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Topographic Mapping from Satellite Imagery in Africa

TOPOGRAPHIC MAPPING FROM SATELLITE IMAGERY IN AFRICA

G. Petrie
Department of Geography & Topographic Science
University of Glasgow, Scotland, U.K.

ABSTRACT

The paper first reviews the situation regarding topographic mapping in Africa. While for some countries, the main concern is the production of new base maps, for many other African countries the main problem is the revision of a large number of existing maps which are now thoroughly out-of-date. The situation prevailing in most African national mapping agencies is then outlined and the availability of satellite photography and scanner imagery over Africa is then discussed. The results of tests of the accuracy and the content of topographic maps derived from satellite imagery conducted over a number of test sites having different landscape characteristics are summarised and discussed. Next some examples of topographic mapping from stereo-SPOT imagery are described, including those from Ethiopia, Djibouti and Guinea. This is followed by further examples of purely planimetric line mapping from Nigeria and image mapping from Central Sudan, using monoscopic SPOT and TM images respectively. This leads on to a further discussion of a UNDP-supported national map revision programme carried out over Uganda. The paper then goes on to make a comparison of the respective attributes of small-scale aerial photography and satellite imagery for topographic mapping in Africa and concludes with a short discussion of the likely impact of the availability of higher resolution satellite imagery which is promised for the near future.

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1. Introduction - Topographic Mapping in Developing Countries

The needs for topographic mapping in developing countries is a matter which receives quite a lot of attention in the literature, though most often at a policy or political level - the basic premise or underlying assumption being that the developing (Third World) countries have very substantial deficiencies in coverage at the standard scale of 1:50,000 used for nation-wide topographic mapping. In practice, it is extremely difficult to discover where exactly this presumption comes from - usually overall percentage figures issued by the U.N. organisation are quoted and are accepted as fact. Almost invariably, Africa is quoted as the poorest mapped continent, with South America as the next poorest and strong hints that parts of Asia have none too good or none too complete cover.

1.1 Review of Existing Topographic Map Coverage in Africa

In fact, a detailed analysis of the African situation gives a rather different and more complex picture. In the first place, it is highly doubtful that comprehensive mapping at 1:50,000 scale is required, since so many of the countries in Africa have enormous areas of desert or semi-arid land with little or no population and few cultural (i.e. man-made) features. In which case, comprehensive mapping at 1:50,000 scale is either unnecessary or, if implemented, is overkill. As an example of the latter, Namibia has complete cover at 1:50,000 scale in the shape of 1,250 individual map sheets executed by the South African Trig Survey organisation. Yet its land area amounts to 824,00 sq. km and its population is 1,400,000, giving an average population density of 1.8 persons per sq. km. And in fact, the actual density is still lower for most of the country when one realises that more than 60% of the people live in urban communities.

With this in mind, many other African countries have adopted a dual scale strategy for their topographic mapping. For example, many of the Francophone West and Central African countries and Djibouti (former French Somaliland) have adopted 1:200,000 as the basic mapping scale with coverage at 1:50,000 scale confined to the more developed parts of their territories only. For Libya, where most of the landscape is pure desert, the basic national map coverage is at 1:250,000 scale - produced in fact as an image map series (127 sheets) from Landsat MSS imagery by the Earthsat Corporation in the U.S.A. in the late 1970s and early 1980s - the 1:50,000 scale coverage being confined to the band of populated and developed land between latitudes 28°N and 32°N adjacent to the Mediterranean Sea. Similarly in Tunisia, the whole country is covered by a 1:200,000 scale series, with the northern half also covered at 1:50,000 scale. The same type of thinking has resulted in the adoption of a dual-scale strategy in several of the former British ruled territories, e.g. in Kenya, Zambia and Botswana, with 1;50,000 adopted as the scale for mapping in the more populous and developed regions and either 1;100,000 or 1:125,000 scale for the more remote and arid or mountainous regions.

In the case of Algeria, a triple scale strategy has been adopted for the mapping of its huge surface area of 2.4 million square miles. Again, as for most of the former French territories, the largest scale used for national coverage is 1:200,000 and is therefore the scale used for the mapping of the Sahara Desert covering Southern Algeria. For the high mountains and plateaux of the Atlas, the basic mapping scale is 1:100,000, while 1:50,000 scale is used only for the more populous northern part of the country bordering the Mediterranean Sea.

In other countries with vast areas of sparse population,and low economic activity, 1:100,000 scale has been adopted as the basic scale for national coverage. This is the case in Sudan, since much of the 2,500,000 sq. km of the country away from the Nile rivers comprises desert, mountains and swamp with sparse population. Similarly the mapping of Somalia has been carried out at 1:100,000 scale by Russian mapping agencies (O'Brien, 1994). In the Malagasy Republic (Madagascar), again the national coverage is at 1:100,000. So when one reads in the UN reports that only 40% of Africa has been mapped at 1:50,000 scale, this doesn't necessarily mean that this is grossly inadequate and that the remaining 60% of the continent has not been covered by adequate or appropriate topographic maps. There seems little point in pursuing mapping at too large a scale, such as 1:50,000, if it is neither appropriate nor sustainable (Leatherdale, 1992).

1.1.1 Eastern, Central and Southern Africa

For the area of Eastern, Central and Southern Africa which is known to the present author through personal visits to a number of the national mapping agencies in the area and information supplied by a number of his graduates from these countries (Petrie, 1993), the situation regarding topographic map coverage is given in Fig. 1 and Table I. It can be seen from this data that, in Eastern, Central and Southern Africa, the generation of new topographic base maps is not the main concern of the national mapping agencies in these countries. Instead the major problem is that most of the topographic map coverage was produced using aerial photogrammetric methods during the period 1950-1975 and is now substantially out-of-date. Some re-mapping of certain limited areas is required, for example in areas where purely planimetric maps have been produced as a preliminary or provisional edition without contours. However, within Eastern, Central and Southern Africa, substantial new topographic mapping is only required in particular countries, most notably Sudan, Ethiopia and Eritrea in North East Africa and in Botswana in Southern Africa, and in certain remote areas in a few other countries.

Thus map revision is the main concern of most national mapping agencies in the Eastern, Central and Southern region of Africa due to the huge changes in the landscape that have taken place over the last 25 years arising from

- (a) civil war, e.g. in Somalia, Uganda, Zimbabwe, Mozambique;
- (b) famine arising from civil war, drought and other natural disasters;
- (c) political policies, e.g. villagization in Tanzania; the break-up of large farms and plantations into small holdings in Kenya, Zimbabwe, etc.;
- (d) large-scale agricultural, forestry and other development projects; and
- (e) considerable growth in population and a consequent expansion of settled rural areas and an explosive growth of urban areas.

In mapping terms, the consequences of these factors have been the following:-

- (i) the basic topography and relief (as represented by the heights and contours shown on the existing base maps) and most of the hydrology have remained unchanged;
- (ii) great changes have taken place in the rural landscape in many areas;
- (iii) in particular, substantial parts of the man-made landscape - comprising settlement, the communications network and the pattern of cultivated land - have been altered in many areas;
- (iv) the natural environment, in particular, the vegetation and forest cover, has changed in many places;
- (v) recurring droughts have led to desertification;
- (vi) there has been a rapid and often uncontrolled growth in many of the towns and cities in the region; and
- (vii) rapid and substantial changes in the landscape can be expected to continue for the foreseeable future.

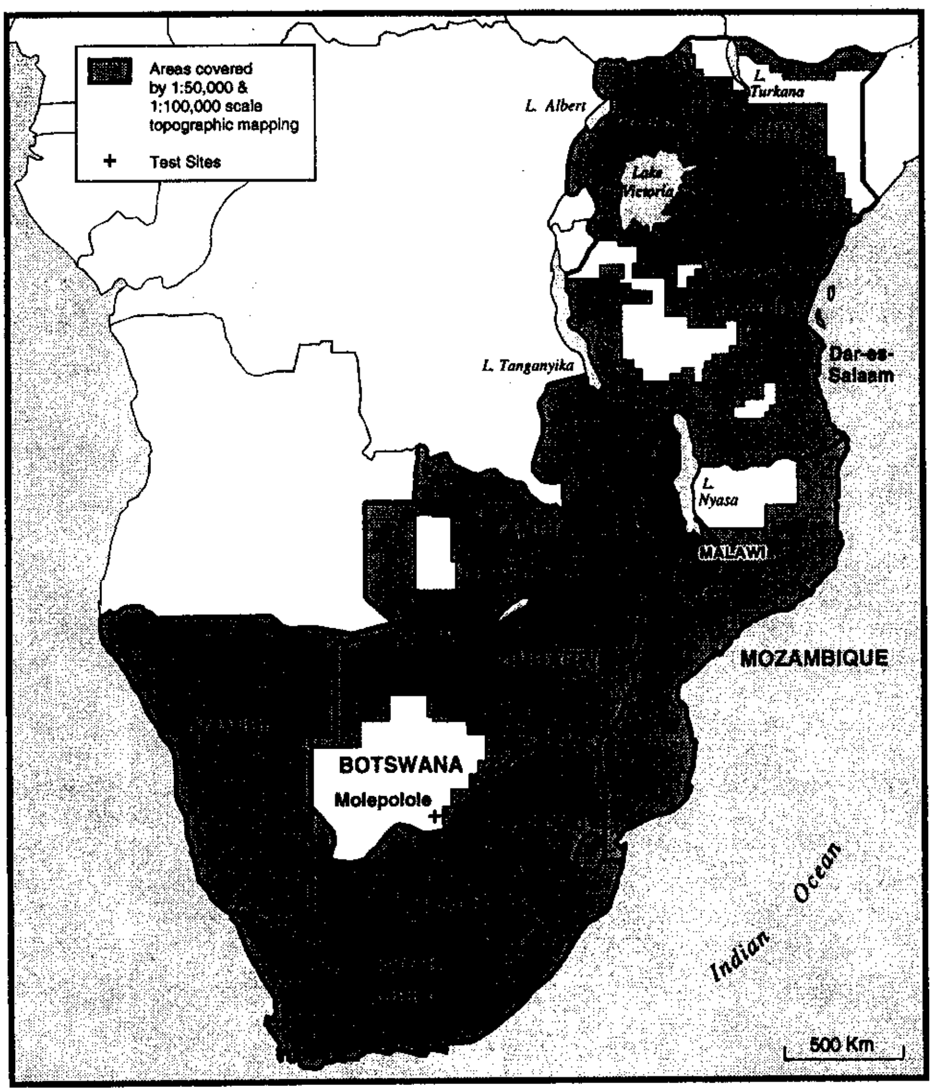
In this situation, it is far more important in these countries to give priority to revising the existing map sheets than to allocate funds to extending the series to remote and sparsely populated areas (Leatherdale, 1992).

1.1.2 West and North Africa

Elsewhere in Africa, it has been much more difficult for the author to obtain comprehensive information on the extent of national map coverage and the size and nature of the mapping problem, more especially for the Francophone countries of West and Central Africa. Certainly for the English speaking countries in West Africa, the situation is not too different to that discussed above for Eastern Africa. Thus in Nigeria, Ghana and Gambia, the principal problem is again one of revising topographic maps that were compiled 20 to 45 years ago. The situation in the Ivory Coast is similar, since it appears also to have a fairly comprehensive map coverage which requires updating.

Table I - Map Coverage in Eastern, Central and Southern Africa

Region	Country	%age Coverage	Mapped by
Eastern Africa	Sudan	10	DOS
	Ethiopia	40	DOS/Own Agency
	Eritrea	0?	?
	Djibouti	100	France
	Somalia	100	DOS/Russia
	Uganda	100	DOS
	Kenya	85	DOS
	Tanzania	95	DOS/Canada/Finland
Central Africa	Zambia	95	DOS/Finland
	Malawi	100	DOS
	Mozambique	90	Own Mapping Agency
Southern Africa	Zimbabwe	100	Own Agency and Canada
	Botswana	50	DOS
	Swaziland	100	DOS
	Lesotho	100	DOS
	Namibia	100	S.African Trig. Survey
	South Africa	100	S.African Trig. Survey



For the countries of North Africa, has also been difficult to get complete information on the map coverage. As noted above, Libya has complete cover at 1:250,000 scale via a satellite image map series, which is now 15 years old and almost certainly needs revision. However Morocco has less than half of its area covered at the scale of 1:100,000 scale designated for its basic mapping and one third at the scale of 1:50,000 scale (Essadiki 1987). In the case of Egypt, coverage is believed to be fairly complete, albeit at different scales, including the mapping of the area of the Eastern Desert between the Nile and the Red Sea carried out in the 1980s under contract by Finnmap. By a process of elimination and inference, it appears that the area of Africa with the poorest map coverage consists of the countries of the Sahel and West Central Africa, especially Zaire.

1.2 African Mapping Specifications

As noted above, the basic scales used in nation-wide topographic mapping in Africa are 1:50,000, 1:100,000 and 1:200,000. Most of the mapping specifications for these maps have been established either by the former colonial powers (e.g. U.K., France, Portugal) or by those counties which have given aid through significant mapping programmes in the post-colonial period (e.g. the Scandinavian countries, Canada, Russia). As a result, the specifications for map accuracy and content are too not dissimilar to those employed in highly developed countries, typically with planimetric accuracies (r.m.s.e. values) set at ±0.3mm and the contour accuracy requirements set at 90% of the points shown by a contour should lie within half the contour line interval. For the three basic scales being discussed, these specifications are shown in Table II.

Table II - Topographic Map Specifications

Scale	Plan Resolution (at 0.1mm)	Plan Accuracy (±0.3mm)	Spot Height Accuracy	Contour Interval (m)
1:50,000	5m	±15m	3m	10 to 20m
1:100,000	10m	±30m	6m	20m+
1:200,000	20m	±60m	12m	25 to 40m

1.3 Situation in African National Mapping Organisations

It is also appropriate to consider the current situation of national mapping organisations in Africa and, in particular, their capabilities to carry out topographic mapping from satellite imagery. While the situation varies considerably from one country to another, in general they suffer from a marked lack of resources to carry out their assigned tasks. This manifests itself for example in an inability to keep parties in the field to carry out survey operations due to a lack of money to pay field allowances, too many unserviceable vehicles and sometimes shortages of fuel. The chronic lack of foreign exchange which afflicts many African countries also results in an inability to purchase spare parts and have instrumentation serviced, repaired and calibrated. In several of the organisations known to the present author, a substantial proportion of the analogue stereoplotting instruments are not operational for this reason; in particular those which have been equipped with encoders and coordinate read-out systems to generate data for input to digital mapping systems are often out of action for long periods. The unreliable electricity supplies with frequent and unpredictable power cuts and brown-outs experienced in some countries are not helpful in this respect (Fanta, 1992).

The utilization and exploitation of satellite stereo-imagery for topographic mapping and map revision purposes also requires the availability of expensive high-tech solutions and systems. In particular, analytical plotters or digital photogrammetric work stations equipped with suitable software need to be available if accurate results or the extraction of heights and contours is required. Yet, in the countries of Eastern Africa known to the author, stretching from Sudan in the north to Namibia and Zimbabwe in the south, such systems are rarely found in national mapping organisations. At present, only the Ethiopian Mapping Agency (EMA) and the Department of the Surveyor-General (DSG) in Zimbabwe possess analytical plotters and only a single one of these in EMA has software that can handle stereo-SPOT images. In the whole of this vast area of Eastern Africa, there are no digital photogrammetric work stations known to the author. Most of the countries in the region do have national remote sensing centres or individual ministries that have installed image processing systems to handle remote sensed imagery, but almost invariably these are used exclusively for environmental monitoring and land cover or thematic mapping of a broad brush nature at small scales. Rosenholm (1993) provides a description of such projects in Namibia, Malawi, etc. which have produced small scale maps of land use, vegetation, forestry, geology, etc. from

Landsat TM and SPOT XS imagery, exploiting their multi-band/multi-spectral capabilities.

Kalensky (1996) has also provided a review of the efforts, largely under the leadership of the Food and Agricultural Organisation (FAO) of the United Nations, to provide land cover mapping and environmental monitoring information on a continent-wide basis from satellite imagery. The Africover project is intended to produce a digital land cover database and associated hard-copy maps at 1:200,000 or 1:250,000 scale (depending on the country concerned) and at 1:1,000,000 scale to provide an overview of the situation. The implementation of this project will be carried out by the United Nations Economic Commission for Africa (UNECA) and selected regional and national mapping agencies. The first phase covering 12 countries in Eastern Africa is under way, funded by Italy. The second project is called ARTEMIS (African Real Time Environmental Monitoring and Information System) and is intended to provide timely inputs from remote sensing data for the early identification of agricultural drought and desert locust risk areas. This uses meteorological imagery from the European Meteosat and from the AVHRR sensors of the American NOAA satellites - so obviously the resolution is limited in terms of satellite mapping scales.

2. Possibilities of Satellite Mapping in Africa

Having outlined the African mapping scene and its varied requirements and situation, the fundamental question to be asked and answered is whether satellite imagery can deliver solutions to satisfy the requirements of topographic mapping, which may vary greatly from one African country to another. Undoubtedly there is much current interest in this question (Nino-Fluck, 1993). In part, this stems from the improved ground resolution of the imagery which has become available from space sensors over the last decade. Along with the improved ground resolution has come the availability of stereo imagery from scanners, e.g. using SPOT and MOMS, a product that previously was a monopoly of photographic cameras. Not only does the stereo-imagery allow elevations to be determined, but the interpretation of the features present in the images is noticeably better under stereo-observation than using monoscopic observation. This availability has led to the possibility of implementing both manual and automated methods of extracting terrain elevation data; the generation of ortho-images and the manual measurement and extraction of point, line and area features from the resulting stereo-models. Associated with this has been the development of the technology (computer-based analytical and digital stereo-plotters) able to cope with these stereo-scanner images.

Quite apart from these improvements in resolution and stereo-capability, which promise to overcome some of the main shortcomings of older types of remotely sensed data, the economics of using satellite imagery appear favourable. Fewer images are required to cover a given area; hence there will be a reduction in the ground control point requirements. There is also the promise of quicker map production as compared with that based on the use of aerial photography, currently the well established source of topographic map data in Africa.

2.1 The Availability of Space Imagery over Africa

At the present time, having regard to the requirements of national topographic mapping and map revision programmes in an African context, in practical terms, there is really very little choice of imagery having the required resolution and geometry.

2.1.1 Space Photography

The characteristics of all the various types of space camera and photography that need to be considered in the present discussion are set out in Table III.

Table III - Characteristics of Space Cameras and Photography

Camera	Format (cm)	Focal Length (m)	Angular Coverage	Flying Height (km)	Ground Coverage (km)	Scale	Ground Resol. (m)	B:Ht. Ratio	Orbital Inclination
MC	23x23	0.30	42x42°	250	190x190	1:820,000	16-33	0.3	28.5°
LFC	23x46	0.30	42x75°	225	170x340	1:740,000	10	0.6	57°
KFA-1000	30x30	1.00	17x17°	270	80x80	1:270,000	5-10	0.12	83°
KFA-3000	30x30	3.00	6x6°	270	27x27	1:90,000	2-3	0.04	83°
TK-350	30x45	0.35	46x65°	220	190x280	1:630,000	7-10	0.52	67°
MK-4	18x18	0.30	33x33°	280	160x160	1:930,000	10	0.24	83°

In fact, the space photographic camera systems utilised by Western Countries such as the Metric Camera (MC) and the Large Format Camera (LFC) have only operated on an experimental basis in the mid-1980s and have only achieved patchy and discontinuous coverage (Fig. 2). This was a consequence of the Challenger disaster in 1986 and the cessation of further Space Shuttle flights for four years. In turn, this meant that the further scheduled flights of the MC and LFC cameras were badly delayed and eventually cancelled. This was a pity since their ground resolution - in the range 10 to 25m - and their stereo capability were of considerable interest to the topographic mapping community (Derenyi 1986, Greer, 1989) and much was expected from the follow-on flights.

It is also appropriate to consider the more recent Russian space photography for the topographic mapping task, more especially that taken by the KFA-1000, TK-350 and MK-4 cameras (Table II). The KFA-1000 with a ground resolution of 5 to 10m has a superior performance in this respect to any other sensor so far discussed. However, although it has a stereo capability, this is limited by its poor base: height ratio (0.12) and the fact that it is often operated in a split-vertical mode (Fig. 3). Jacobsen (1993) reports its spot height accuracy as ±32m in tests carried out over Germany. Thus its main potential would appear to lie in its use for purely planimetric mapping or in the map revision role. The MK-4 photography has a somewhat better base:height ratio (0.24) than that of the KFA-1000, but has a less good ground resolution (circa 10m), though still in the class of the LFC. A rather worrying feature reported by Jacobsen (1992) is the quite large and irregular image distortions which have been detected in his tests of the KFA-1000 and MK-4 photography. These appear to be the result of asymmetric lens distortions and/or a lack of film stability. The third of these Russian camera systems, the TK-350, is in many ways analogous to the LFC, combining as it does, both high ground resolution (7 to 10m) and good geometry (base:height ratio of 0.52). The major problem likely to cause potential users to hesitate to use the TK-350 photography is the ultra-large format size (30 x 45cm) which certainly cannot be accommodated in the photogrammetric systems available to most national mapping organisations in developed countries, never mind Africa.

In summary, it remains to be seen whether any African country will adopt these Russian photographic images for systematic mapping. In this respect, there is a certain deterrent in the fact that it is not easy to obtain information regarding their coverage and availability, casting some doubt on the wisdom of relying on them for a national mapping programme. It would seem that the Russian agencies involved will need to improve their marketing and distribution facilities if they are to persuade customers to adopt and use their space photographic products on such programmes.

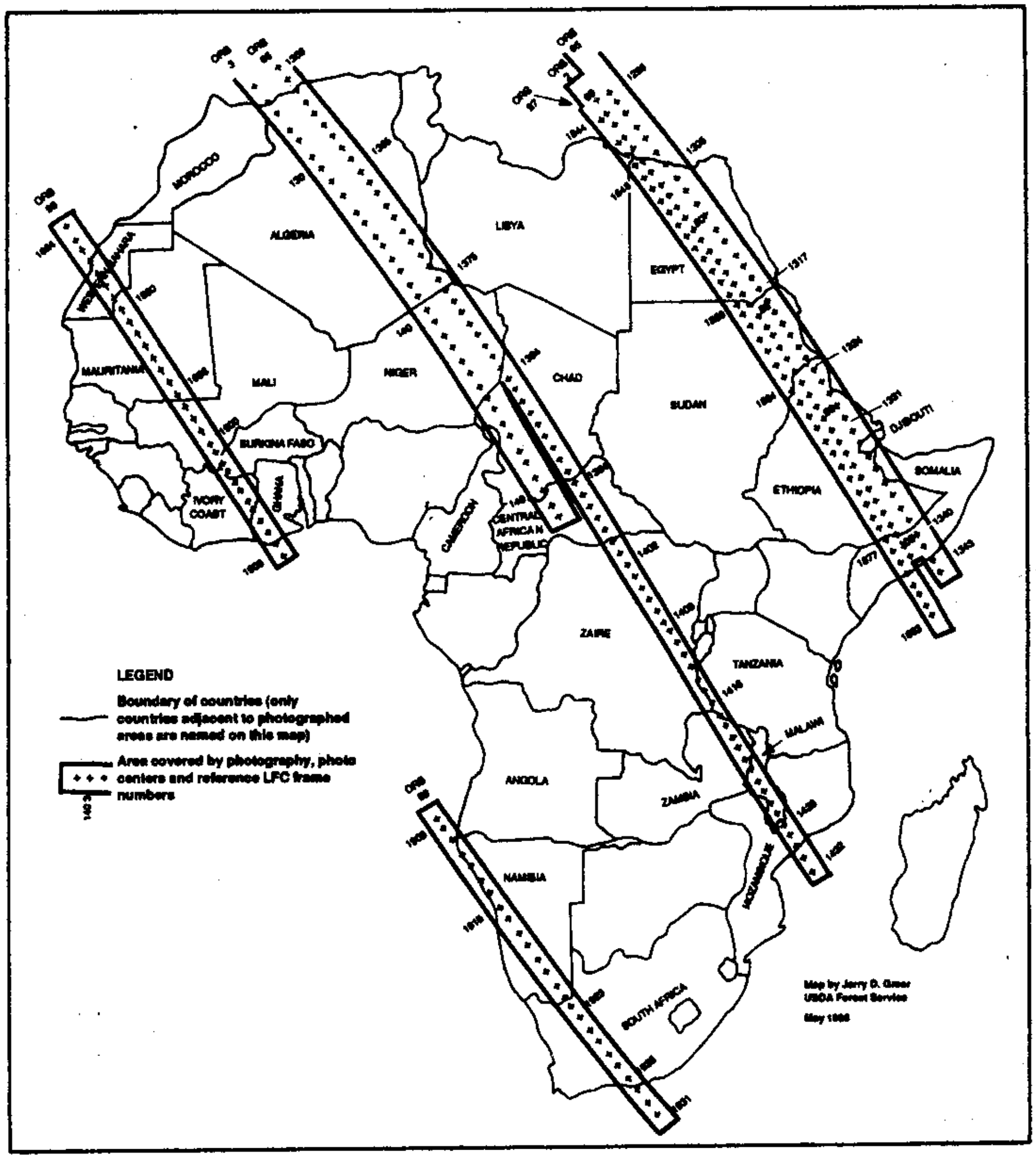
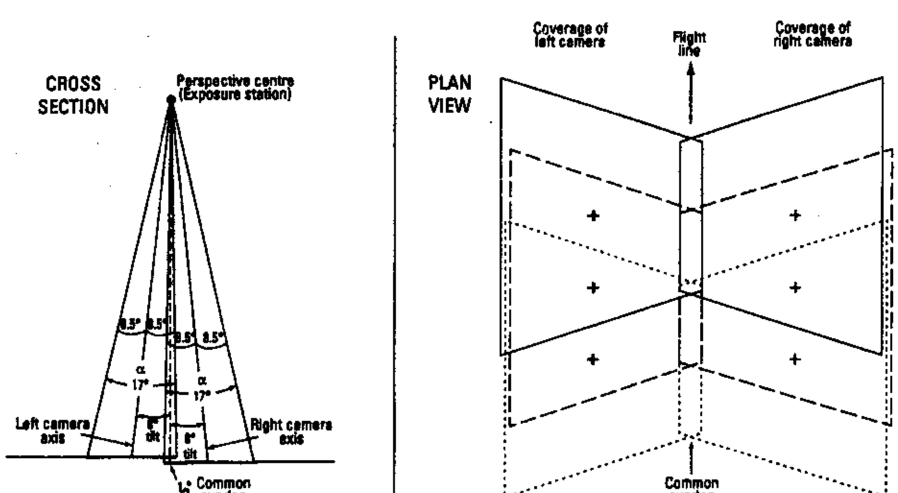


Fig. 2. LFC coverage of Africa (Greer, 1989).



2.1.2 Scanner Imagery

Essentially the two main operational Earth observation systems which are of interest to the African topographic mapping community are the Landsat TM and SPOT scanner systems. However TM with its 30m pixel size and 45m ground resolution has limited spatial resolution and no stereo capability, so its use will be limited to purely planimetric mapping and map revision at fairly small scales. Its advantage over SPOT of having a much wider (seven band) spectral coverage is more suited to the requirements of environmental monitoring and land cover and thematic mapping than topographic mapping. Thus SPOT with its higher spatial resolution - 10m pixel and 15 to 18m ground resolution from its Pan channel - and its stereo capability (with base: height ratios up to 1.0) is really the principal system of current interest to those concerned with topographic mapping in Africa. As noted above, this is the result of the situation in the late 1980s when the Shuttle-based MC and LFC cameras were grounded and so the SPOT system has become established and has achieved a dominant position during this period when it lacked real competition from sensors with comparable resolution and geometry.

As with the MC and LFC photographic missions, the MOMS-02 along-track stereo scanner system with its excellent geometry (base:height ratio of 0.3) has till now been largely experimental and has only achieved limited and fragmentary coverage to date (Fig. 4) - a consequence of its low orbital inclination (i=28.5°) and latitudinal coverage and its limited mission duration. This situation may change in the near future with the implementation of the joint German-Russian collaboration by which the MOMS-02 system will be operated from the PRIRODA module of the MIR space station. With its orbital inclination of 51.6°, this will enable it to cover all of Africa - weather permitting.

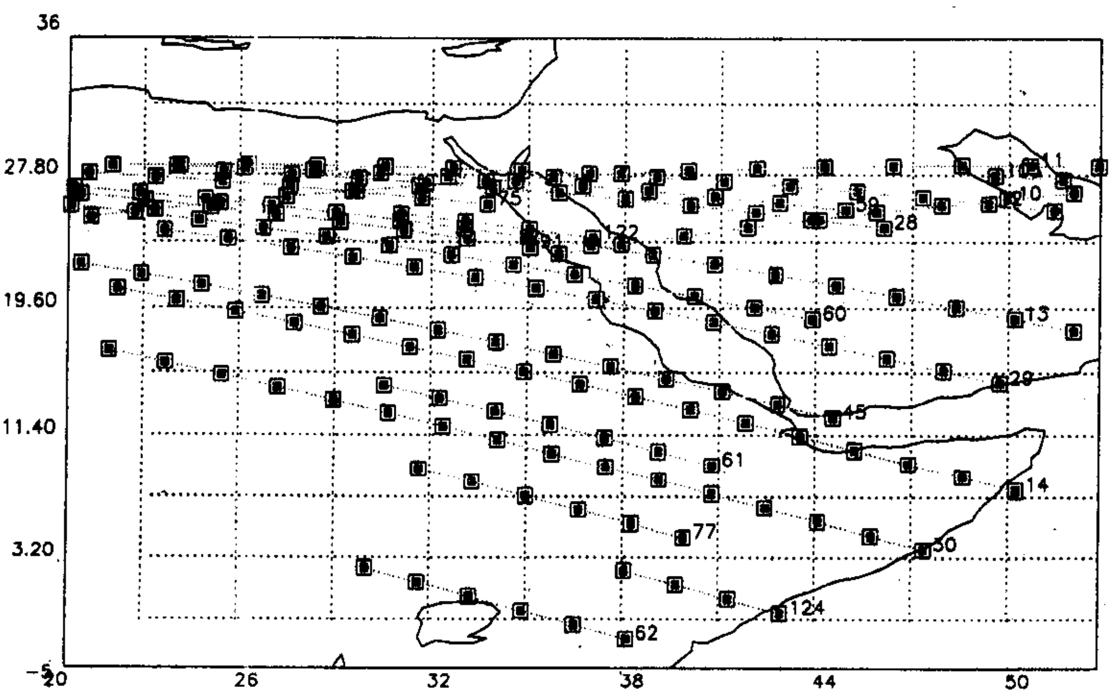


Fig. 4. MOMS-02/D2 ground tracks over Africa are concentrated in the north-eastern part of the continent - there is little coverage elsewhere.

The Japanese space agency (NASDA) has also deployed an experimental pushbroom scanner, OPS, on its JERS-1 satellite. This device is also able to acquire along-track stereo-imagery, albeit with a poorer base:height ratio of 0.3, resulting from the combination of a vertical pointing and a forward pointing linear array. The Pan sensor on the Indian IRS-1C satellite launched in December 1995 is in many respects similar to SPOT with a swath width of 70km, an off-nadir pointing capability, stereo-viewing and a rather better ground resolution arising from the use of a 6m pixel size. If this works reliably, and a suitable supply and pricing policy is implemented, then its imagery

It is also worth noting the situation regarding direct data reception and processing of high resolution satellite scanner imagery in Africa - as distinct from weather satellite data. In spite of many proposals and discussions for permanent receiving stations to be established in Eastern Africa (Nairobi), Central Africa (Kinshasa) and Western Africa (Ouagadougou and Ile-Ife), mainly at the Regional Centres for Mapping set up under the auspices of the UN Economic Commission for Africa (UNECA), this simply has not happened (Fanta, 1992). The result is that data acquisition is restricted to that which can be achieved from SPOT with its on-board tape recorders or that which can received from stations in neighbouring countries such as those operated by ESA at Fucino, Italy and Maspalomas, Canary Islands and the national stations located in Riyadh, Saudi Arabia and Pretoria, South Africa. This results in delays in data supply - though this is a matter which is probably more significant to environmental monitoring programmes and the timely warning of natural disasters than to topographic mapping programmes.

2.2 Tests of Map Accuracy and Content from Satellite Imagery

With regard to the planimetric and height accuracies and the information content that can be extracted from satellite imagery, these parameters have largely been established through a series of tests carried out in North West Europe, North America and Australia, more especially in the period 1984-90. It must be said that the conditions for these tests carried out in these highly developed countries have been near to optimal since they comprise

(a) large areas of developed land with many well-defined man-made features;
(b) extensive geodetic networks of high accuracy;
(c) existing comprehensive and up-to-date topographic map coverage; and
(d) the availability of well-equipped national mapping agencies and universities with sophisticated facilities and expert staff to carry out these trials.

By contrast, the situation in many African countries is very different, given the following situation:-

(a) totally different environmental conditions prevail - e.g. large areas of arid and semi-arid lan, savanna country, dense tropical forest, etc.;
(b) huge land areas have to be mapped with many poorly defined features, including roads, tracks and buildings having a low contrast arising from the use of local materials and agricultural areas comprising numerous small plots instead of large fields often devoted to monoculture;
(c) survey control networks and existing map coverage are often of a moderate quality and poorly maintained; and
(d) national survey and mapping agencies are frequently poorly resourced and lack the modern equipment and expertise required to handle satellite imagery.

In view of this very different scenario, quite extensive tests have been carried out to establish the geometric accuracy and the information content of maps that can be derived from different types of satellite imagery over test sites in the Sudan. These have included Landsat MSS, RBV and TM, MOMS-01, Metric Camera (MC) and Large Format Camera (LFC) images taken over sites in the Khartoum/Gezira area; in the rugged and barren Red Sea Hills; and in the Kassala area close to the border with Ethiopia. Organisations that have carried out these tests have included the University of Glasgow (El Niweiri, 1988; Petrie & El Niweiri, 1992, 1994), the University of Hannover (Engel & Konecny, 1985; Schroder, Schuhr & Schuring, 1985), the Ordnance Survey (Hartley, 1987; Rackham,1987); OEEPE (Rollin & Dowman, 1988); and the UN Economic Commission for Africa (Ihemadu, 1985). Also a test of simulated SPOT imagery for planimetric accuracy only was carried out at the University of Khartoum (Ali 1986). The concentration on the Sudan for test sites was largely a consequence of the availability of a substantial area of new 1:100,000 scale topographic mapping produced from aerial photographs by DOS/OSI under a British aid programme. These maps were available for test and comparative purposes for these areas. While the Khartoum /Gezira area contained many well defined points and objects, the Red Sea Hills test areas had very few.

2.2.1 Accuracy Tests in the Sudan

A short representative summary of the results of the accuracy tests carried out over these Sudanese test sites is given in Table IV for the more relevant TM, SPOT, MC and LFC images only.

Table IV - Results of Accuracy Tests

	PLAN			HEIGHT		
Sensor	m_x (m)	m_y (m)	m_p (m)	m_z (m)	CI (m)	Source
TM	14	13	20	-	-	Petrie/El Niweiri
SPOT	11	11	15/18	10/12	? 30	OS/IGN
MC	17	19	25	25	? 50	Petrie/El Niweiri
LFC	14	12	18	18/20	? 50	Petrie/El Niweiri

In general terms, it can be said that these figures for planimetric accuracy are reasonably compatible with those for an r.m.s.e. = ±0.3mm specified above in Table II for small-scale topographic maps - i.e. ±15m @ 1:50,000 scale; ±30m @ 1:100,000 scale; and ±60m @ 1:200,000 scale.

It can be seen also that the main shortcomings in purely measurement/accuracy terms lie in the area of heighting, where there is a real shortfall, both in the spot height accuracy and the possible contour interval. The height accuracy figures are only compatible with wide contour intervals (40-60m) instead of the 20m commonly specified for topographic maps at these scales. Indeed for flat desert areas, a 10m contour interval may be a more appropriate requirement. In general terms, these height accuracy figures are incompatible with standard topographic map specifications. It is also worth noting the quite frequent references (e.g. Jacobsen 1993, Jobre 1993) to the difficulties experienced in height measurement with stereo-SPOT imagery in certain areas, mostly due to the changes in vegetation, hydrology, etc. occurring as a result of seasonal changes in weather conditions over the substantial time interval which may elapse between the acquisition of the individual side-pointing images making up the stereo-pair.

2.2.2 Interpretation Tests

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 feature extraction phase will almost certainly be required irrespective of whether the original imagery or stereo-model is being used for the task or a derived orthoimage. It requires good resolution and the need for good contrast in the imagery 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 - in contrast to the extraction of land use/land cover types and areas for thematic mapping, often carried out using automated or semi-automated machine classification techniques.

The other major problem occurring with satellite imagery lies in the shortfall in the ground resolution of the images. The 10 and 20m pixel sizes of the SPOT XS and Pan images translate to values of 15 and 30m respectively in terms of their ground resolution. In practice, these values are not too substantially different to the ground resolution values of the MC (16 to 20m) and LFC (10 to 14m) respectively. Obviously these resolution values will result in difficulties in the detection of the smaller objects present on the ground, especially isolated or individual buildings, footpaths and tracks, streams and other drainage features, etc. These objects will often have dimensions (<10m) which are smaller than these quoted figures for ground resolution and may exhibit poor contrast with the surrounding terrain, especially in arid and semi-arid areas. Any inability to detect such objects means that the resulting map detail is then seriously deficient or incomplete. In turn, this results in the need for a thorough and systematic field completion procedure to be executed on the ground to locate missing features and to incorporate local knowledge, e.g. names, road and building classification, etc.

2.2.3 Interpretation Tests in the Sudan

With this in mind, tests have also been carried out over the Sudanese test areas to establish the map content that can be extracted from satellite imagery. Detailed accounts of the results achieved by El Niweiri are given in the paper by Petrie & El Niweiri (1992). In general terms, these showed that many of the hydrological features, land forms and vegetation/land cover can be detected, identified and plotted from the TM satellite scanner imagery and the MC and LFC space photography. However the results obtained with the man-made features existing in the test areas in the Sudan were very poor. In particular, the minor roads and tracks and the narrow gauge railways (which are so important in these remote areas) were largely missing. Furthermore towns were difficult to delineate, most villages could not be discerned and individual buildings (which are vital items in such remote areas) were impossible to find, as were pipelines, power lines and storage tanks. While the situation was somewhat better for the MC and LFC photography than the scanner imagery, it still meant that a very substantial field completion effort would be needed to ensure a satisfactory coverage of the communications and settlement which are present in such areas.

2.2.4 Further Interpretation Tests in Eastern, Central and Southern Africa

Since it could be seen from the results of the tests in the Sudan given above that the planimetric accuracy of satellite-based maps is not a substantial issue, it was decided to carry out further tests at the University of Glasgow (Petrie and Liwa, 1995) concerning the interpretation and the extraction of detail for topographic mapping from SPOT Pan satellite images - since this is the highest resolution production-type imagery that is currently available to users. These tests have been carried out mainly by Liwa for a wide variety of landscapes - ranging from semi-arid to heavily vegetated areas and from urban and suburban areas to rural areas with scattered cultivation and settlement - located in different countries in Eastern, Central and Southern Africa.

Hard copy images enlarged to 1:50,000 scale were produced to allow their registration and overlay on the existing topographic maps of the test areas. This allowed the detail to be interpreted and measured using a large-format digitizer equipped with a large-aperture magnifier. For one area, the digital SPOT image was used in conjunction with an image processing system that allowed on-screen digitizing of the interpreted detail. Comparisons were made with the detail plotted from small-scale aerial photography taken with super-wide-angle cameras at 1:65,000 to 1:75,000 scale, since currently this is the main source of the data used to compile topographic maps and carry out map revision in the region. The interpretation and measurement of the detail on these photographs was undertaken in a Kern PG-2 stereo-plotter.

Details of the test areas and materials are given in Table V below.

Table V - Materials used in the Eastern African Interpretation/Content Tests

	SPOT Imagery			Aerial Photography		
Test Area	Type	Scale	Processed Level	f (cm)	H (km)	Scale
1. Korogwe (Tanzania)	XS3 XS2 XS/FC Pan	1:150.000 1:150,000 1:150,000 1:50,000	1B 1B 1B 1A	8.85	6.5	1:75,000
2. Dar-es-Salaam (Tanzania)	Pan	1:25,000	1A	8.5	5.8	1:65,000
3. Thika (Kenya)	XS3	1:150,000	1B	-	-	-
4. Naivasha (Kenya)	XS3	1:150,000	1B	-	-	-
5. Lusaka (Zambia)	Pan	1:50,000	1B	-	-	-
6. Molepolole (Botswana)	Pan	1:150,000	3	-	-	-

A detailed account of the results has been published by Petrie and Liwa (1995). Table VI has been taken from that publication. With regard to the SPOT imagery, in line with the previous experience in the Sudan, the main deficiencies lie with the communications network and the other man-made features. In the former case, the main tarred-surfaced and gravel-surfaced roads were mostly visible and identifiable, whereas the numerous unsurfaced minor roads and tracks (which form by far the largest part of the communications network) were very substantially deficient and incomplete. In the latter case, the larger urban areas can be defined, but sometimes the main street pattern cannot be discerned. Moreover many of the minor settlements, e.g. villages and hamlets comprising groups of small farms, cannot be located with any confidence. Individual buildings and farms, which may be very important features in maps of rural areas, cannot be discerned.

Table VI - Results - Interpretation/Information Content of SPOT Imagery & Small Scale Air 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

With regard to land cover and vegetation, large fields and plantations show up well on the SPOT images, whereas the cultivated areas associated with the numerous small farms are difficult to locate and delineate. In general, thicker woodlands and forests are well defined, whereas scrubland and bush country are not. The mapping of hydrological and geomorphological features is rather variable depending on terrain type and the specific feature concerned. It is good in some areas; poor in others. In very broad terms, one can say that, for the areas of Africa covered in these tests, the deficiencies or shortfall in the planimetric features required for 1:50,000 scale topographic mapping are of the order of 30% of the total map content. Thus a thorough and comprehensive field completion is necessary if the resulting product is to meet the specification and the standards of completeness expected of a topographic map.

By contrast, the detail obtainable from the super-wide-angle aerial photography is much higher - normally at the 90 to 95% level. Given the much higher resolution (1.5 to 2m) available on the photography, this is not too surprising. Still some field completion will be required, since some of the smaller point and line features (bridges, footpaths, wells, etc.) cannot be detected and identified with confidence on the photographs. However this will incur only a fraction of the time, effort and expense needed to complete the plots derived from SPOT satellite images.

2.2.5 Interpretation Test in North East Tanzania

It is useful to note also the experiences of Dowman and Peacegood (1988) who investigated the information content of both Landsat TM and the same SPOT Pan and XS images of Korogwe that have been used in the tests described above. The Landsat TM imagery 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 of the 1:50,000 scale map was available from 1957, together with the corresponding photogrammetric plot from the DOS/OSI re-mapping programme from the same aerial photography as was used in the series of tests carried out by Liwa. However the test undertaken by Dowman and Peacegood concentrated on the differences between the communication features (roads + tracks + railways) as plotted from the satellite images and those shown on the corresponding 1957 map. The published results are given in Table VII below in terms of percentage errors of commission (i.e. wrongly plotted or misidentified features) or omission (i.e. features left out) as follows:-

Table VII - Test of Communications Features, Kirogwe
(Dowman and Peacegood 1988)

Image	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

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 were as follows:-

Image	Roads (%)	Rail (%)	Tracks(%)	Road+Rail+Tracks
TM (3+2+1)	-	-	-	33/33
SPOT Pan	-	-	-	37/17

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". Obviously the results of this particular test supplement and confirm some of the findings of the more comprehensive tests reported above.

2.2.6 Interpretation Test in Nigeria

A further set of interpretation tests has been carried out by Ajayi (1992) using a ContextVision GOP 302 image processing system at the University of Hannover. This project aimed to examine the possibility of carrying out the revision of 1:50,000 scale topographic maps of Nigeria from SPOT imagery. The two small test areas were extracted from a SPOT Level 1A image covering part of the Delta State of Nigeria; the first comprised a mainly urban area, the second a mainly rural agricultural area with some forest. The test appears to have concentrated on the communication features and settlement, Ajayi's report making little comment on the cultivated areas, vegetation, forest, landforms and hydrology of the area. However Ajayi's experiences and conclusions were not too dissimilar to those of the Eastern African tests. Main roads and most minor roads could be plotted fairly comprehensively, but tracks and footpaths, which are especially important in the rural area, could not be detected. Larger settlements could be interpreted and their boundaries demarcated, but the identification of smaller compounds was not possible. Ajayi also felt that "very extensive field verification would be required to assess the amount of omission/commission errors in the image interpretation and plotting. Ground verification is a very tedious task because of the small scale of the images. In most cases, such checks have to be supported by the use of aerial photographs which are not always available". Again this helps to confirm the findings of the East African tests regarding communication features and settlement.

3. Topographic Mapping and Map Revision from Satellite Imagery in Africa

Some examples of the topographic mapping and map revision operations actually undertaken in Africa from satellite imagery by national mapping agencies can also be given and assessed. These include national mapping programmes in Ethiopia, Djibouti and Guinea, a map revision programme in Uganda and a combined mapping and map revision project in Nigeria.

3.1 Topographic Mapping from Stereo-SPOT Imagery in Ethiopia

As noted in Section 2 above, besides Sudan and Eritrea, the only other country in Eastern Africa that has a substantial shortfall in its topographic map coverage is Ethiopia. Almost 40% of the country had been mapped by DOS/OSI under a British aid programme, but only slow progress had been made since its completion. An initial pilot project to assess the possibilites of utilising stereo-SPOT imagery was carried out by SSC Satellitbild and Swedesurvey over the Asela area (Kihlblom 1993). This used advanced digital techniques, including multi-point matching to produce a digital elevation model (DEM) and orthoimage, followed by manual interpretation and compilation to produce line overlays (Westin, Rosenholm and Dahlberg 1988). Since then, stereo-SPOT imagery has been adopted by the Ethiopian Mapping Agency (EMA) for the continuation of the 1:50,000 scale mapping of the country (Jobre, 1993; Medhin, 1993). This uses hard-copy SPOT Pan images in a Wild BC-2 analytical plotter running the Aviosoft package. Composite sampling, comprising a grid of elevation values plus height values measured along rivers, watersheds and terrain break lines is carried out to form a digital terrain model (DTM). Ground control points are provided using GPS receivers. The final output is an ortho-image produced at 1:50,000 scale using a Wild OR-1 analytical orthophotoprinter, together with a contour plot derived by interpolation from the DTM data. According to Medhin (1995/1996), 31 ortho-image maps at 1:50,000 scale have been produced for the Shararo-Humera area in Tigray and a further 48 ortho-images at the same scale for the Abay-Takeze area. The latter project has used SPOT triangulation techniques to supplement the ground control points, with assistance from IGN in France.

Whereas the areas mapped from stereo-SPOT imagery in Yemen (by DOS/OSI) and Djibouti (by IGN), which will be described below were almost entirely desert or semi-arid in character, this is not the case in Ethiopia. Thus difficulties were experienced with orientation and plotting when the individual SPOT images making up the stereo-pair have been acquired some months apart, e.g. at the beginning and the end of the rainy season. These result in the very different appearance of vegetation, cultivated areas and water bodies in the corresponding images, resulting in problems with stereo-viewing and orientation. It is worth noting too that the final product is simply an ortho-image. No attempt has been made by EMA to acquire the missing data through the implementation of field completion procedures.

3.2 Topographic Mapping from Stereo-SPOT Imagery in Djibouti and Guinea

The territory of Djibouti (former French Somaliland), which lies adjacent to Ethiopia, has also been mapped from stereo-SPOT imagery by IGN, the French national mapping organisation (Veillet, 1990, 1992). For this territory, a map at 1;200,000 scale covers the whole country, while the more developed and populated part is covered by 1:50,000 scale mapping. The country is covered by 16 SPOT stereo-pairs (Fig. 5). The preparatory field survey operations were undertaken in late 1988 using GPS to fix 30 ground control points (GCPs) and were followed by a spatial triangulation and block adjustment of the stereo-pairs. This provided the additional control points and orientation elements required for the setting up of the individual stereo-models to allow traditional stereo-plotting of the planimetric detail and contours. All the photogrammetric operations and measurements were carried out on Matra Traster analytical plotters and were followed by field completion and cartographic processing to produce the traditional type of line map.

From information appearing in the marketing literature of SPOT Image, it appears that a similar project to produce 1:50,000 scale topographic maps has been undertaken by IGN for the country of Guinea in West Africa. However, up till now, the author been unable to obtain further details of this project. There is also a reference in the Algerian National Report submitted to the XVIII Congress in Vienna to the production of an ortho-image map of the Ghardaia area located in the desert area of South Algeria from SPOT imagery by the Algerian National Cartographic Institute (INC), again in collaboration with IGN.

In 1988, an experiment using SPOT imagery for 1:50,000 scale map revision was carried out on behalf of DINAGECAD, the national mapping agency of Mozambique by IGN. This involved the measurement of SPOT Pan imagery of Maputo in a Matra Traster T2 analytical plotter. According to Ferrao (1990) problems were experienced in plotting narrow linear features such as roads, railways and streams. Some of these major features have been correctly plotted, but elsewhere, in areas where they are too dense or have considerable vegetation cover they have been omitted. Ferrao's own test comparing the results of plotting revision data from SPOT imagery with those achieved from 1:38,000 scale aerial photography clearly showed the great advantages of the latter in terms of the interpretation of features and the completeness of the revision.

It is interesting to note that, at much the same time (1988-89) as the Djibouti project was being executed, a short distance across the Gulf of Aden from Djibouti, a very similar mapping project was also being undertaken in Yemen by Ordnance Survey International (OSI). This comprised the mapping of North East Yemen at 1:100,000 scale from stereo-SPOT imagery (Hartley, 1988; Murray and Farrow, 1988; Murray and Newby, 1990; Murray and Gilbert, 199O). The earlier topographic mapping of the rest of the country had been carried out by DOS/OSI under a British aid programme using aerial photography. However North East Yemen was (and is) a sensitive and disputed border area where it is not practicable to fly aerial photography. So hard-copy stereo-SPOT imagery was used to produce the required map information, 18 stereomodels being plotted in a Kern DSR analytical plotter at 1:100,000 scale with a 40m contour interval. The ground control was supplied by satellite doppler techniques. A substantial field completion was required with a particular emphasis on the villages. buildings, roads and tracks, many of which could not be located and measured during the stereo-plotting.

3.3 Planimetric Mapping and Map Revision in Nigeria

Nigeria is one of the largest African countries with an area of 1,000,000 sq. km, which is covered by 1,300 topographic map sheets at 1:50,000 scale. About 90% of these sheets had been completed by 1989, although by this time, many were out-of-date. In order to get the complete coverage required for the planning and implementation of the 1991 national population census, including the delineation of the Enumeration Areas, it was decided to execute the missing map coverage (Fig. 6) using monoscopic SPOT XS and Pan imagery (Atilola 1992). The initial work of receiving and precision processing the imagery to Level 2 standard was contracted to and undertaken by SSC Satellitbild. The individual processed images were digitally mosaiced and then transformed into hard copy form as film transparencies and photographic prints which were supplied to the Nigerian customer, the National Population Commission (NPC). The subsequent production of annotated image maps and planimetric maps at 1:50,000 scale was carried out by seven local Nigerian contractors. A total of 177 sheets were produced in this way for the areas of Nigeria that

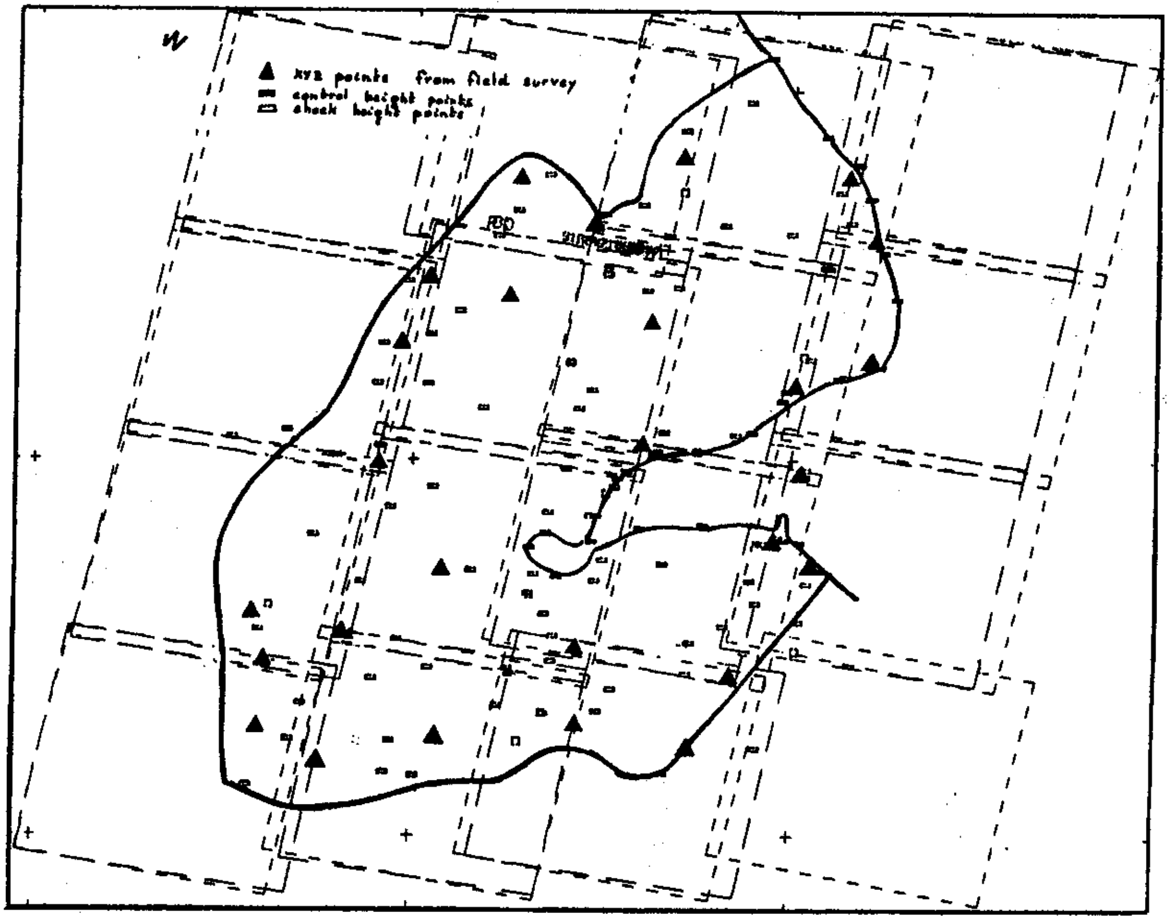


Fig. 5. IGN satellite mapping project of Djibouti showing the coverage of the SPOT scenes and the locations of the ground control points (Veillet, 1990).

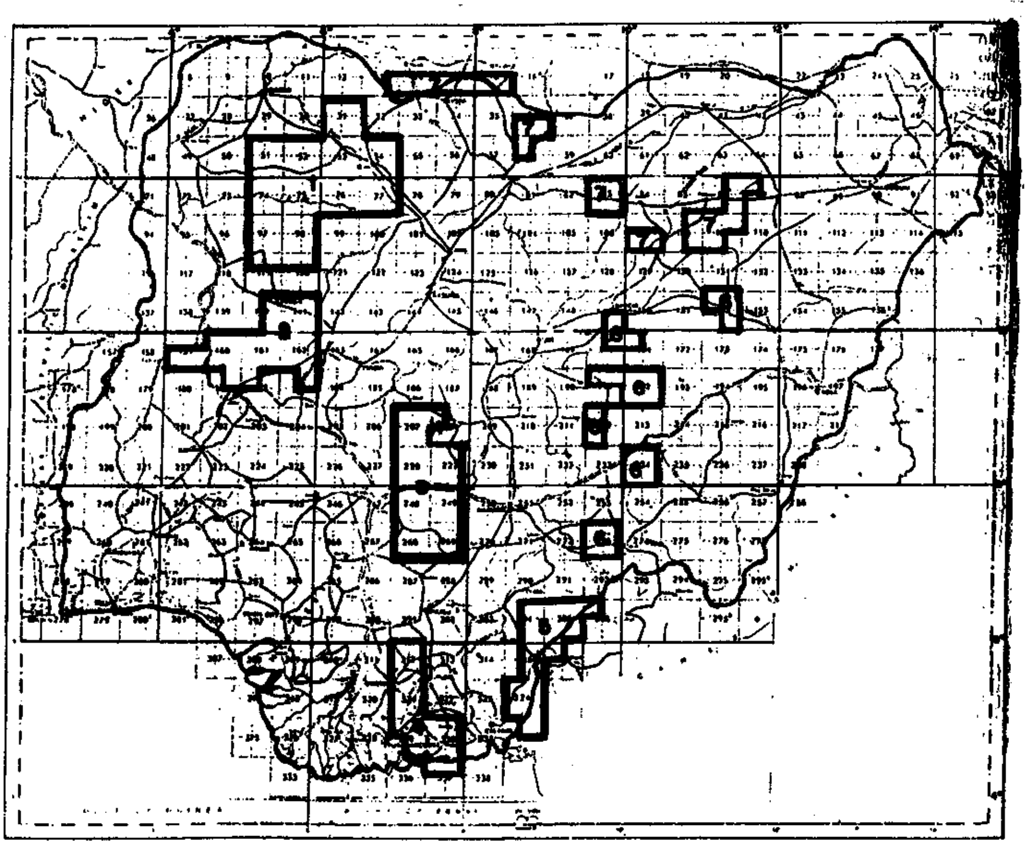


Fig. 6. Map of Nigeria showing [illegible] covered by NRC mapping project (Atilola, 1992)

Atilola (1992) outlines the technique used for the image map production and planimetric mapping. For the former, the XS and Pan mosaics were combined with a film overlay of the settlements, road network and place names to produce a single annotated half-tone film positive from which multiple copies could be made for use in the field and in offices. The planimetric line maps were then compiled using a PROCOM-2 optical transfer device equipped with a tablet digitizer, followed by extensive field completion and verification work to obtain place names, classify roads and tracks, add missing detail and delete erroneous information. The NPC project was regarded as a success and, as a result, the use of SPOT imagery has since been adopted for map revision purposes at 1:50,000 and 1:100,000 scale both by the Federal Surveys of Nigeria and by the Shell Company of Nigeria. The Federal Surveys uses GPS for the establishment of the ground control points and a Matra Traster T5 analytical plotter for the map compilation and revision work (Allo 1993).

3.4 Image Mapping in the Sudan

A project which has implemented very small scale mapping from satellite imagery for a limited area in the Sudan to produce both topographic base maps and vegetation maps is the Sudan Resources Assessment and Development (SRAAD) Project (Falconer 1990). This has been implemented by the Sudan Forests National Corporation (SFNC) with the help of the Sudan Survey Department (SSD) (Abdalla 1991). It has been concerned with the production of 1:250,000 scale maps of the so-called Gum Belt in Kordofan lying to the west of the Nile River and south of the town of El Obeid. The Project was initiated by USAID with the involvement of the U.S. Forest Service with a view to rehabilitating the severely degraded forest cover of the area. The USGS provided the initial TM images used as the base for the Project which resulted in the production of both 1:250,000 and 1:100,000 scale base maps and vegetation maps of the Kazgail test area (Mohie El Din 1991). Since the withdrawal of USAID, the project has continued using local expertise to carry out both the digital image processing from TM tapes on a Terra Mar system and the generation of the map overlays using a PC Arc/Info system. The ground control points needed for the image rectification have been provided by GPS receivers. Several 1:250,000 scale image map sheets and vegetation sheets have been produced locally in this way, though the current status of the Project is not known to the author.

3.5 Topographic Map Revision in Uganda

Uganda is one of the East African countries already mentioned above where the map revision problem is particularly acute having regard to its turbulent history of the last 25 years. The military coup of 1971 was followed by a war with and invasion from Tanzania, then a civil war and anarchy, topped off by the influx of large numbers of refugees from the civil wars in neighbouring Sudan and Rwanda. The result has been huge shifts of population to the towns and cities and to the more stable rural areas. As a consequence of these events, some rural areas have lost much of their population, while other more remote areas have seen little change.

The topographic coverage (310 sheets) at 1:50,000 scale was carried out by DOS/OSI under a British aid programme and completed in the early 1970s. It is now badly out-of-date as a result of the events described above. Formerly the national Department of Lands and Surveys was competent and well equipped, but during the period of anarchy, it was looted and many facilities damaged. This situation was then compounded by a lack of funding for the Department and the non-availability of foreign exchange for the purchase of equipment and spares. Given this poor situation, a new UNDP supported programme has been implemented to restore the Department to an operational condition. Part of the rehabilitation programme has been a project to update the 1:50,000 scale topographic map series using SPOT XS (20m pixel) imagery (Jansen, 1993). The raw SPOT data has been supplied by SSC Satellitbild and digitally processed by the contractor, Viak, in Norway. Final hard-copy enlargements were produced at 1:50,000 scale to correspond with the individual sheets of the topographic map series. Visual interpretation has then been carried out over light tables in the Ugandan Department to generate correction overlays (Fig. 7). The final cartographic production has also been executed in Uganda.

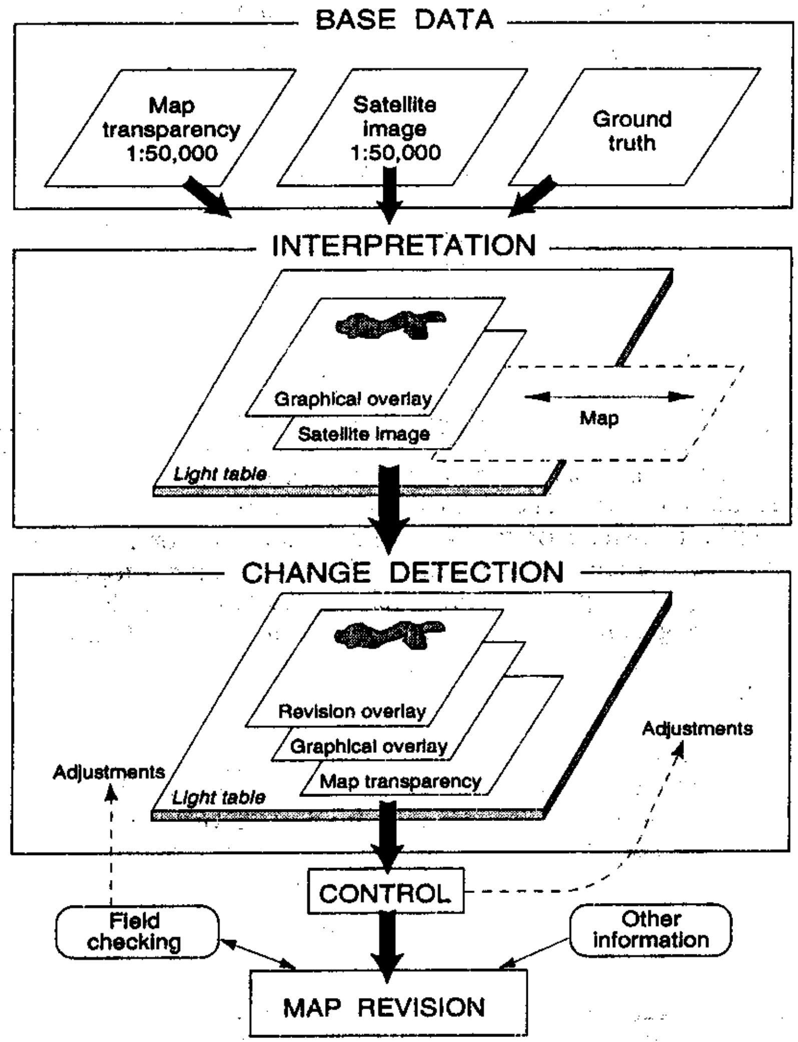


Fig. 7. Overall procedure used for image interpretation and change detection for the revision of the Ugandan 1:50,000 scale topographic map series from SPOT-XS imagery (Jansen, 1993).

It is interesting to note the experience gained in this project as recounted by Jansen (1993) of Viak. He reports that "small features (buildings, farms, groups of houses, etc.) are difficult to find; seasonal swamps are hard to detect; and forests are difficult to identify and to delineate in mixed forest/clearing areas. Furthermore, while main roads can be detected and plotted, many minor roads are not visible; and the numerous motorable tracks cannot be found at all". In summary, he gives his opinion that, "while SPOT image data is a useful tool for updating topographic maps, it can only be used if the normal criteria for accuracy and completeness are reduced. The resulting updating can only be considered temporary; complete revision requires the use of aerial photography". This opinion is reinforced by tests carried out by Kajumbula (1993) of the Ugandan Department using aerial photography of the Mabira area in Uganda. This encountered no difficulties with the detection and interpretation of the large number of changes that have occurred in the test area. In particular, the many scattered small farms, cultivated areas and minor roads and motorable tracks not visible on SPOT images were easily located and plotted from the photographs.

However the SPOT satellite imagery does have the advantage of relative cheapness, availability and speed, even if it is deficient in the details needed for a full map revision. Also multiple use and cost-sharing is another advantage - in this case, the National Biomass Group has also been able to use the SPOT XS images to generate the location and distribution of land use/land

3.6 Topographic Map Revision in the Ivory Coast

As discussed above, the situation regarding topographic mapping in the Ivory Coast is typical of that found in Francophone West Africa with complete national coverage at 1:200,000 scale and 68% coverage at 1:50,000 scale. A very detailed proposal to carry out the revision of the 1:200,000 scale series using SPOT Level 1B imagery supplemented by medium scale aerial photography was made by Tayour et al (1988). However the present status of this proposal and its actual implementation are not known to the present author.

4. Space Imagery Versus Aerial Photography - Comparison of Imageries

The situation regarding topographic mapping and map revision in many parts of Africa is that mostly it is still carried out using small-scale aerial photography in the scale range 1:60,000 to 1:80,000. Indeed bids for large contracts for such photography are currently being sought in both Zimbabwe and Namibia.

In this context, it is worth noting that, in recent years, there have been dramatic improvements in the performance achievable with aerial photographic cameras, e.g. the RMK-TOP and LMK 3000 from Zeiss and the RC30 from Leica/Wild. These arise from the development of gyro-controlled platforms and forward motion compensation (f.m.c.) which, in turn, permit the use of slow-speed high resolution films. These allow the resolution of the lens/film combination to reach the figure of 70 to 80lp/mm instead of the 40lp/mm which has for long been the standard for metric cameras. With this performance, it is possible to plan for aerial photography taken with a super-wide-angle camera from a high flying jet aircraft such as a Learjet or Falcon at scales between 1:120,000 and 1:150,000 to give a ground resolution of 1.5 to 2m. In turn, this means fewer photographs are required to cover a given area with a consequent reduction in the number of ground control points required, especially with GPS-controlled photography.

However, it is usually more expensive to acquire aerial photographic coverage of an area for mapping or map revision purposes, since more images are required. Consequently more ground control points have to be provided. However the ground resolution is an order of magnitude better - 1.5 to 2m versus 15m. Hence far more detail can be extracted from the photography - 90 to 95% in most cases. Hence very much less effort, expense and time is required for field completion and a superior final product.

Summarizing the current situation, based on the tests and production experience reported in this paper, satellite imaging such as the current standard production SPOT Pan images are less expensive, with fewer images and ground control points required for topographic mapping at 1:50,000 and 1:100,000 scales. However these images are substantially deficient in terms of content - on average, 30% of the total map content is missing in the context of the specification for mapping at these scales. This requires a very large effort in terms of field completion to remedy this deficiency. Of course, another quite different viewpoint can be taken, more especially in those countries with a large deficiency in their topographic map coverage, namely that for new mapping, a 1:50,000 scale base map produced to a relaxed specification from SPOT imagery 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 for 1:50,000 scale mapping.

5. Looking to the Future

With regard to remedying the current deficiencies of satellite imagery for topographic mapping, it is apparent that higher resolution images should become available in the future. When it is launched, the SPOT 5 Pan sensor will have a 5m pixel, which translates to a ground resolution of 7 to 8m. The experimental MOMS-02 imagery with its 4.5m pixel has a very similar performance, and it is hoped to convert this to a fully operational production system from 1996/97 onwards via the joint German/Russian PRIRODA mission. Still higher resolutions are also becoming available from the Russian space reconnaissance photography taken with KFA-1000, KFA-3000 and KWR-1000 cameras with ground resolutions ranging from 2 to 5m. While the use of the long focal lengths (f=1,000 to 3,000mm) does not allow useful heighting and contouring to be extracted from these photographs - due to the poor base:height ratio - the high ground resolutions could be useful for both planimetric mapping and map revision.

But high performance should also be forthcoming from the new American commercial satellite remote sensing companies such as Earthwatch (with its Early Bird and Quick Bird systems); Space Imaging and Orb Imaging (with its OrbView satellite). These are planned to come into operation during 1996 and 1997. All of these are aiming to produce Pan imagery with 1 to 3m pixel - say 2 to 5m ground resolution. Furthermore either along-track or cross-track stereoscopic capabilities (or both) are planned for these systems. With their higher resolution and good geometry over relatively small areas, these images will also be of great interest for mapping at medium to large scales as required for the mapping of densely populated rural areas and urban areas. The latter are a high priority given the rapid growth of so many African towns and cities and the pressing requirement to try and solve the problems accompanying this growth through the provision of an infrastructure and services to meet the needs of these rapidly expanding societies.

Thus the future is intriguing to say the least, especially with the advent of both small-scale aerial photography and space imagery of a quality and geometry superior to that currently available to the African topographic mapping community. Undoubtedly both types of imagery will have similar capabilities and both will have a part to play both in topographic mapping and in map revision operations in Africa. However it is also very apparent that, if national mapping agencies within Africa are to benefit from the forthcoming high performance imagery, they need also to be equipped with the photogrammetric technology that can exploit it. Unfortunately it is difficult to see this being implemented on a substantial scale without a large expenditure of precious and scarce foreign exchange and a much better local infrastructure, including reliable electricity supplies, comprehensive technical support and local expertise in analytical and digital photogrammetry.

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