quality of the Spot images varied considerably between one image and another and also between one area and another. Thus, for example, all Korogwe images (Figure 2) exhibited a quite noticeable series of scan lines—which was quite distracting and reduced their quality somewhat. In contrast, the individual XS band images of the Thika (Figure 3) and Naivasha areas were quite free from this effect, while the Lusaka pan image (Figure 4) was of far superior quality to any of the other pan images.

Aerial photographs were available for only the Korogwe and Dar-es-Salaam areas. As noted in Table 3, all photographs were in the scale range 1:65,000 to 1:75,000 and all had been exposed on panchromatic film using cameras equipped with super-wide-angle (f = 85 or 88.5 mm) lenses.

The 1:50,000 scale maps used to provide control points and baseline information for the study were supplied by OS International or the national mapping agency of the country concerned.

INSTRUMENTATION AND METHODS

The aerial photographs (stereo-pairs) were interpreted under a mirror stereoscope. The required detail was then measured and compiled on a Kern PG-2L stereo-plotting instrument equipped with encoders to generate X, Y and Z coordinates in digital form; the measured detail was displayed on the graphics display monitor of a PC using Ross Instruments RPLOT software (see Figure 5).

As noted above, with the exception of the Korogwe satellite images where the information content was also extracted using a digital image processing system, all interpretations and measurements of the Spot images were carried out visually on hard-copy images for the appropriate part of each image covered by the 1:50,000 scale map. The interpreted detail from these hard copies was measured on a tablet digitizer equipped with a large-aperture magnifier and illuminating lamp to facilitate the identification of features (Figure 6). The digitizer read out X,Y coordinates to a PC. Intergraph's MicroStation CAD package was mounted on this PC and was used for digitizing, editing and plotting the data from the satellite images. For the digital satellite images of Korogwe, the PC-based DIAD 32 system (Figure 7) was used for edge detection, contrast stretching and filtering to enhance the features required for mapping. An on-screen digitizing facility, the so-called DIAD Mapping System, was employed to measure the features required for mapping. The data from both the RPLOT and DIAD systems were converted to DXF format and exported to the MicroStation PC system which produced the final plots from all interpreted/measured images using digital mapping techniques.

Broadly speaking, the features shown on the 1:50,000 scale maps of all test areas were mapped to a common specification (all original maps had been produced by a single organization: DOS). These features may be grouped conveniently into five categories, as follows:

(1) *lines of communication,* including linear features such as roads, tracks, footpaths, railways, etc, and point

TABLE 3 Test materials

Test area	*Spot images*			*Aerial photographs*		
	Type	*Scale*	*Processed level*	*f (cm)*	*H (km)*	*Scale*
Korogwe, Tanzania	XS3	1:150,000	1B	8.85	6.5	1:75,000
	XS2	1:150,000	1B			
	XS/FC	1:150,000	1B			
	Pan	1:50,000	1A			
Dar-es-Salaam, Tanzania	Pan	1:25,000	1A	8.5	5.8	1:65,000
Thika, Kenya	XS3	1:150,000	1B			
Naivasha, Kenya	XS3	1:150,000	1B			
Lusaka, Zambia	Pan	1:50,000	1B			
Molepolole, Botswana	Pan	1:150,000	3			

features such as bridges and railway stations

(2) *cultural features*, including areal features such as built-up areas (towns and villages); linear features such as power and telephone lines; and point features such as individual buildings, transmitters and water tanks

(3) *land cover and vegetation*, including cultivated land, forests, marshes, etc, all of which are areal features

(4) *hydrologic features*, comprising linear features such as rivers, streams and irrigation canals and ditches, and areal features such as lakes, reservoirs, ponds, etc

(5) *geomorphic features* such as cliffs (linear features), rocky areas, gravel beds (areal features), etc.

For each test area, the occurrence of each type of feature on the satellite image was compared with its occurrence on the existing map or on the contemporary aerial photographs. For point features, the ratio of the number of features occurring on the satellite image to the number present on the map and photographs gave a percentage figure. For linear features, the evaluation was carried out by comparing the length of the features in a particular class plotted from the satellite image with the total length of the corresponding features derived from the map and the aerial photographs, and again deriving a percentage figure. Finally with the areal features, again an estimate was made of the percentage area plotted against the area derived from the map and photographs. In each case, due allowance was given to the changes that had occurred between the dates of map production and image acquisition. These changes were of course also noted, since they gave specific information as to the comparative usefulness of both the satellite images and the aerial photographs for map revision.

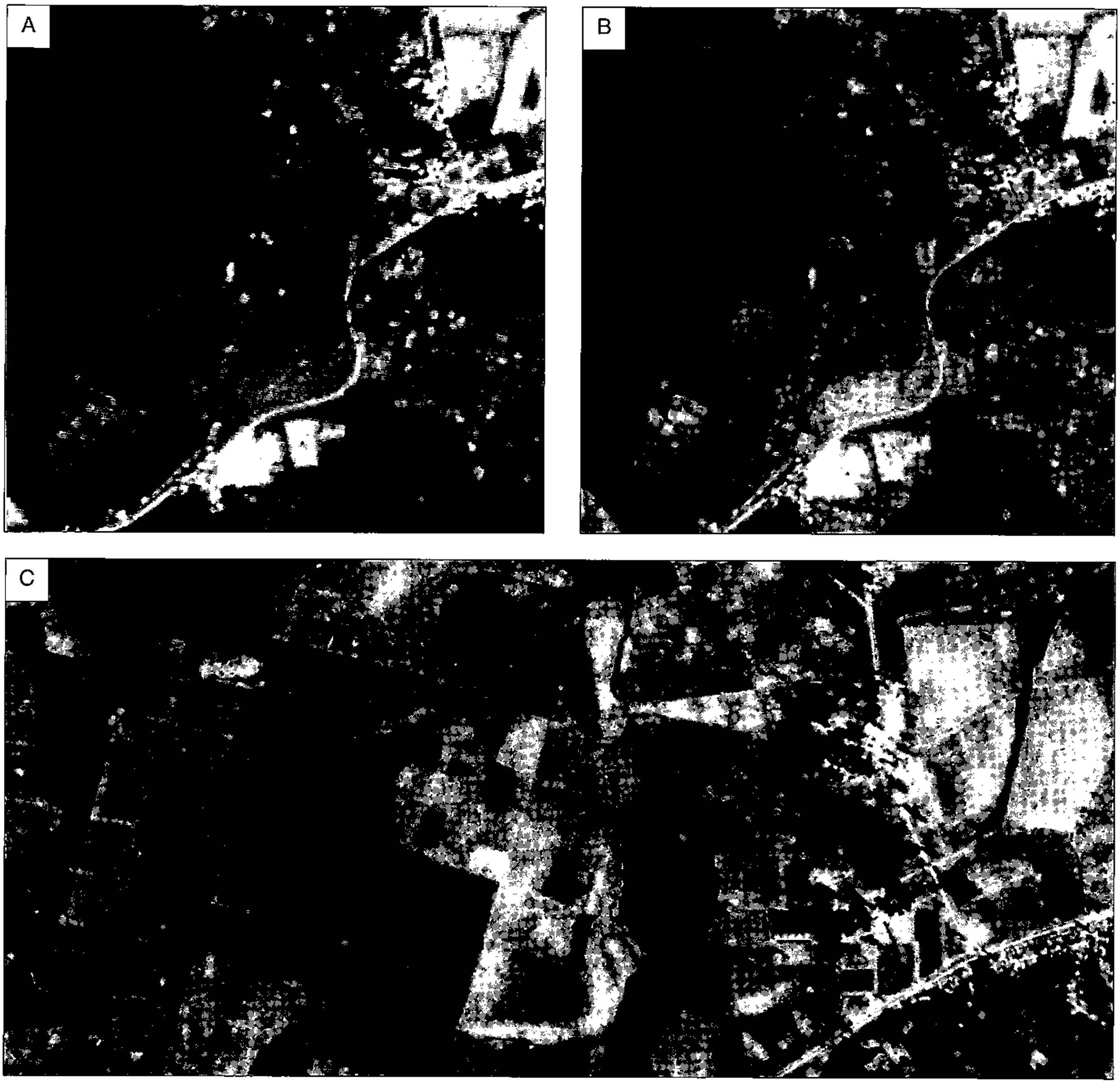

FIGURE 2 (A) Spot XS2 and (B) pan images of a small part of the Korogwe test area, Tanzania, 1:50,000 scale. The scan line pattern is quite noticeable. (C) The corresponding aerial photograph of the upper part of the same area at 2x enlargement (1:37,500 scale)

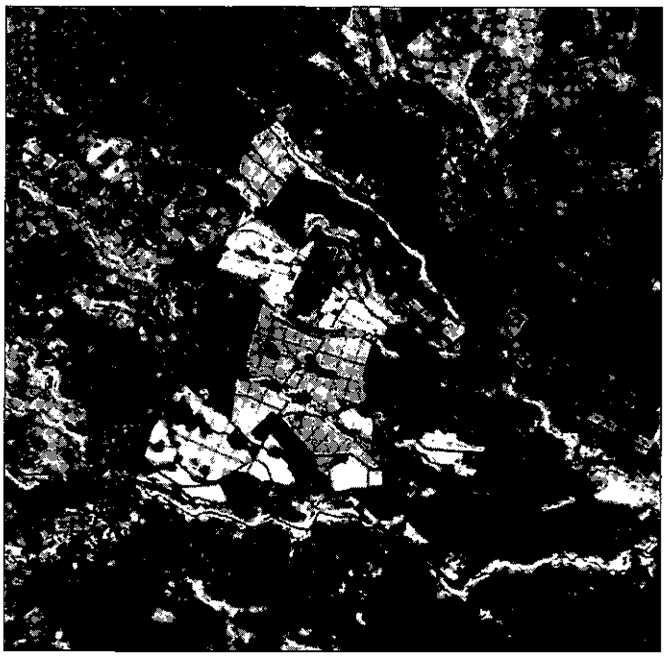

FIGURE 3 Spot XS3 image at 1:150,000 scale of the Thika area, Kenya. The plantations show up very clearly

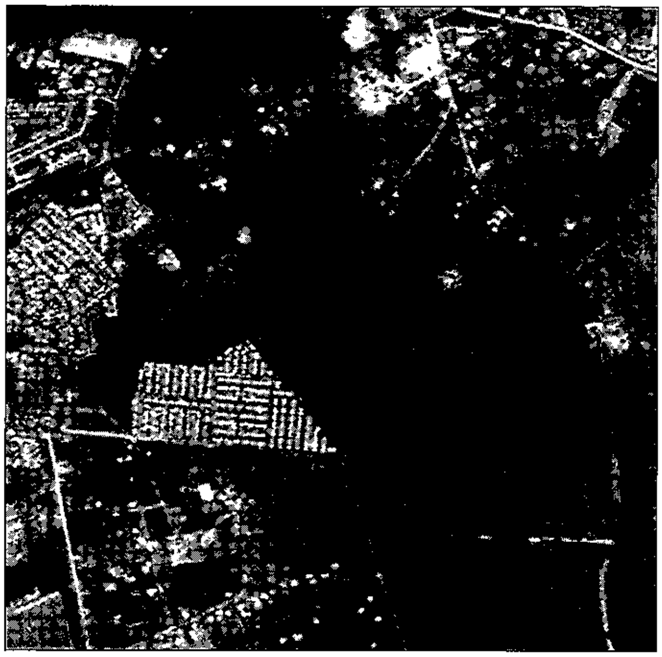

FIGURE 4 Spot pan image at 1:50,000 scale of an area on the northwest edge of the city of Lusaka, Zambia

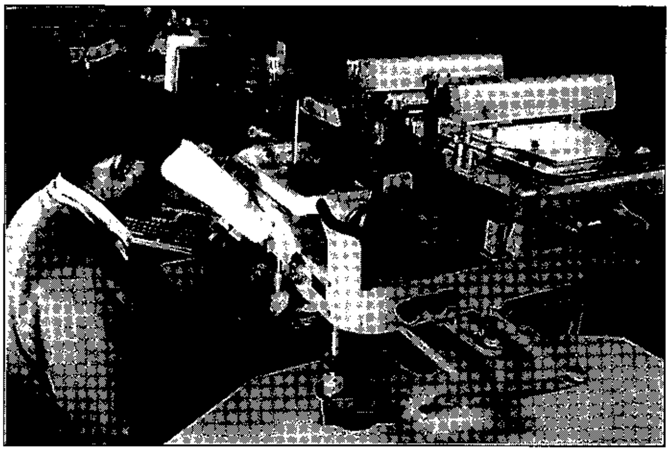

FIGURE 5 Kern PG-2L stereo-plotting instrument equipped with encoders and used for the compilation of map data from aerial photographs using PC-based RPLOT software

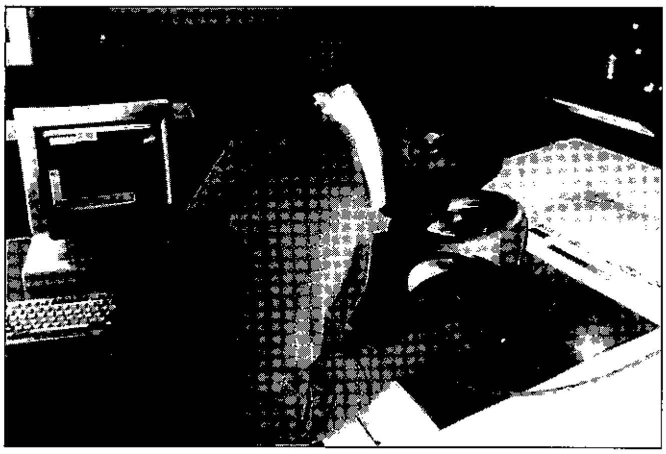

FIGURE 6 Tablet digitizer and large aperture magnifier used to measure map data from Spot hard-copy images using PC-based Intergraph MicroStation software

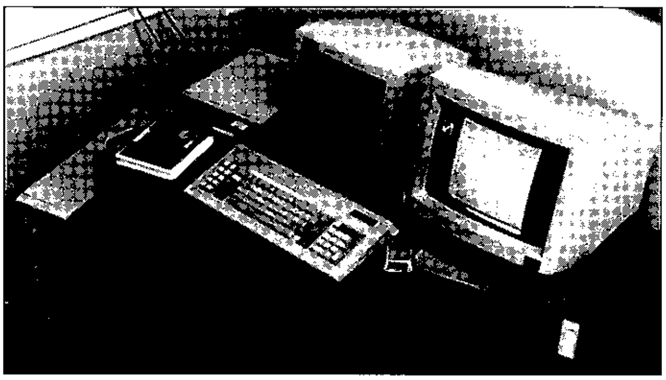

FIGURE 7 PC-based DIAD 32 image processing system used for the interpretation and on-screen digitizing of Spot images of Korogwe

TEST RESULTS

The overall results of the tests conducted on both the Spot images and the small-scale aerial photographs are presented in Table 4. There was a clear distinction regarding the information content that can be extracted from each of the two image types, with the small-scale aerial photographs providing a noticeably greater level of the information required for 1:50,000 scale topographic mapping. A further distinction could be made regarding the information content of the Spot pan images compared with that which could be extracted from the Spot XS images. A detailed discussion of these distinctions is presented below.

LINES OF COMMUNICATION

There was no difficulty in detecting, identifying and measuring hard-surfaced main roads on most of the Spot images, whether pan or XS. However, in certain places on the Lusaka pan scene, the black image of the tarred surface of the road merged with the dark tone of the adjacent ground, resulting in a gap in the road image. Much the same could also be said about the so-called unsurfaced roads which have, in fact, gravel surfaces and appeared mostly as bright white lines on the Spot

TABLE 4 Interpretation/information content of Spot images and small-scale aerial photos (% completeness of features extracted from the images)

Features	*Aerial Photographs*		*Spot (pan)*				*Spot (XS)*		
	Dar 1:65,000	*Korogwe 1:75,000*	*Dar*	*Korogwe*	*Lusaka*	*Molepolole*	*Korogwe XS2/FC*	*Thika XS3*	*Naivasha XS3/FC*
Communications									
Hard-surfaced roads	100	100	100	100	95	100	100/100	100	100/100
Unsurfaced roads	100	100	100	100	90	10	80/50	80	70/80
Motorable tracks	100	100	75	60	65	10	80/50	70	70/60
Streets	100	100	50	10	45	0	80/50	30	0/0
Footpaths	80	80	5	60	35	0	10/20	0	5/10
Bridges	50	50	0	0	0	0	0/0	0	0/0
Railway lines	100	100	80	100	50	-	100/100	70	70/75
Cultural features									
Towns	100	100	40	60	85	10	50/50	100	100/100
Smaller villages	-	100	-	50	5	0	40/40	0	20/20
Isolated buildings	100	100	40	60	40	0	15/15	0	20/20
Pipelines	0	0	0	0	0	0	0/0	0	0/0
Power lines	90	90	100	60	0	0	60/60	0	0/0
Wells	0	0	0	0	0	0	0/0	0	0/0
Storage tanks	100	0	100	0	0	0	0/0	0	0/0
Cemeteries	0	0	0	0	0	0	0/0	0	0/0
Vegetation/land cover									
Cultivated land	100	100	20	50	50	80	60/60	70	85/90
Forest/woodland	100	100	100	85	60	-	80/100	60	100/100
Scattered trees	0	0	0	0	30	0	0/0	0	0/0
Scrub	0	0	0	0	0	0	0/0	0	0/0
Hydrology									
Rivers	100	100	70	65	60	-	30/90	100	40/40
Streams	100	100	0	30	50	80	25/80	80	50/0
Irrigation channels	-	50	-	0	-	-	0/0	0	0/0
Water bodies	100	100	100	100	40	80	70/100	95	80/80
Geomorphology									
Large rocky areas	-	100	-	20	-	90	70/100	95	80/80
Gravel beds	100	100	70	70	-	0	5/5	0	0/0

pan images. Again most of these could be detected and measured without much difficulty. However, these roads were much less easily identified on the Spot XS images, where the lower resolution resulted in difficulties with this class of feature. Only about 50 to 60 percent success was achieved with the FC composite image of Korogwe; however, this rose to the 80 percent level with the monochromatic images of the specific bands (XS2/XS3) of the Korogwe, Thika and Naivasha areas.

The street patterns shown on the 1:50,000 scale topographic maps comprised only the larger streets, but these were surprisingly difficult to locate and plot accurately and completely. In Lusaka, this proved to be the case in both the city center and the southern suburbs of Woodlands and Chilente, where there are many trees and it is either very difficult or impossible to discern the street pattern.

With motorable tracks, which are essentially unsurfaced roads scraped out from the underlying terrain, much depended on the their contrast with the overall background of soils and vegetation. Thus the success rate for this class of road, which is the dominant category in most of the areas tested, was only 75 to 80 percent in the Dar-es-Salaam pan and Korogwe XS2 images, falling to 65 percent for the Lusaka pan image and 50 to 60 percent for the Korogwe pan and the Korogwe and Naivasha FC images, and to only 10 percent for the semiarid Molepolole area. Footpaths, as might be expected in view of their narrow width, could be detected only occasionally in most areas. The result was that they were often discontinuous and incomplete.

Railway lines are mostly narrow single-tracks throughout the region. Thus, even with the wider swath and the associated cuttings and embankments, there could be difficulties in following the route over the terrain in certain areas. For example, in open areas, where these helpful associated features are largely absent, the track often exhibited a lack of contrast with the background, while in wooded areas, overhanging vegetation could hamper its detection. Bridges, whether constructed for roads or railways, proved to be very difficult to identify with any certainty on all Spot images tested.

CULTURAL FEATURES

The detection, identification and correct delineation of the boundaries of major built-up areas was relatively straightforward on the pan images of the two cities, Dar-es-Salaam and Lusaka, covered in the tests. However, where the built-up areas consisted mainly of small towns, there was some difficulty in almost all test areas. The greatest success with this category of feature was achieved with the XS3 and FC images of Thika and Naivasha, with a nearly 100 percent success rate, whereas with the corresponding XS images of Korogwe, the figure was only 50 percent. For villages in general, the results achieved with the higher resolution Spot pan images were poor, with the poorest results over the semiarid Molepolole area, where the lack of contrast of the buildings with the background terrain caused many problems in detecting their occurrence and location. The smallest villages, often comprising groups of huts, which are so important in the mapping of rural areas, gave considerable difficulty in all test areas, as did the large numbers of scattered farms and houses in these rural areas. Similarly, the detection of individual isolated buildings, which can be vital items for inclusion in the maps of the more remote areas, gave difficulties with all Spot images, no matter which landscape was being interpreted. Obviously, many of the difficulties experienced with the villages, groups of huts, farms and isolated buildings resulted from both the small size of the structures themselves and the types of building materials (mud bricks, wood, brushwood, etc) commonly used in the rural areas, which exhibit little contrast with the surrounding ground.

Regarding linear features, the location of power lines was possible in suitable terrain, largely because the vegetation beneath them had been cleared, resulting in distinctive straight-line swaths cut through the forest or scrubland. These were easy to detect, interpret and measure. However, in more open ground, such cleared lines do not occur, in which case the feature could not be detected. In particular, in the Lusaka area, where the existing map showed a dense grid of power lines, not a single one could be detected on the pan image. Also in this category, pipelines did not show up on the Spot images that were tested. This was to be expected if they were long-established, in which case all signs of ground disturbance have disappeared and the natural vegetation has regenerated to cover the line.

Finally, the point features such as transmitters, microwave towers and triangulation stations were (not unexpectedly because of their small dimensions) impossible to find on the images. Similarly, water storage tanks could be detected on the Spot pan image of Dar-es-Salaam only with the help of the detailed local knowledge of the interpreter (EJL). Cemeteries could not be detected on any of the images tested.

LAND COVER AND VEGETATION

The cultivated areas varied greatly in character, ranging from the large plantations of sisal (in the Korogwe area) and pineapple (in the Thika area), through large farms with regularly patterned fields to numerous irregularly shaped fields and smallholdings. The larger cultivated areas usually appeared as very distinctive patches on the Spot images and were easily identified. However, the cultivated patches of the numerous small farms typical of many rural areas within the region were quite difficult to discern and the results for this class of feature were quite haphazard with regard to the quality and completeness of the resulting maps. The particular season during which the Spot image is acquired—which tends to be the dry season—obviously also plays a large part in determining the quality of the final results. On the basis of the experience gained from the tests described here, it can be said that the results achieved with the Dar-es-Salaam, Korogwe and Lusaka pan images were quite poor with respect to these small farms and their associated cultivated areas. The results with the individual XS-band images and the FC composite images for Korogwe, Thika and Naivasha were better, but also varied between 60 and 90 percent (as shown in Table 4).

The results with woodland and forests were somewhat better. With the exception of the Thika and Lusaka areas, the identification of the forested areas was at the 80 to 100 percent level with both the pan and XS/FC images. But the images would be of little use if the interpretation and delineation of areas of scattered trees or scrubland are demanded by the map specification.

HYDROLOGIC FEATURES

Experience with the identification and extraction of hydrologic features varied greatly, both between the different types of Spot image and between different landscapes within the region. By far the most satisfactory result was achieved with the XS3 image of the Thika area, where the detection success rate was 100 percent for rivers, 80 percent for streams and 95 percent for large water bodies such as reservoirs and sewage treatment ponds. The FC image of Korogwe also gave fairly good results. In contrast, with the Spot pan images of Dar-es-Salaam, Korogwe and Lusaka, the success rate fell to 60 to 70 percent for rivers and 30 to 50 percent for streams, although the water bodies were identified at the 100 percent level in the first two areas. With the other XS images of Korogwe (XS2) and Naivasha (XS3/FC), experience with the detection of the rivers and streams was poor, though, once again, the interpretation of the water bodies gave a considerably better result. However, the locations of the narrow irrigation ditches known to be present in these areas could not be discerned.

Factors which gave rise to these poor results included the inability of the interpreter to detect and follow the courses of rivers and streams in forested and heavily vegetated areas. Another factor was that, in drier areas, these features may be semi-permanent and not visible on the images acquired in the dry season. The same remarks apply to the marshy areas which were not easy to map with any confidence, even on the XS/FC images.

GEOMORPHIC FEATURES

These features can be very difficult to locate and delineate correctly, especially when there is substantial vegetation cover that obscures their depiction on the satellite image. By far the best result (90 percent) was achieved with the Molepolole pan ortho-image, where the semiarid terrain had little vegetation cover and relief features, such as the large bare rocky hills, appeared with great clarity. At the other extreme, the results achieved for this class of feature with all XS images used in the test were very poor.

OVERALL EXPERIENCE WITH SPOT IMAGES

Experience with the extraction of the content required for the production of 1:50,000 scale topographic maps from Spot images was very different for each area tested. With the Dar-es-Salaam pan image, the overall amount of data that could be extracted was far better than for any other area. This resulted in part from the relatively open periurban area which contained many newly constructed and well-defined features that showed up well on the higher-resolution pan image. But it also resulted from the fact that the interpreter/photogrammetrist (EJL) lived in the area and was very familiar with it. In the Korogwe area, the overall identification of the required features was again best on the pan image and superior to that of the Spot XS2 and FC images, though certain specific features were more easily extracted from the latter images. In general, the more favourable results in terms of completeness obtained from the pan images were not too unexpected, given their superior resolution. Without doubt, this was the vital factor when so much of the detail required for topographic mapping concerns point and line objects of relatively small dimensions. This is in distinct contrast to the objects of considerable areal extent that are of major concern in thematic mapping of land cover, vegetation, soils, geology, etc. This need to map so many objects of relatively small dimensions may also help explain why the interpretation of the digital images (carried out for the Korogwe area only) was disappointingly poorer than that of the corresponding continuous-tone hard-copy images.

For the two test areas in Kenya—Thika and Naivasha—the plots derived from the Spot XS images were noticeably poorer in terms of their degree of completeness compared with those achieved with the Dar-es-Salaam and Korogwe images. The plot from the Molepolole pan ortho-image contained the least information needed for 1:50,000 scale mapping or map revision. In particular, most cultural features could not be located on the image of this particular landscape—though the registration of this ortho-image was of course better than that of any other image used in the test.

OVERALL EXPERIENCE WITH THE SMALL-SCALE AERIAL PHOTOGRAPHS

The interpretation and stereo-plotting of a single model of the 1:65,000 scale Dar-es-Salaam photographs and three models of the 1:75,000 scale photographs of Korogwe in the digitized Kern PG-2L stereo-plotting instrument can be regarded as being the current conventional photogrammetric solution to 1:50,000 scale mapping in Africa, and one which is within the current capacity of all national mapping agencies in the region. The superiority of this solution in terms of its high geometric resolution (1.5 to 2.0 m) was immediately apparent, even on an initial inspection of the photographs, and was confirmed by the very high percentage figures that were achieved for almost all feature classes required for topographic mapping at this scale. In particular, the 100 percent completeness figures achieved for all roads, tracks and railways, for towns, villages and isolated buildings, and for rivers, roads and water bodies emphasized the essential differences between the two types of image. The data compiled from the aerial photographs will still require some field completion, since some of the smallest point and line features (bridges, footpaths, wells, etc) could still not be detected and interpreted with confidence on the photographs. However, the work involved in the subsequent field completion stage is quite small compared with that required with even the best plots compiled from the satellite images. It must also be said that the whole operation of stereo-plotting with the aerial photographs is much more comfortable for the operator than that of interpreting and measuring the satellite images, where the operator is continually straining to find and extract the features required for the mapping, given its inherent limitations in terms of ground resolution. This can often be a frustrating and somewhat exhausting experience.

However, it should also be noted that, when setting up the stereo-models, problems may occasionally be encountered with the absolute orientation in terms of fitting the control point positions shown on the aerial photographs to the corresponding positions shown on the existing map. At least some of these difficulties appear to result from the detail shown on the map not having been measured and plotted correctly during the original map compilation. This does of course considerably complicate the task of map revision and indeed, in some cases, a completely new photogrammetric compilation from aerial photographs will be required as the only solution to an otherwise irreconcilable set of problems.

RESULTS OF OTHER COMPARABLE TESTS

A similar series of tests comparing the information which can be extracted from Spot images with that from small-scale aerial photographs were also undertaken in Australia [14]. To conduct the test, 26 stereo-models of a rural and mining area in central Queensland were set up and measured on a digitized Kern PG-2 instrument interfaced to an Automap digital mapping system. The scale of the super-wide-angle photographs was 1:80,000 and that of the map 1:50,000. Spot pan stereo-images in hard-copy form at 1:400,000 scale with a base:height ratio of 0.8 were also measured in a Zeiss Oberkochen Planicomp C100 analytical plotter for the same area. The two sets of data were then compared with each other and with the existing maps of the area, which had been subjected to a thorough field check. The comparison revealed that only 70 percent of the linear features and 36 percent of point features could be identified from the Spot pan images, while 90 percent of the linear features and 97 percent of the point features were identified on the aerial photographs. A further comparison then took place between the Spot pan images and the corresponding XS colour-composite image in which it was found that quite a number of the features missed on the pan image could be extracted from the XS false-colour composite, though still nowhere near the level achieved with the aerial photographs.

Another similar but quite separate Australian test covering the rural areas south and west of Brisbane on the coast of Queensland reported quite substantial shortfalls in the features plotted from Spot pan stereo-images on a Zeiss Oberkochen Planicomp compared with those which appeared on a recently revised series of maps covering the same area [24]. The shortfalls were especially large among the communication features (roads, tracks, railways, etc), fences, buildings, and small water-storage dams and tanks.

It is useful to note also the experiences of Dowman and Peacegood [2] who investigated the information content of both Landsat TM and the same Spot pan and XS images of Korogwe that were used in the tests described here. The Landsat TM images from 1984 comprised three hard copies produced using various alternative false-colour combinations—bands 1 + 2 + 3, 2 + 3 + 5 and 3 + 4 + 7, respectively. The Spot XS and pan monoscopic images of the area were available both as hard-copy images and in digital form for use on an I^2S image processing system. For the test, the first edition (1957) of the 1:50,000 scale map was available, together with the corresponding photogrammetric plot from the OS/DOS remapping programme from the same aerial photographs as used in the present series of tests. However, the test undertaken by Dowman and Peacegood concentrated on the differences between the communication features (roads, tracks and railways) plotted from the satellite images and those shown on the corresponding 1957 map. The published results were given in terms of percentage errors of commission (*ie*, incorrectly plotted or misidentified features) or omission (*ie*, features left out) as shown in Table 5.

Comparing the data extracted from one of the Landsat TM images and the Spot pan image with the data contained in the photogrammetric plot, the results for the combination of roads, rails and tracks were TM (3+2+1) = 33/33 percent and Spot pan = 37/17 percent. Regarding the other features, the two authors simply noted that "Settlements and road/tracks were much more difficult to detect in the Tanzanian imagery than in the European areas and this probably reflects the natural building materials more widely used in this area". The results of this particular test obviously supplement and confirm some of the findings of the more comprehensive tests reported above.

TABLE 5 Test of communication features, Korogwe [2]

	Roads (%)	*Rail (%)*	*Tracks (%)*	*Road+rail+tracks (%)*
TM (3+2+1)	28/31	50/48	90/90	59/59
TM (5+3+2)	38/51	54/51	88/78	59/48
TM (6+4+3)	34/46	48/51	83/74	60/50
Spot	51/46	47/47	97/88	75/47

AFRICAN EXPERIENCES WITH TOPOGRAPHIC MAPPING FROM SPOT SATELLITE IMAGES

While no country in eastern, central and southern Africa has embarked on a programme of original topographic mapping from satellite images, some limited programmes have been implemented in the countries to the north, bordering the Red Sea. In particular, parts of North Yemen [5, 18, 19] and Djibouti [26] have been mapped in this way. These projects involved plotting 18 and 16 Spot stereo-models, respectively, at 1:50,000 and 1:100,000 scales in North Yemen and 1:50,000 and 1:200,000 scales in Djibouti. Both projects required a thorough field completion to pick up missing features. A 40 m contour interval was used in North Yemen.

It is of course worth noting that both mapping projects were carried out by well endowed and technically highly competent European national mapping agencies—the British Ordnance Survey (OS) and French Institut Geographic National (IGN)—under aid programmes. For this purpose, they were able to deploy analytical plotters with appropriate software, plus experienced and expert photogrammetrists to execute this demanding work. These resources are simply not available in most countries within the region.

TOPOGRAPHIC MAPPING FROM SPOT STEREO-IMAGES IN ETHIOPIA

The exception to these remarks is the Ethiopian Mapping Agency (EMA) which has carried out topographic mapping from stereo-Spot hard-copy images processed to level 1AP, using a Wild BC-2 analytical plotter in conjunction with a Wild OR-1 computer-controlled orthophoto printer [9]. This work started with a pilot project covering the Adele area carried out by SSC Satellitbild and Swedsurvey in Sweden [11]. Later, after EMA had acquired the BC-2/OR-1 combination, it then carried out a trial over the Addis Ababa area using well-defined features on the existing maps as ground control points (GCPs). The result from this trial was an ortho-image map with contours derived from a DTM produced by manual/visual measurement along breaklines and major rivers, in addition to grid-based sampling. The results were judged to be acceptable, so EMA has gone ahead with plotting a further seven Spot stereo-pairs with the GCPs provided by field survey methods utilizing GPS receivers transported by helicopter over the rough ground that is being mapped [16]. A further 21 Spot stereo-pairs are now being used for continuation of this work.

Specific difficulties have included those arising from the individual side-pointing (off-nadir) Spot images comprising a stereo-pair being acquired three months apart at the beginning and the end of the rainy season—resulting in the very different appearance of vegetation and water features in the two images. This caused difficulties with stereo-viewing and measurement. Jacobsen [7] also commented in similar terms on experience in trying to measure Spot stereo-images in Germany, where the individual images had been taken at different stages in the growing season. Of course, such difficulties also preclude the use of automatic correlation (image matching) techniques for height measurement.

In the context of the main theme of this paper, we note that the papers published by Jobre [9] and Medhin [16] of EMA made no mention of the degree of completeness of the information derived from the Spot images, nor was there any account of the field completion work necessary to make the 1:50,000 scale ortho-image into a product having a content comparable to that of a conventional topographic line map. It will be most interesting to learn of their experiences in due course.

TOPOGRAPHIC MAP REVISION FROM SPOT IMAGES IN UGANDA

As described above, the main problem for most countries in the region lies in the revision of the existing, very extensive topographic map coverage completed using aerial photogrammetric methods during the period 1950-1980. In Uganda, the political, economic and security problems experienced both during and after the overthrow of the Idi Amin regime, including war with Tanzania and the subsequent anarchy and civil war, have been enormous. In particular, from the mapping point of view, there have been massive movements of population as a result of these events, such that certain areas have been substantially depopulated or deserted. At the same time, the main towns and certain rural areas have had huge increases in population and large-scale expansion. In connection with the last item, very large areas of forest, including designated national forests, have been felled and cleared to accommodate numerous new settlers and to allow many new farms to be created. For many areas, the landscapes shown in the 1:50,000 scale topographic map series completed by DOS in the early

1970s have been greatly altered and the series badly needed revision.

A UNDP-funded project has been helping to update the Ugandan 1:50,000 scale topographic map series using Spot XS satellite images [8]. A contract for this work was awarded to the Norwegian VIAK company which has carried out the image processing operations at its Arendal office in Norway using a MicroVax-based Teragon image processing system and outputting the results in the form of stable hard-copy film transparencies and prints on photographic paper via a film writer. The geometrically corrected raw image data were supplied by SSC Satellitbild in Kiruna. The final processed images correspond to the individual sheets of the Ugandan 1:50,000 scale topographic map series.

By February 1993, 72 Spot XS scenes (out of 86 to cover the whole country) had been processed, corresponding to 233 map sheets. Data for 80 sheets had still to be acquired, mostly for areas in the southwest of the country, which have persistent cloud cover.

The interpretation and updating of the 1:50,000 scale maps from film transparencies of the Spot XS images were carried out visually, manually and graphically on light tables to produce revision overlays at the Ugandan Department of Survey and Mapping (see Figure 8). The resulting cartographic work and printing of the new maps has also been the responsibility of the national mapping organization.

It is interesting to quote Jansen of VIAK on his experience with this project: "Problems encountered include the interpretation of small features (buildings, etc) which is limited by the Spot satellite's geometric resolution—20 x 20 m pixel. Seasonal swamps may be hard to detect on images taken in the dry season. Roads are recognized as lineaments. Main roads are easy to detect, minor roads may be partly invisible and motorable tracks are sometimes not recognized at all. Roads should be interpreted in close interaction with the existing map. Forests are usually clearly defined with a distinct outline, but problems may occur in areas with forest/woodland mosaics and in transitional zones towards vigorous bush or thickets."

It is also of value to note Jansen's final conclusions: "Experience from the project shows that Spot satellite data is a useful tool for updating topographic maps, if accuracy and detail criteria are reduced compared with traditional mapping procedures. The updating should be considered as being temporary since a complete updating of all details would require the use of aerial photographs."

This view was indeed confirmed by the experience of Kajumbula [10] of the Ugandan department, who carried out comparative tests of satellite images and 1:30,000 scale aerial photos of the Mabira forest area. He found that the missing communication and settlement features can indeed be picked up readily on the aerial photographs and plotted using conventional analog stereoplotters or the digital monoplotting technique.

However, the Spot satellite images do have the advantage of relative cheapness, availability and speed, even if they are deficient in the details needed for full map revision. Multiple use and cost-sharing are another advantage—in this case, the National Biomass Group was also able to use the Spot XS images to determine the location and distribution of land use/land cover classes to calculate the areas of woody biomass in Uganda.

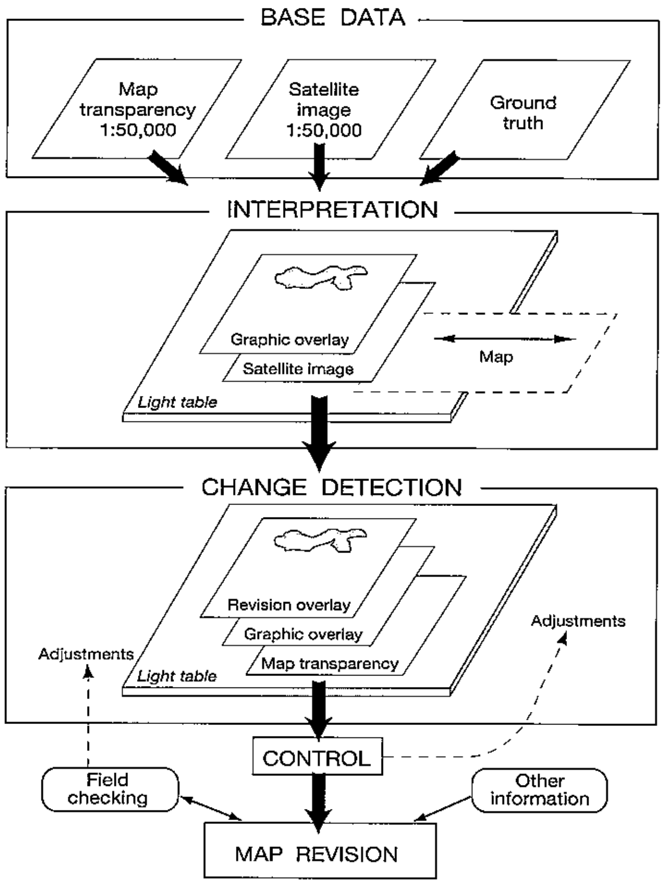

FIGURE 8 Overall procedure used for image interpretation and change detection for the revision of the 1:50,000 scale topographic map series in Uganda (from [8])

CONCLUSION

The overall results of the tests reported in this paper showed that, for the landscapes in eastern, central and southern Africa, Spot pan and XS images can supply the data for only a preliminary or provisional edition of a 1:50,000 scale topographic map or the rapid but incomplete revision of an existing map at that scale. It is clear from the results of these tests, supplemented by results from other tests and production experience in the region, that the present Spot data are still substantially deficient in providing the details required for the production of a full or final edition of a new 1:50,000 scale map or for the comprehensive revision of an existing published map at that scale. These deficiencies are particularly apparent with regard to both the communication features and many of the smaller man-made cultural features present in the landscapes of the region. To overcome these deficiencies, which can account for as much as 30 percent of the total map content, an additional comprehensive field completion is necessary—which will be both time-consuming and expensive. Moreover, without this extensive additional work on the ground, there is a danger that the product will be substantially incomplete and may not then be acceptable to users.

Of course, another quite different viewpoint can be taken, namely that for new mapping, a 1:50,000 base map produced to a relaxed specification from Spot images would be of great value to users, especially when the alternative is a substantial wait for the new map to be produced to the full specification. However, in this