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THE USE OF SPOT-IMAGERY FOR THE DETECTION OF GEOMORPHOLOGICAL AND SUPERFICIAL HYDROGEOLOGICAL PHENOMENA IN THE LUBUMBASHI AREA (SHABA, ZAIRE)

par

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SUMMARY - Digital SPOT image processing, combined with conventional panchromatic B&W airphoto interpretation and field observation, is used to survey and map geomorphological and superficial hydrogeological phenomena in the Lubumbashi area (Shaba, Zaire) a typical wet-and-dry tropical environment. The digital treatment includes LAI and biomass calculations, boxclassification, mask techniques and image stretching.

KEYWORD - Africa, Southern Zaire, tropical geomorphology, SPOT, digital image processing, aerial photo interpretation, soil drainage detection, landdegradation.

The following text presents research results of the Belgian scientific research program in the field of spatial remote sensing (Service of the Prime Minister - Science Policy Office). The scientific responsibility is assumed by its authors.

1. INTRODUCTION AND MATERIALS

The aim of this paper is to explore the possibilities of SPOT-imagery to detect geomorphological and superficial hydrogeological phenomena in a typical wet-and-dry tropical environment. To achieve that goal, investigations are done on a digital SPOT-image covering about 3,600 km^2 in the Lubumbashi area of southern Shaba (Zaire) and dated 4 June 1986 (124-373). The satellite data are compared with field observations and with interpretations of conventional panchromatic B&W aerial pictures on scale 1/40,000 and dated 13 and 19 May 1954 (E'ville 2629-2636 and 2528-2536).

Lubumbashi is the capital of Shaba province and a booming town; its population quadrupled from 133,017 inhabitants in 1954 to 533,510 inhabitants in 1984 (LOOTENS-DE MUYNCK, 1985). MALAISSE *et al.*, (1980) estimated the annual deforestation caused by the Lubumbashi population's need for charcoal at 140 km^2 in 1980. According to SOYER and ALEXANDRE (1987) a subcircular area of 1,700 km^2 around Lubumbashi was already affected by deforestation in 1985.

To avoid the expansion of the human influence during the time gap between the taking up of the aerial pictures and the satellite image as much as possible, a remote testarea covering 250 km^2 is chosen. It is part of the basin of the Upper Kifumanzi and located at some 40 km to the NNE of Lubumbashi, quite far from the railway and the road to Kolwezi and from the road to Kasenga.

2. ENVIRONMENTAL SETTINGS

The Kifumanzi river is an affluent of subsequently the Luiswishi and the Kafubu. The latter is drained by the Luapula river, belonging to the upper reaches of the Zaire. The Upper-Kifumanzi is developed on the watershed between the Luapula and the Lufira rivers. On that watershed, situated at an altitude of about 1,250 m a.m.s.l., the features of the vast End-Tertiary planation surface are well preserved. The terrain slopes very gently (less than 1%) and is underlain by deeply weathered sedimentary rocks of the Katanga-system (Upper Precambrian), subdivided in the

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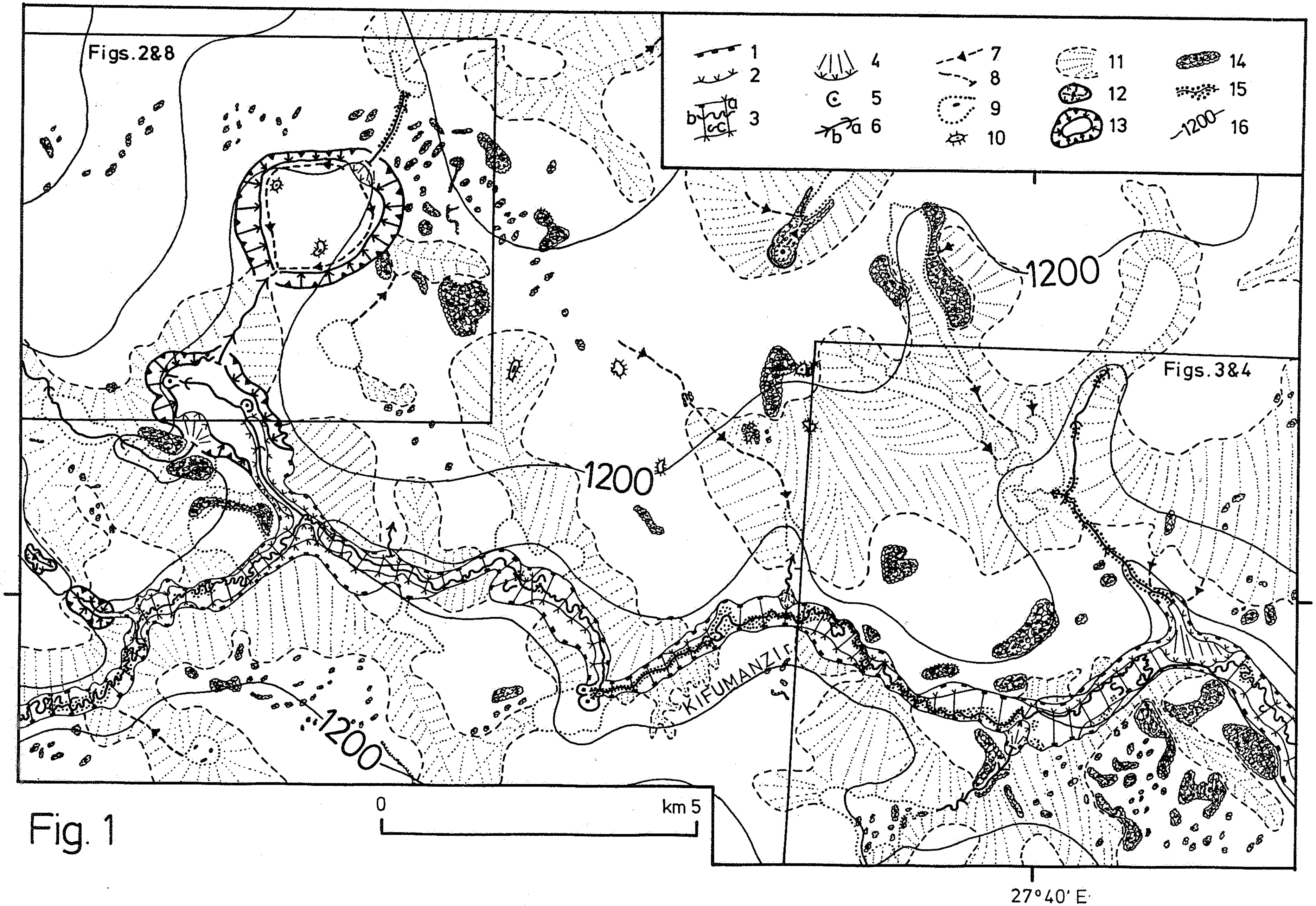
Figs. 2&8
Figs. 3&4
1
2
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KIFUMANZI
11°20'S
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0
km 5

Fig. 1

Figure 1. Morphographic map of the Upper Kifumanzi testarea. Based on conventional panchromatic B&W aerial pictures on scale 1/40.000 (May 1954). The location of figures 2 & 8 and 3 & 4 is indicated.

Legend :

1. break of slope at topconvexity
2. base concavity
3. valley flat-bottom : a. floodplain width
   b. riverchannel
   c. abandonned meander (oxbow)
4. alluvial fan
5. spring amphitheater
6. valley side tributary with : a. arch-like cross-section
   b. wing-like cross-section
7. shallow channel on interfluve
8. vanishment of channel
9. dambo, eventually with pan(s)
10. pan, eventually with central depression
11. wash zone
12. isolated low hill
13. dolina
14. dense dry forest (muhulu)
15. riparian dense forest (mushitu)
16. contour line; contour interval : 25 meters.

the Roan and the Kundelungu formations (BEUGNIES, 1950; LEPERSONNE, 1974). Part of these deposits have been mineralized (copper, cobalt, zinc); they have been mined in numerous small excavations (f.i. Kinsevere in the testarea) and are actually extracted at the important underground mine of Kipushi. The testarea is situated in the eastward reach of the folded Katanga arc, wherein the stratigraphic units are arranged in a suite of parallel anticlines and synclines. The flanks of the anticlines are mainly composed of sandstone, conglomerate or quartzite and support some inselbergs (SOYER and KAKISINGI, 1981); only one such inselberg, small but well isolated, is present at the western boundary of the testarea (fig. 1).

The Roan formation, largely composed of limestones, dolomites and dolomitized rocks, occasionally crops out in the cores of the anticlines. This is the case in the western part of the testarea and gives rise to three well developed dolinas (fig. 1 and 2).

The macroclimate of the Lubumbashi region is characterized by a wet season (November to March), a dry season (May to September) and two transitory months (October and April). The mean annual precipitation amounts to about 1,270mm (MALAISSE *et al.*, 1978), although there is a considerable annual variability (extreme values of 717 and 1770 mm, according to LOOTENS and KISHIMBI (1986)).Thus the aerial pictures and the satellite image were taken at the onset of the dry season. The mean annual temperature is ca. 29°C; the coolest month is July (15,6°C), the warmest month is October (23°C).

Well documented data on the vegetation are available for the Luiswishi experimental station, located at 18 km to the S of the testarea (MALAISSE, 1978). The overruling vegetation formation is the miombo, an open dry forest dominated by Brachystegia - Jubelnardia - Isoberlinia. According to MALAISSE (1978), the miombo is a degeneration phase of the muhulu, a dense dry forest that forms the climax vegetation formation. Numerous small islands of muhulu still remain in the miombo (fig. 1). The miombo itself is degraded, mainly by direct human influence, into a wooded savanna. Large termite mounds (8 m high; 14-15 m basal diameter) occur throughout the basin, 3 to 5 mounds per ha (SYS, 1961).

The testarea shows the typical geomorphological buildup of the region (fig. 1, 2, 3 and 4) (DE DAPPER, 1981). The Kifumanzi river flows in a flat-bottom valley. The channel, eventually lined by riparian dense forest (mushitu) developed on its banks, meanders in a broad floodplain covered by marshland with Phragmites mauritianus; some abandoned meander loops subsist. The valley sides are only a few meters high and are sharply limited by a break of slope, often sustained by a ferricrete layer, at the top convexity. The valley side tributaries are cut in the very gently sloping interfluve and show arch-like or wing-like cross-sections.

In some cases they are fed by springs that develop amphitheaters. They form well developed alluvial fans where debouching into the main valley. On the interfluves denudation overrules incision. The headward extension of the tributaries is formed by shallow hardly incised channels and in many cases by

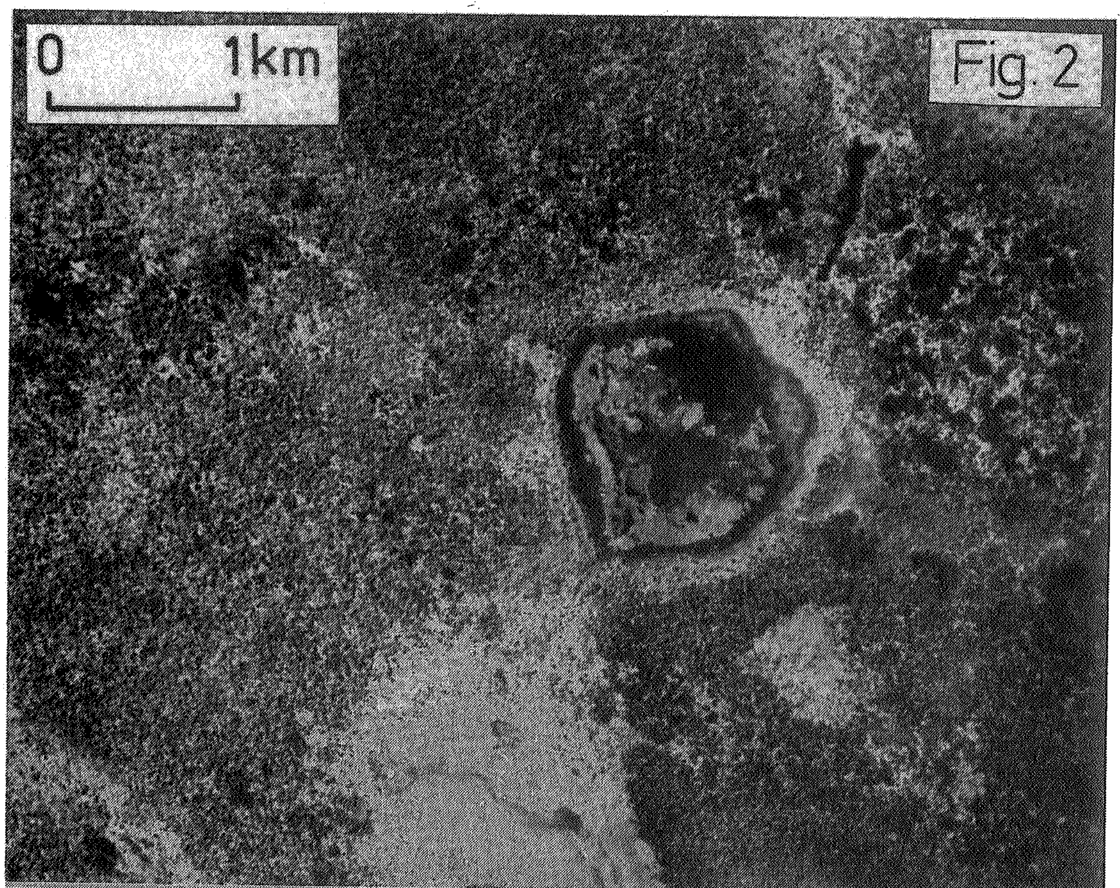

Fig. 2

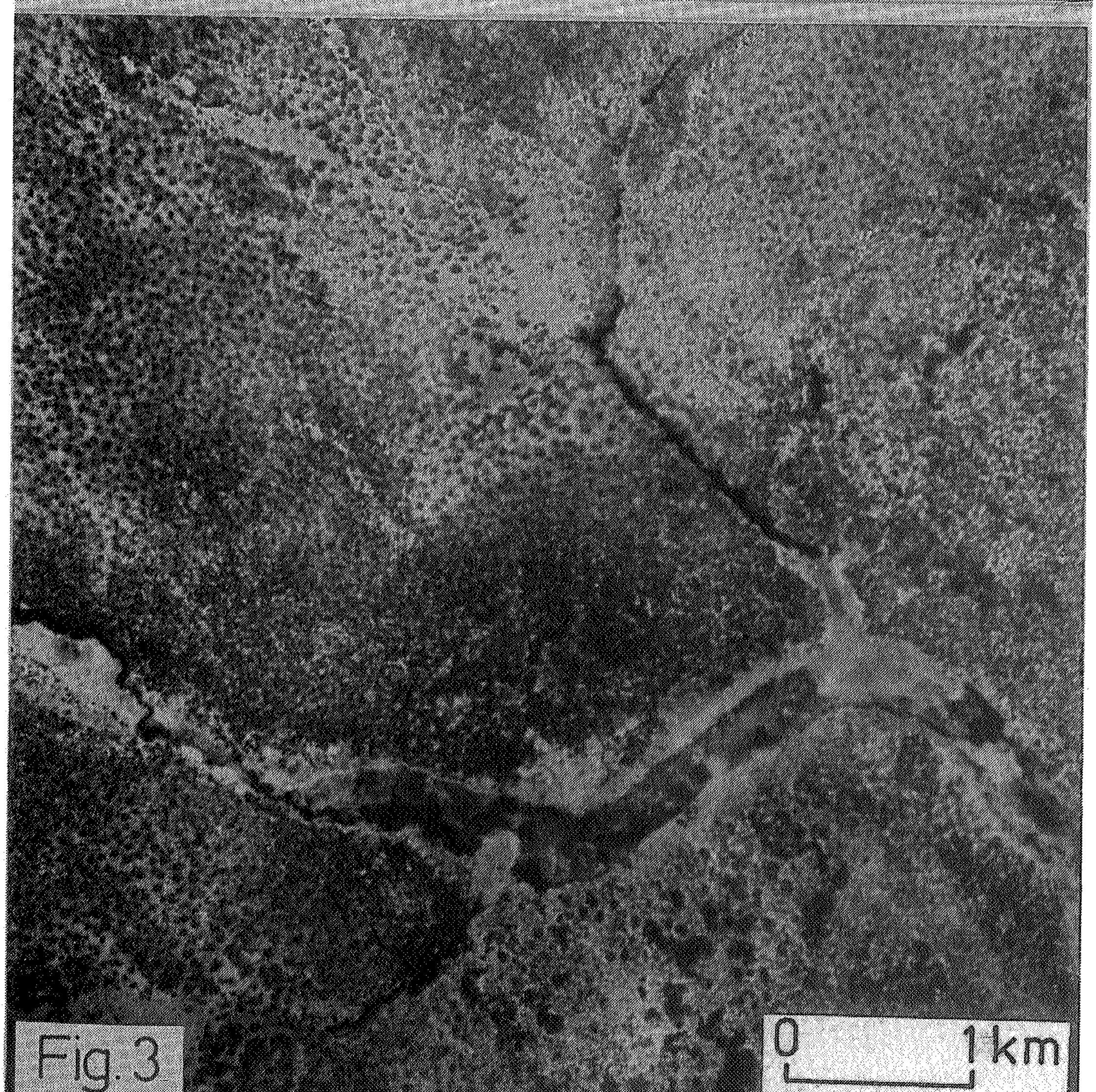

Fig. 3

Figure 2. Extract of B&W aerial picture E'ville 2630 (1/40.000. 19 May 1954). The location is indicated on the morphographic map (Figure 1, northwestern part). The central part of the photo shows a dolina developed on carbonatic rocks of the Roan formation.

Figure 3. Extract of B&W aerial picture E'ville 2534 (1/40.000. 13 May 1954). The location is indicated on the morphographic map (Figure 1, southeastern part). The photo shows part of the Kifumanzi flat-bottom valley, valley side tributaries with alluvial fans at the mouth and dambos and wash zones on the interfluves.

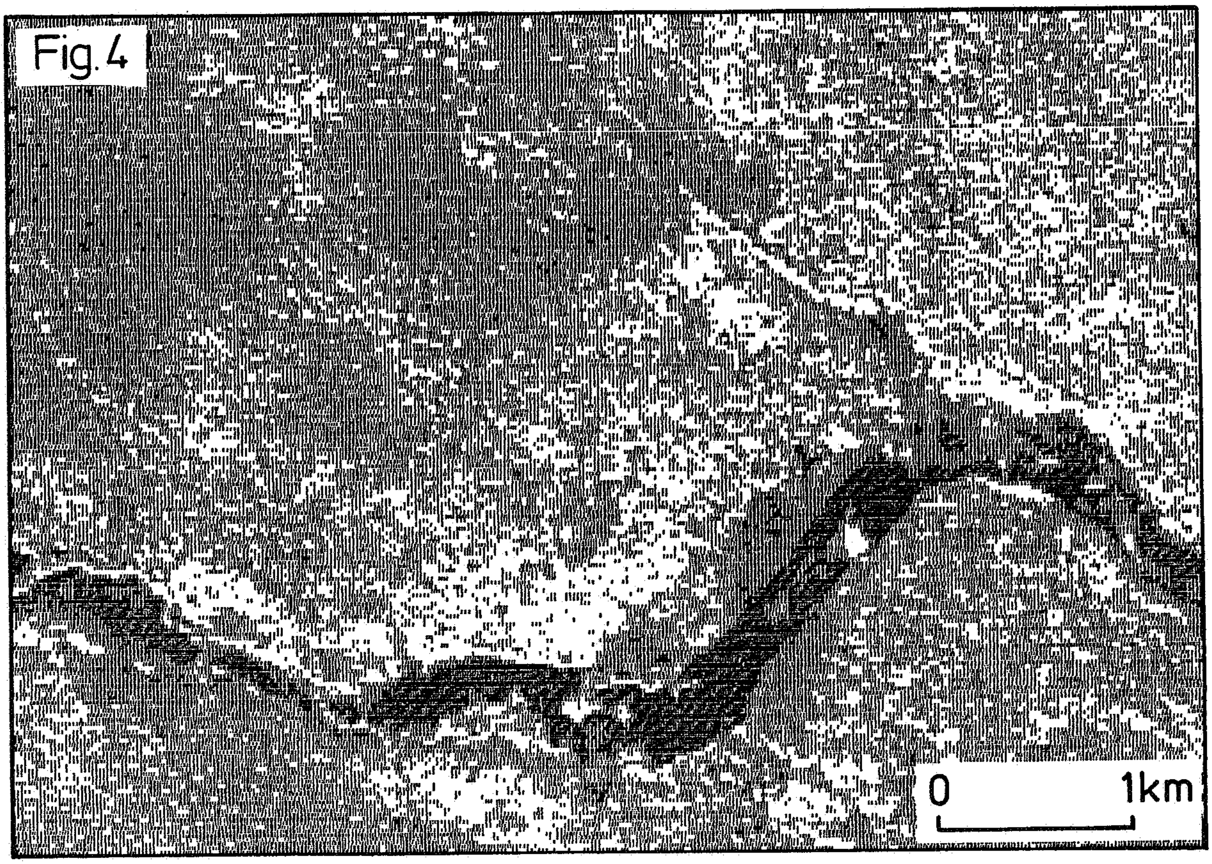

Figure 4. B&W outprint of part of the digital SPOT image, indicating biomass indices. The location is indicated on the morphographic map (Figure 1, southeastern part; see also figure 3) (Copright SPOT, CNES, DPWB)

typical headwater dambos : shallow broad channelless depressions covered by a grass vegetation with typha (THOMAS and GOUDIE, 1985; LOOTENS and KISHIMBI, 1986). In some cases river dambos are developed directly on the sides of the main valley. Some small closed pans are developed in the dambos. or close to them. Large wash zones are developed on the interfluves; they extend mainly around the dambos but can also connect directly with the main valley. In the wash zones the miombo is degraded and sheet- and rill erosion predominate.

3. TREATMENT AND RESULTS OF THE SPOT-DATA

3.1. DIGITAL TREATMENT

The SPOT satellite digital image is treated on an IBM PC/AT using IBM-PCIPS and own developed software. Different image processing methods are used.

a. LAI (Leaf Area Index)

The LAI expresses a ratio between the infrared and red bands (RICHARDSON and WIEGAND, 1977) and gives an indication of the photosynthetically active vegetation density. In the case of a SPOT multispectral image.

$$LAI = \frac{\text{Pixel intensity (PI) of band 3}}{\text{Pixel intensity (PI) of band 2}}$$

Band 2 is mostly influenced by the reflection of bare soil, whereas on band 3 the reflection of IR-light by 'green' plants is predominant. High LAI values thus express high vegetation densities. As on gently sloping terrain vegetation density is a good measure for denudational erosion, LAI is an important datum for the present study.

b. Biomass

The biomass index is expressed by the ratio :

$$Biomass = \frac{PI\ 3 + PI\ 2}{PI\ 3 - PI\ 2}$$

(RICHARDSON & WIEGAND,1977)

It is a refinement of the LAI and includes a (theoretical) correction for the background scattering of the bare soil, which is quite important for band 2.

c. Boxclassification

A boxclassification is a supervised classification (CURRAN, 1985). Small homogeneous areas, for which the groundtruth is precisely stated, are classified and isolated on the image display. For each band, minimum and maximum pixel intensity values are subsequently calculated for each class.

In this way boxes, around different classes, considered to cover a homogeneous groundtruth, are constructed in a 3D-features space (fig. 5). Pixel intensity values included in a same box are classified and considered to represent the same groundtruth. Pixel intensity values which are not included in any box are considered as non-classified. It is possible that two ore more boxes overlap each other. Pixel intensity values which are located in an overlapping zone are considered to have the features of each composing box. Those pixel intensity values belong to a confusion zone. Once the image is classified, following data are calculated : number of pixels for each class, number of non-classified pixels, number of pixels in the confusion zone, area for each class.

Fig. 5

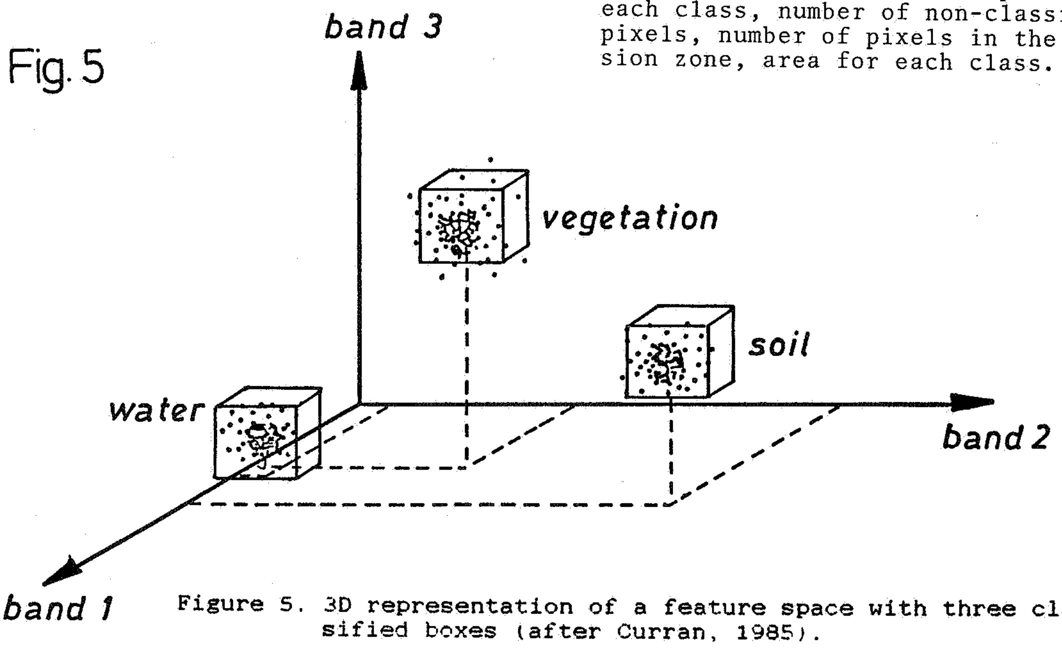

Figure 5. 3D representation of a feature space with three classified boxes (after Curran, 1985).

d. Mask techniques

Mask techniques are applied to enhance the image contrast of specific zones. On the displayed pixel intensity values, a zone of pixels between a minimum and a maximum value is chosen (fig. 6). Pixels outside this values are masked and appear with a black tonality, allowing to emphasize the not-masked zone.

e. Image stretching

This method allows to raise the contrast in the image display. In this case the linear stretch method is used. A whole histogram or a part of it is stretched over the available colours (fig. 7).

3.2. IMAGE INTERPRETATION AND DISCUSSION

a. Detection of vegetation density

To assess the vegetation density, the LAI and biomass methods are applied. The best results are obtained with the biomass method. The floodplain of the Kifumanzi, holds the photosynthetically most active vegetation. Miombo-muhulu and mushitu are grouped in one class. They can only be separated by their specific geomorphological position in the landscape; miombo-muhulu shows a dotted pattern and is present on the interfluves; whereas mushitu shows an elongated pattern lining river channels. The interfluves are characterized by a medium dense vegetation cover. Zones wit sparse vegetation are located on the valley sides of the main river, around dambos and in wash zones. Alluvial fans, which represent highly morphodynamic environments, are also characterized by low biomass indices.

The boxclassification method combined with a mask technique allows to distinguish following classes in the northwestern part of the testarea (fig. 1 and 2, tab. 1) :

1. non classified
2. miombo
3. wash zone
4. wet soils in dolina bottom
5. confusion zone : zones endangered by denudational erosion
6. muhulu and mushitu (by mask technique)
7. confusion zone : non identified.

Table 1. Boxclassification for vegetation density types in the northwestern part of the testarea (Figures 1 and 2).

CLASS	BOX LIMITS B1	B2	B3	n° PIXELS	PERCENT	SURFACE (ha)
1				3344	5.26	133.76
2	27-31	18-24	38-51	51418	80.34	2056.72
3	29-38	23-30	47-62	3098	4.84	123.92
4	28-32	20-24	30-39	1361	2.13	54.44
5	29-32	23-24	47-51	1786	2.79	71.44
6		16-19		1819	2.84	72.76
7				1174	1.83	46.96
sum				64000	100.00	2560.00

Classified : 92.94%
Non-classified : 5.26%
Confusion : 1.83%

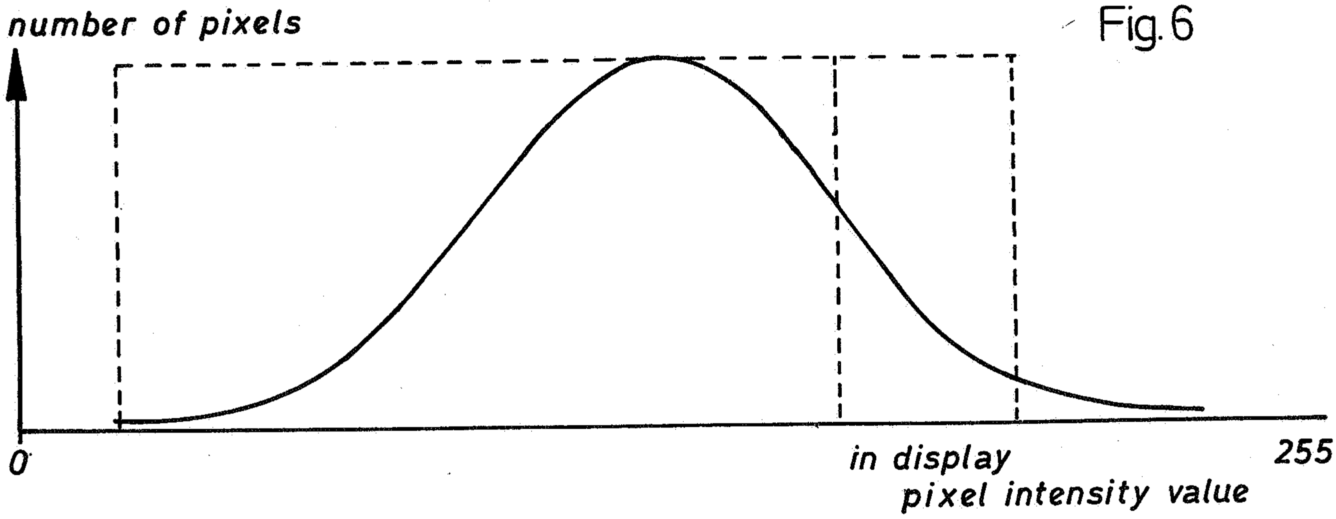

Figure 6. Mask technique : only a part of the pixel intensity values is put in display.

Class 5 represents a confusion zone of the boxes 'miombo' and 'wash zone'. On the ground it coincides with areas marginal to the wash zones and spreading into the miombo. Also from the spectral point of view, class 5 holds the middle between miombo and wash zones. In this way it is possible to detect those transitional, endangered zones in an early stage. In this case respectively nearly 5% and 3% of the investigated area is dominated or endangered by denudational erosion.
Class 6 is extracted from band 2 by using a mask technique between pixel intensity values 16 and 19. This mask was superimposed on the image of the boxclassification.

b. Detection of superficial hydrogeological conditions

A mask technique and a linear stretch method, allows to make an assessment of soil drainage conditions in the bottom of a dolina in the northwestern part of the testarea (fig. 1, 2 and 8). the flat dolina-bottom shows a pronounced microrelief that gives rise to outspoken differences in soil drainage.

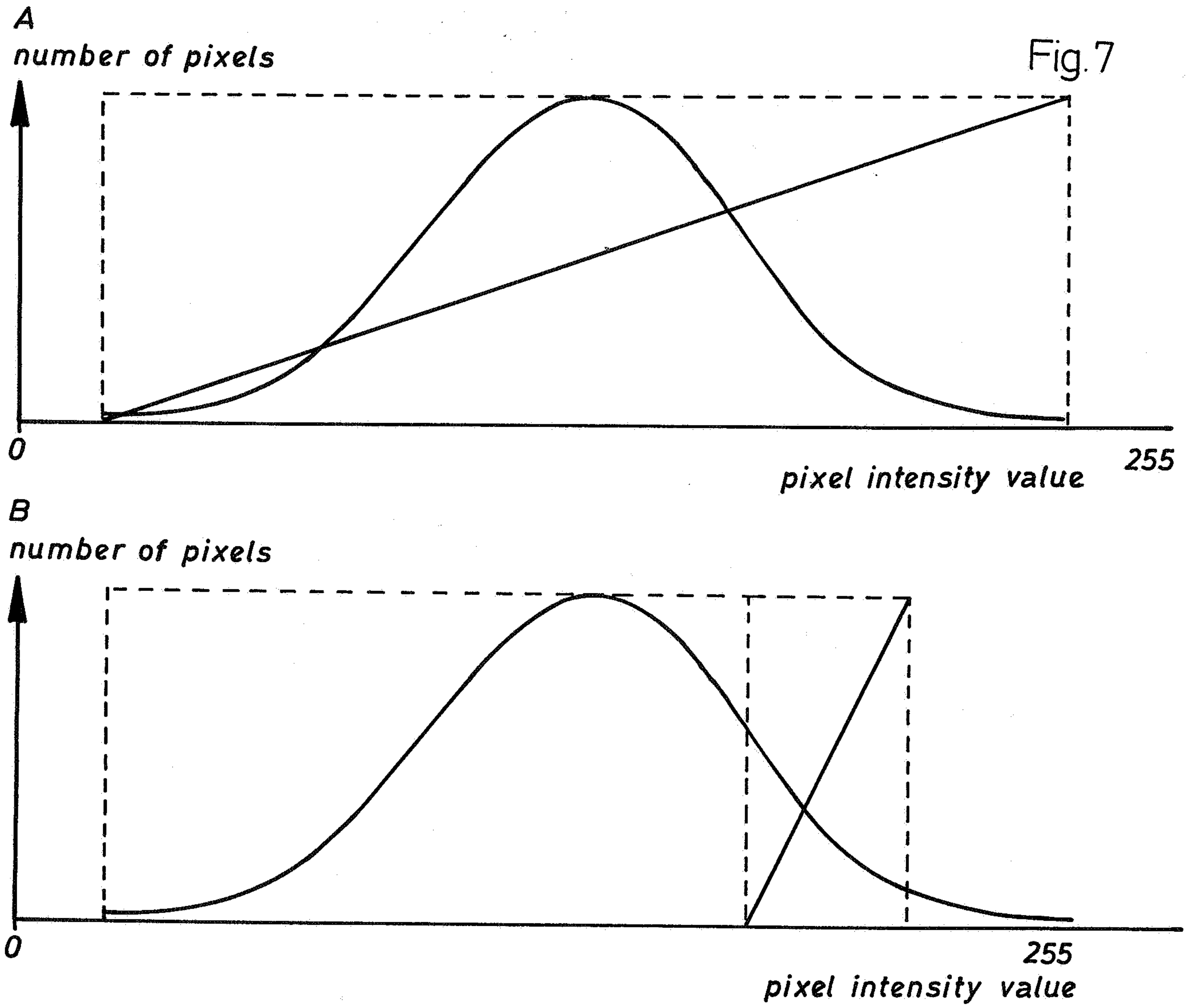

Figure 7. Linear image stretching : a whole histogram (A) of the pixel intensity values is stretched or only a part (B) of it.

The mask technique allows to extract the wet soils, included in the pixel intensity values interval 31-39, from the IR-band. According to KRINOV (1947), bare soils are more absorbing and less reflecting, the higher their moisture content is (fig. 9). A linear stretch subsequently applied on the same pixel intensity value interval leads to a maximal contrast on minimal spectral reflection differences.

Figure 8 shows the results of the linear stretch applied on the dolina bottom. On the northern side an alluvial fan is developed. Channel water entering the fan, seeps at the lower edge and gives there rise to very poorly drained soils. The higher parts of the dolina bottom, colonized by grasses and low shrub, represent well drained soils. Whereas the rest of the bottom soils are poorly drained.

4. CONCLUSIONS

Digital SPOT image processing, combined with conventional panchromatic B&W airphoto interpretation and field observations, is an efficient method to survey and map geomorphological phenomena, land degradation and soil drainage conditions in a remote wet-and-dry tropical environment. B&W airphoto allow for stereoscopical vision (and thus replace the rare and very expensive stereoscopical SPOT data), whereas SPOT-images provide wider spectral information and a more comprehensive overview.

If applied in a multitemporal sequence, the method used permits to survey the evolution of vast areas endangered by denudational erosion. Those zones spread out from established wash zones and profilerate to the detriment of the miombo; their progress is a measure for the savanisation, an important land degradation process in the miombo environment.

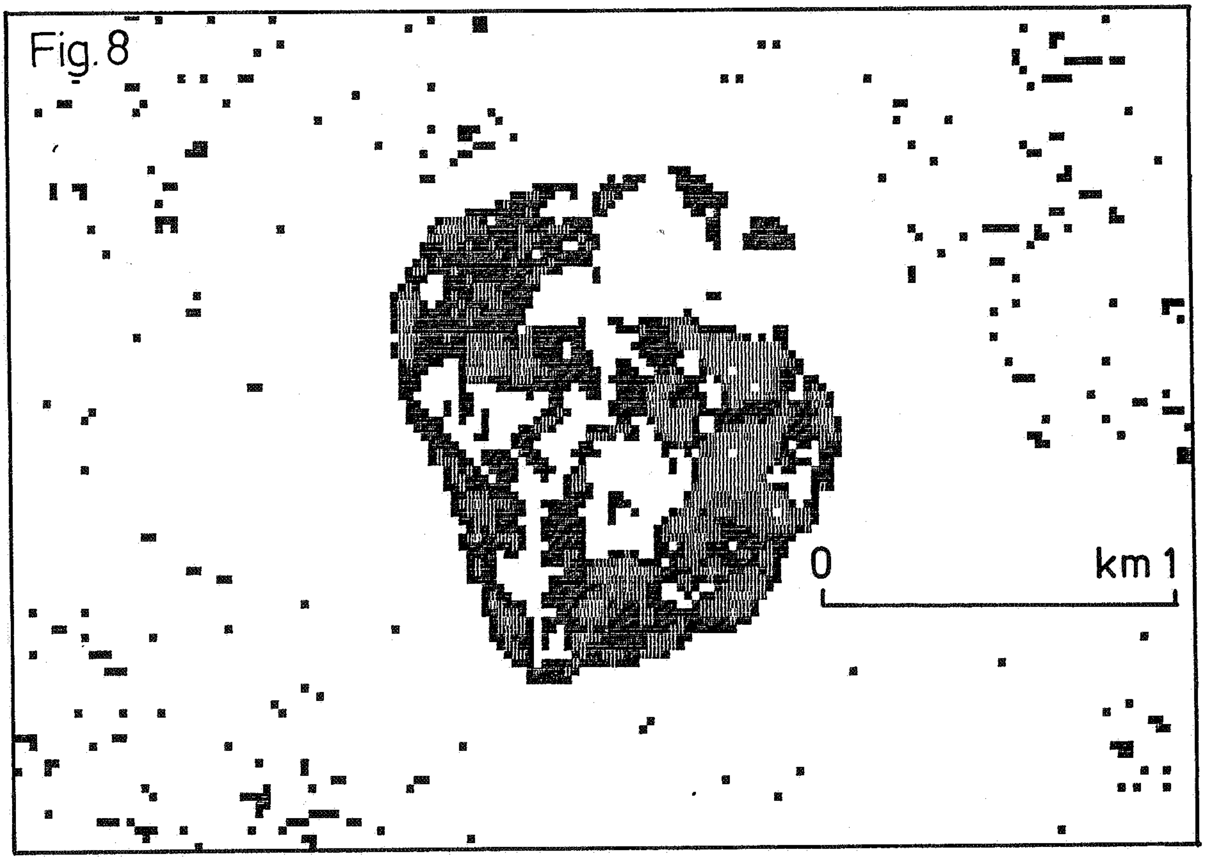

Figure 8. B&W outprint of part of the digital SPOT image, indicating soil drainage conditions. The location is indicated on the morphographic map (figure 1, north-western part; see also figure 2) (Copyright SPOT, CNES, DPWB).
Legend :
- light gray : seepage zones
- dark gray & black : poorly drained soils
- white : well drained soils.

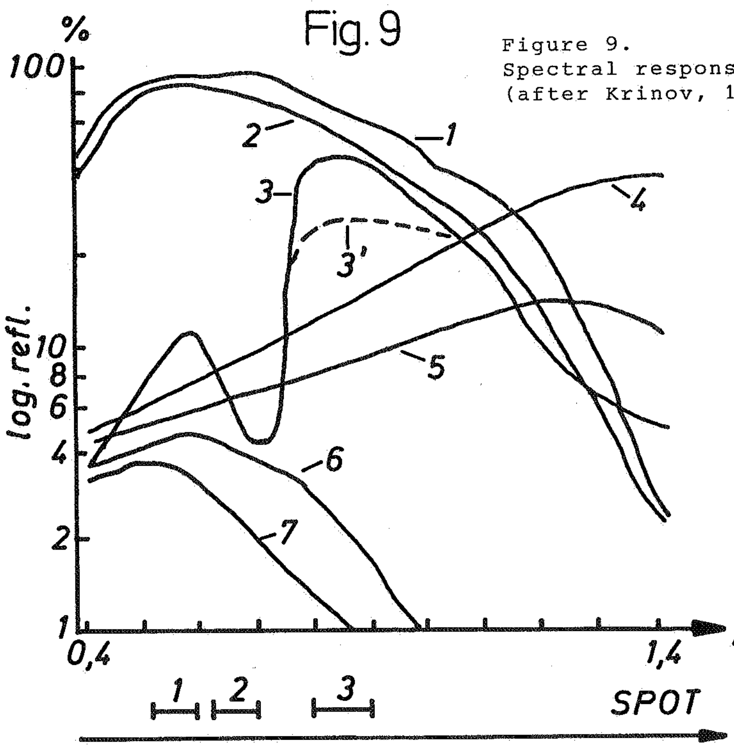

Figure 9.
Spectral response for different landscape elements (after Krinov, 1947 and Townshend, 1981).

Legend :
1. fresh snow
2. firn and ice
3. vegetation
3'. pinetrees
4. dry soil
5. wet soil
6. water with suspended load
7. clear water

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