NO. 34

REPORT ON THE LANDSAT ANALYSIS, THE FOREST RESOURCES INVENTORY IN THE NORTH-EASTERN REGION, THE REPUBLIC OF PARAGUAY

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JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A)

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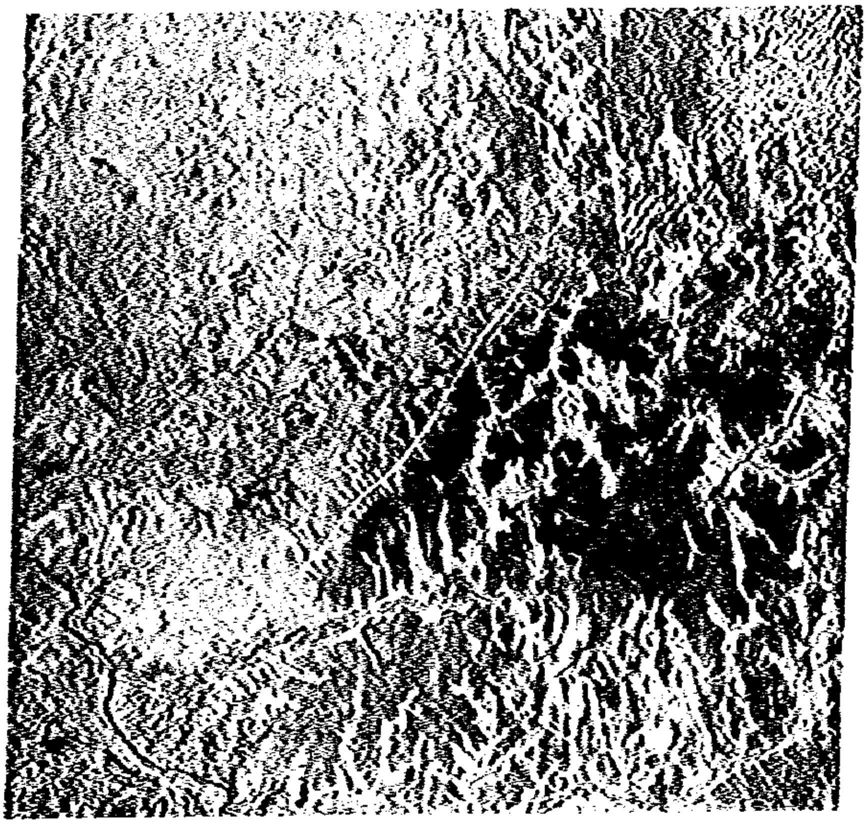
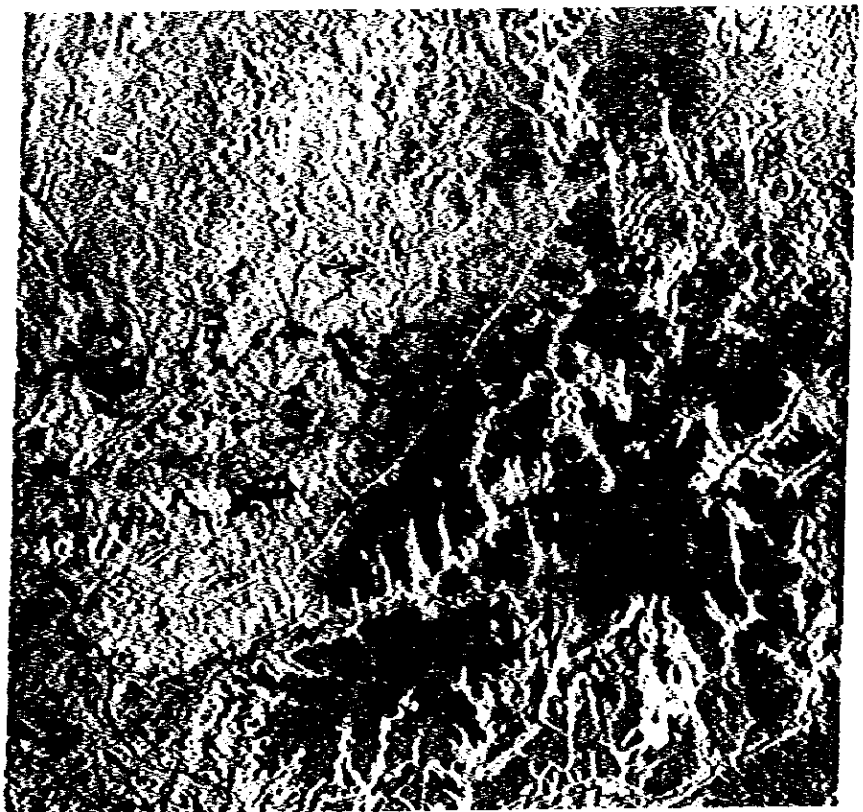
ランドサット衛星によるパラグアイ東北部
Landsat Images in the North-Easten study area of Paraguay

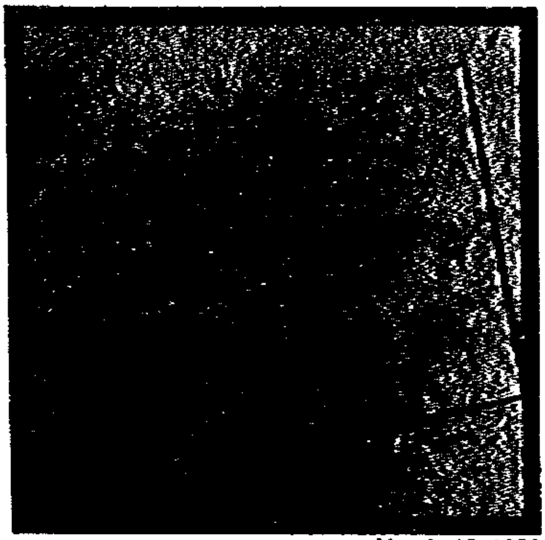


◀赤外カラー合成写真
False color composite print
(Infrared)

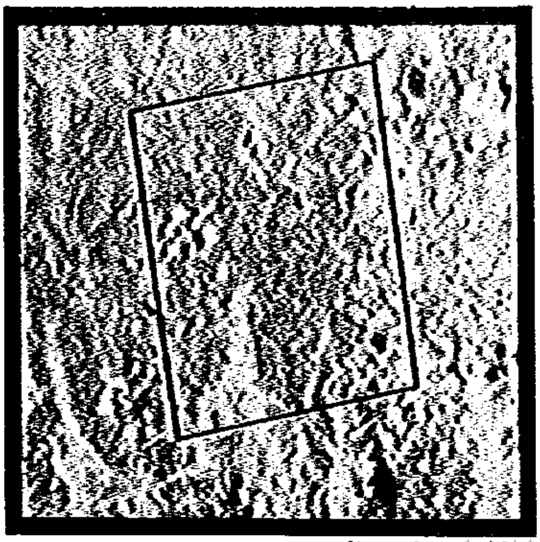


◀天然カラー合成写真
False color composite print
(Natural)

03 Nov. 1975 ID Number:8228513006500

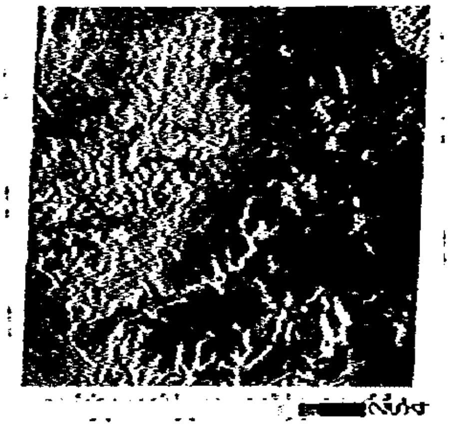


March 15, 1973

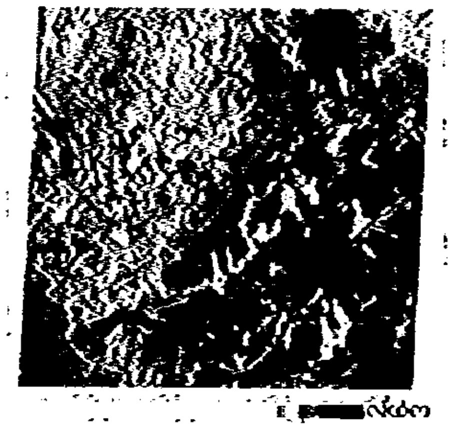


November 3, 1975

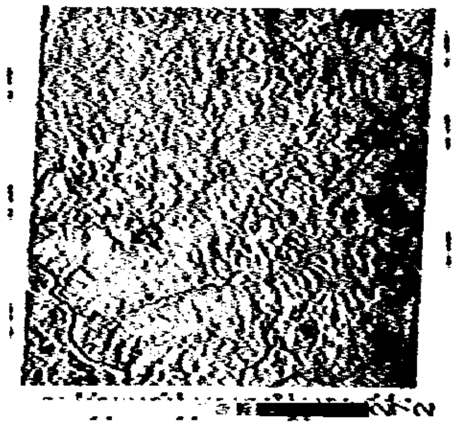
▲経年変化分析に使われたランドサット衛星によるカラー合成写真
Color composite prints used for measuring deforested area



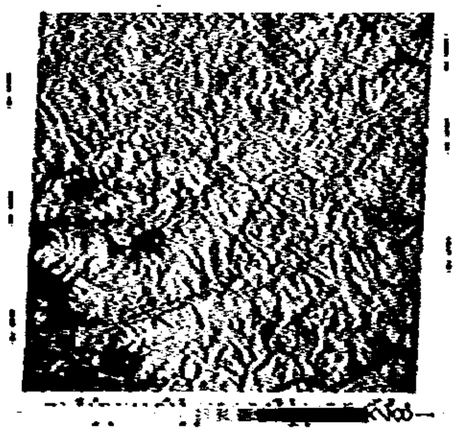
Band 4 (Green)



Band 5 (Red)



Band 6 (Infrared)



Band 7 (Infrared)

▲パラグアイ東北部のランドサット衛星による各MSSバンド
The images of Landsat spectral bands for the MSS

PREFACE

In response to the request of the Government of Paraguay, the Japanese Government decided to conduct Forestry Inventory and entrusted the inventory to Japan International Cooperation Agency (J.I.C.A.).

The J.I.C.A. sent to Paraguay an inventory team from July, 1980 to January, 1981. The team also analyzed the data provided by LANDSAT and the present report has been prepared.

I hope that this report will serve for the development of forestry in Paraguay and contribute to the promotion of friendly relations between our two countries.

March, 1981

Katsura WATANABE

Director,
Forestry and Fisheries
Development Cooperation Dept.
Japan International Cooperation Agency

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1. INTRODUCTION

It is reported that the available forest is mostly centered in the east of Paraguay. The FAO performed a forest inventory in the South-Eastern region during the period 1967-71. Subsequently, the National Forest Service of Paraguay requested an updated inventory for the North-Eastern region, covering about 50,000 sq. km. (Figure 1).

An inventory providing detailed forest measurements and observations is needed for efficient forest management. Such an inventory is usually performed by aquiring aerial photographs, interpreting forest stand condition maps, taking forest samples on the ground, and computing timber volumes. This complex operation is usually very time-consuming.

However, this study area is so particular, so that these forest are very quickly lost for the "Peroba War", which means the competitions for logging timbers of Peroba. Because Peroba's timber is in great demand by Brazil, and the forest have almost Peroba species, sometimes 100 percent of tall trees. Therefore, the extracting and logging timber can be done with low prices. It is reported that there are still many Peroba trees in this area, especially the northern area. However, when we investigated this northern area close to Pedro Juan Caballero city in 1980, it was very difficult to find virgin forests. Because of the huge flat ground, there is nothing about obstacles to extracting and logging timbers. Therefore, they can easily make a boundary line more or less 5 sq. km first, and can clearly cut and burn everything during 2 or 3 years. Therefore, not even re-generated forest can be expected.

The use of satellite multispectral scanner imagery provides a new and unique way of surveying forest resources for an area as large as the North-Eastern region of Paraguay. Even though a satellite survey cannot provide the detailed information available in a conventional inventory, it can provide a synoptic view of large land areas in a very short time and at a reasonable cost.

We obtained the data used in this study area as follows;

i) Landsat data

a. 82100412290x0- 22 Oct. 77 imagery
b. 82100412292x0- 22 Oct. 77 imagery
c. 82091312285x0- 23 Jul. 77 imagery
d. 8235813054500- 15 Jan. 76 imagery
e. 8212313015500- 26 May 75 imagery
f. 8228513005500- 03 Nov. 75 imagery and digital data
g. 8123513144500- 15 Mar. 73 imagery
h. 8123513151500- 15 Mar. 73 imagery
i. 8105413075500- 15 Sep. 72 imagery and digital data

ii) Aerial photographs

a. black and white, scale 1: 60,000, 1968
b. black and white, scale 1: 20,000, 1980

2. OBJECTIVE

- make a forest type and land use map of the study area by computer analysis using Landsat digital data; November 3, 1975 and September 15, 1972.
- measure deforested areas in part of the North-Eastern region of Paraguay using aerial photographs, taken in 1968 and 1980.

3. THE LANDSAT SYSTEM

This satellite moves in an almost perfectly circular orbit at an altitude of 917 km inclined at 81° relative to a plane passing through the Earth's Equator. This near polar orbit is also Sun synchronous, crossing the Equator on the day side of Earth 14 times every day at approximately 9:30 a.m. local time in each transit. Each successive orbit shifts westward about 2,872 km at the Equator. On the following day, the next 14 orbits parallel those of the previous day, but each

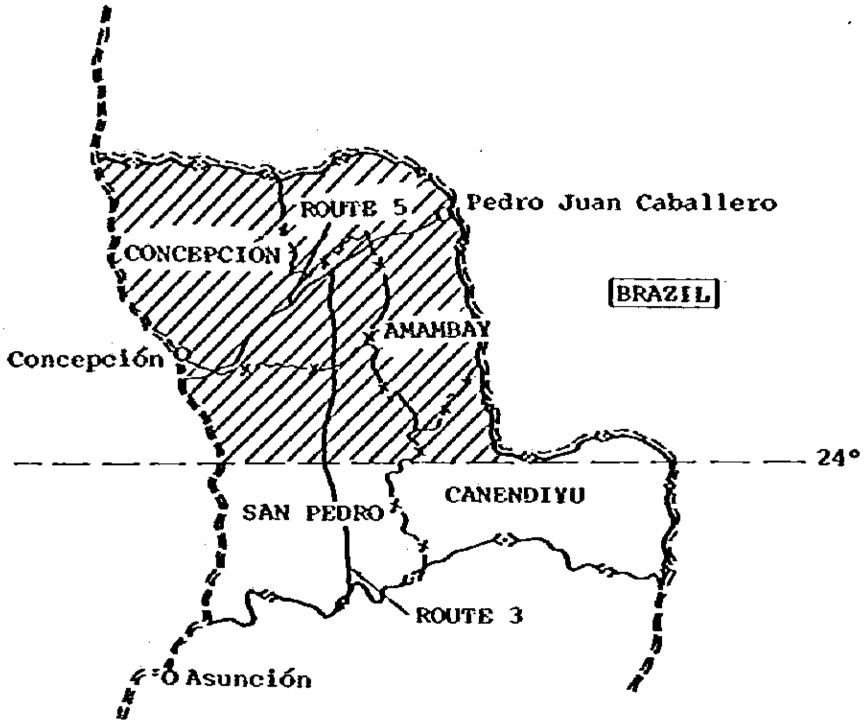


Figure-1. Study Area

one is offset westward by about 159 km. Images obtained for any two adjacent orbits show about 15 percent sidelap at the Equator; this sidelap increases to about 85 percent near the poles. All parts of the Earth are imaged during the succession of shifted orbits in a circule lasting 18 days. Thus, in principle, any area can be imaged every 18 days. In addition, because Landsat II and III are now in operation, any area can be imaged every 9 days. However, in practice, cloud cover usually reduces the coverage to some simple multiple of 9, which depends on the geographic location and time of year.

Two imaging sensor systems operate on the Landsats. One, a television camera system referred to by the acronym RBV (for return beam vidicon), was shut down in the Landsat I and II operation, but available on the Landsat III. The second is a multispectral scanner (MSS), which produces a continuous image strip built up from successive scan lines extended perpendicular to the forward direction of the satellite's orbital motion. Reflected light from the ground is transfered by an osillating mirror in the MSS to a recording system after passing through filters that select different wavelength intervals of this light. Each of the four wavelength channels processes a predetermined spectral interval or band (the bands of the MSS are numbered 4, 5, 6, and 7 simply to avoid confusion with the three RBV bands, which are numbered 1, 2, and 3) according to the following arrangement;

MSS band no.	Wavelength, μm	Spectral region
4	0.5 to 0.6	Green
5	0.6 to 0.7	Red
6	0.7 to 0.8	Near infrared
7	0.8 to 1.1	Near infrared

ORBIT

The Landsat I spacecraft was launched on July 23, 1972, Landsat II on January 22, 1975, and Landsat III on March 5, 1978, but, Landsat I's operation ended January 6, 1978. They were positioned in the orbit shown in Figure 2.

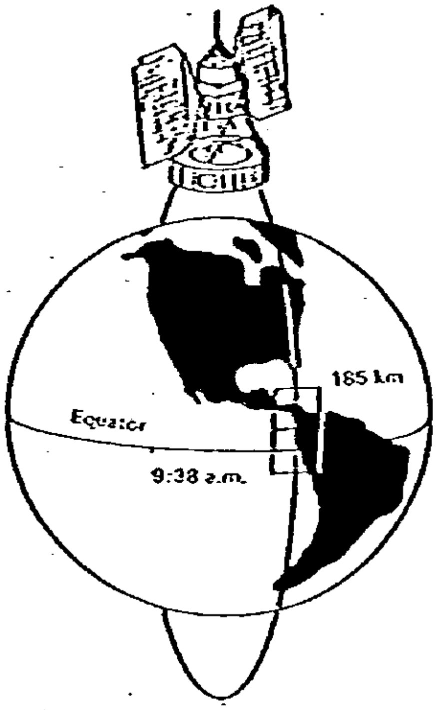


Figure-2. Landsat orbit

They have a nominal altitude of 917 km, and Sun-syncronous orbits, which means that the orbit plane processes about the Earth at the same angular rate that the Earth moves about the Sun. This feature enables the spacecraft to cross the Equator at the same local time (about 9:30 to 10:00 a.m.) on the sun-lit side of the Earth. The multispectral scanner views an area 185 km on a side. From one orbit to the next, the satellite point moves 2,872 km at the Equator as the Earth rotates beneath the spacecraft. The next day, 14 orbits later, it is approximately back to its original location, with orbit 15 displaced westward from orbit 1 by 159 km at the Equator. This continues for 18 days after which orbit 252 falls directly over orbit 1. In addition, because two satellites are operating, we can have a chance of obtaining the same scene every 9 days.

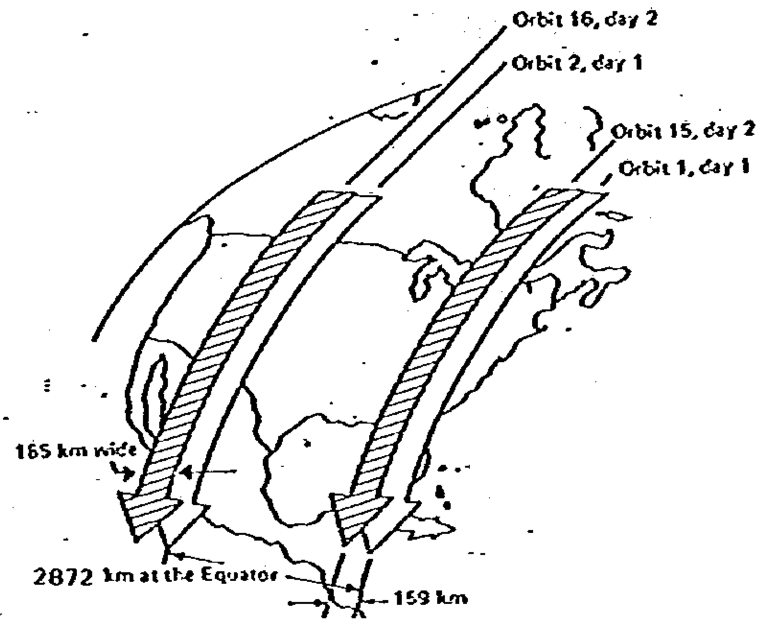


Figure-3. Landsat ground coverage pattern

As indicated in Figure 3, there is a sidelap of 26 km in coverage at the Equator from the adjacent orbits on consecutive days. It is important to note that this sidelap increases with inceasing latitude, to approximately 57 percent at 60°. Thus, at high latitudes, sidelap coverage is obtained on consecutive days over a large portion of an image. Sidelap coverage is essential for stereoscopic or three-dimensional viewing; it also permits the monitoring of changes that occur over the 1-day period. It should be noted, however, that as the area of sidelap increases with latitude, the stereo-viewing angle decreases.

PAYLOAD

The sensors are mounted on the bottom of the spacecraft. The RBV system of the Landsat II consists of three dimensional television-type cameras, each covering a different spectral region; images are obtained on a frame-by-frame basis. The spectral characteristics of the RBV system are shown in Table 1. Landsat III's two cameras, however, take the same spectral region.

	Wavelength (μm)	Resolution	Image format
Return beam vidicon cameras (RBV)			
Landsat-1 and-2 three RBVs:			Simultaneous view from 3 cameras of scene
Band 1	0.475-0.575 (blue-green)		185 x 185 km
Band 2	0.580-0.680 (yellow-red)	80m	14% sidelap at Equator
Band 3	0.690-0.830 (red - IR)		10% forward lap
Landsat-3, two RBVs	0.505-0.750 (panchromatic)	40m	2 side-by-side images 98 x 98 km (4 RBV images coincide nearly with one MSS frame)
Multispectral Scanner			
Landsat-1,-2,-3			
Band 4	0.50-0.60 (green)		185-km strip image framed
Band 5	0.60-0.70 (red)		with 10% forward lap
Band 6	0.70-0.80 (near	80m	14% sidelap at Equator,
Band 7	0.80-1.1 infrared)		increasing toward poles
Landsat-3 only:			
Band 8	10.4-12.6 (thermal IR)	240m	

Table-1. Summary of Landsat Payload System

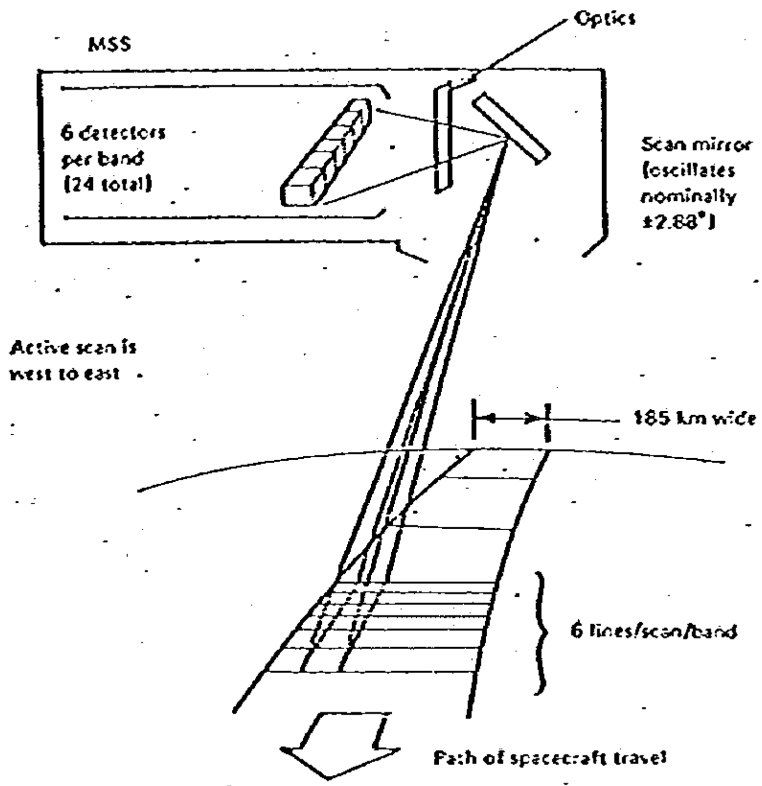


Figure-4. MSS orientation

Figure 4 depicts both the concept of the MSS multidetector array and the scanning system. The scanning mirror oscillates through an angular displacement of ±2.89°. Because the angle of incidence is equal to the angle of reflection, the scanned beam is approximately 11° wide. Six parallel detectors in each of the four bands view the ground simultaneously. The instantaneous field of view on the ground for each detector is 79 m sq. Thus, each mirror scan covers an along-track distance of approximately 480 m on the ground. The ground resolution is effectively about 80 m. However, the ability to distinguish adjacent objects depends greatly on their contrast. In fact, bridges over water and dirt roads passing through vegetation are visible to widths of 10 m.

DATA PROCESSING

The digital data for the Landsat can be re-formated into 7- or 9- track computer-compatible tapes (CCT's). Alternatively, the digital data can be re-converted at ground-processing facilities into sets of black and white images representing a particular spectral band; the gray tones associated with individual features vary from one band image to the next in proportion to the amount of light reflected from each small surface area. Color images are made from combinations of individual black and white images by projecting each given band through a particular filter. The usual combination consists of band 4 (green) projected through a blue filter, and 5 (red) projected through a green filter, and band 7 (infrared) projected through a red filter. In this form (call a false color image), which is equivalent to the standard false color infrared product of conventional color infrared photography, growing vegetation will appear in various shades of red, rocks and soils will normally show colors ranging from bluish through yellows and browns, water will stand out blue to black depending on depth and amounts of suspended sediment, and artificial features (towns and roads) will usually be recognized by bluish-black tones arrenged in characteristic patterns. While the other color composite consists of band 4 projected through the blue filter, band 5 projected through the red filter, and band 7 projected through the green filter. This is also the false color composite. It is looks like natural color. (see the head prints.)

These general identifying colors will vary somewhat depending on such intrinsic scene factors as angle of illumination (time of year), vegetational differences (season), and atomospheric conditions, as well as on the processing and printing methods used in a particular lab.

The products produced by this system include 70-mm black and white positive and negative transparencies, 24.1-cm black and white positive transparencies and prints,24.1-cm color composite transparencies and prints. At 24.1-cm size, the image itself is scaled at 1:1,000,000, i.e. 1 cm of the print corresponds to 1,000,000 cm (10 km) on the ground. For this scale, the dimensions of the scene outline are approximately equivalent to a 185 km square. A Landsat scene therefore covers approximately 34,225 sq. km. The effective resolution is about 80 m. Owing to the high altitude of the satellite and narrow field of view (±5.8°), the shapes, dimensions, and relative locations of individual features remain almost constant over the entire image.

4. COMPUTER ANALYSIS FOR THE LANDSAT DATA

One principal use of the Landsat multispectral capability stems from a basic property of materials. Because various classes of features found on the surface reflect differing amounts of light at different wavelengths, they can be separated and identified by their own characteristic reflection patterns, or spectral "signatures". For example, vegetation typically reflects more green light than red and is very reflective (bright) in the infrared. Many dry soils, by contrast, reflects less light in the green than in the red and moderately more so in the infrared; wet soils show similar patterns of relative reflection in the four bands but the magnitude or intensity of light reflected in each band is reduced by the general light-absorbing character of water. (Figure 5)

The light reflection data obtained by the MSS on board Landsat are first converted to electrical signals, which vary in proportion to the intensity measured for each band. These analog signals are then converted into a digital form and transmitted to receiving stations on the ground. This digital video data can be re-formatted into computer-compatible tapes (CCT's) and analyzed by investigators and users through a variety of computer-based programs.

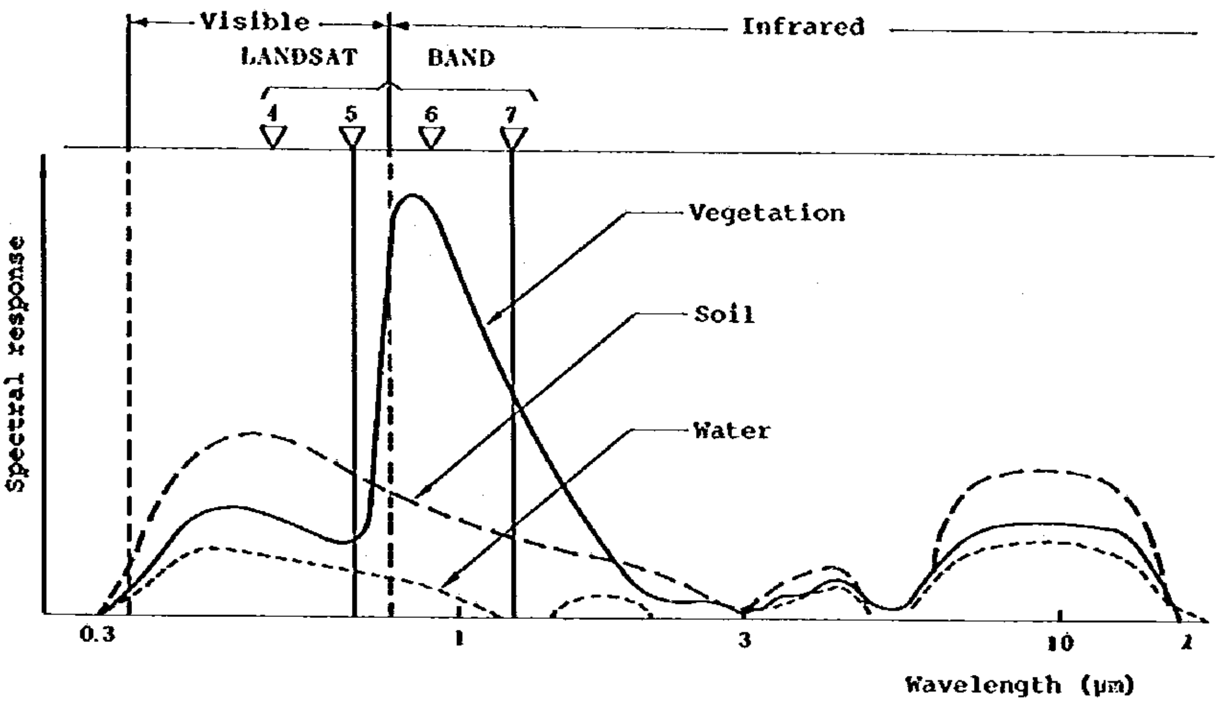


Figure-5. Characteristic reflection patterns, or spectral "signatures"

Recently, the technology for applications of computer-aided analysis of the Landsat data has greatly improved. For example, areas and amounts of crops, timber, and wild habitat can be estimated precisely. In addition, monitoring and forecast of pollution or the probability of disasters can be done at reasonable cost.

Generally, there are two basic methods of classification by computer-aided analysis. One is an unsupervised classification method, which is adopted when the "Ground Truth" is not known. This automatically divides multi-dimensional digital data into some homogeneous cluster. In this statistical method, the computer usually calculates averages and standard deviations of clusters and composes vectors for them. In one case, it may be judged that a cluster is not homogeneous depending on a criterion of an average or a standard deviation that the analysts suggest; the cluster can be separated into two new clusters. In another case, it may be judged that two clusters are similar depending on the criteria, and the two clusters can be combined into one new cluster. These computation is repeated until a final number of clusters is determined, which also depends on human judgement. Then, the result of this analysis can be referred to ground information or some reasonable evidence. Therefore, these criteria usually need to be determined by experienced analysts. By the way, it should be noted that this classification method can be reformed only by differences in multispectral data, but, not relative to man's purposes. On the other hand, a distance of the different multispectral patterns is not always successful in a difference of man's available values.

The other is the supervised classification method,which is adopted when the "Ground Truth" is known;the "Ground Truth" is an area for which we know detailed information of conditions on the ground. If we want to classify some category and we know exactly where it is located, we can input the multi-spectral data corresponding with the locations into a computer that can memorize them and make a multi-dimensional "feature space." The feature space is a space whose axes are composed in response to the categorized spectrum. Any reflection or radiance response of each categorized spectrum can be transformed into a feature space with each substance having its unique vector in the feature space. Figure 6 shows two dimensional feature space as an explanation. For example, vegetation, soil and water are shown as feature vectors A, B, and C respectively in a feature space whose horizontal and vertical axes are respectively composed of the responses for band 5 and band 7 of the categorized Landsat spectrum. If spectral response of a certain object can be obtained, its nature can be inferred. This method may be acceptable as a classification for human utilization. Because many categories obtained by the "Ground Truth" can be selected for human utilization or profit. However, it may sometimes happen that the accuracy is not acceptable for use as a result of this classification, because not all spectra of materials are applicable to human use.

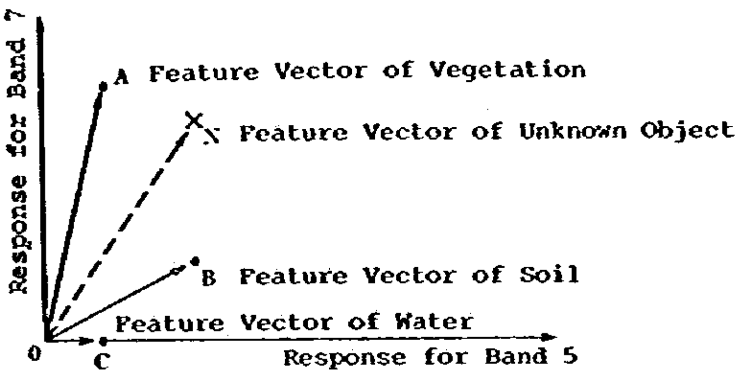


Figure-6. Feature space

5. PROCEDURE FOR PRODUCING A LAND USE MAP

i) THE DATA

We listed up all Landsat data until 1979 with the criterion of less than 30 percent cloud cover, and selected Landsat scene 8228513005500 November 3, 1975. This scene mostly covers the study area except for a small part in the east close to the Brazilian boundary. (Figure 7) Unfortunately, the complementary data was not found simultaneously, it being Landsat I scene 8105413075500 September 15, 1972.

Aerial photographs for the "Ground Truth" were obtained from the Paraguay government's photographs taken in 1968 on a scale of 1 : 60,000 in panchromatic black and white, and JICA (Japan International Cooperation Agency) photographs taken in 1980 on a scale of 1:20,000 in panchromatic black and white.

On the other data, we prepared Paraguay maps on a scale of 1 : 2,000,000 and 1 : 1,000,000, a vegetation map on a scale of 1 : 500,000, and topographic maps on a scale of 1 : 50,000.

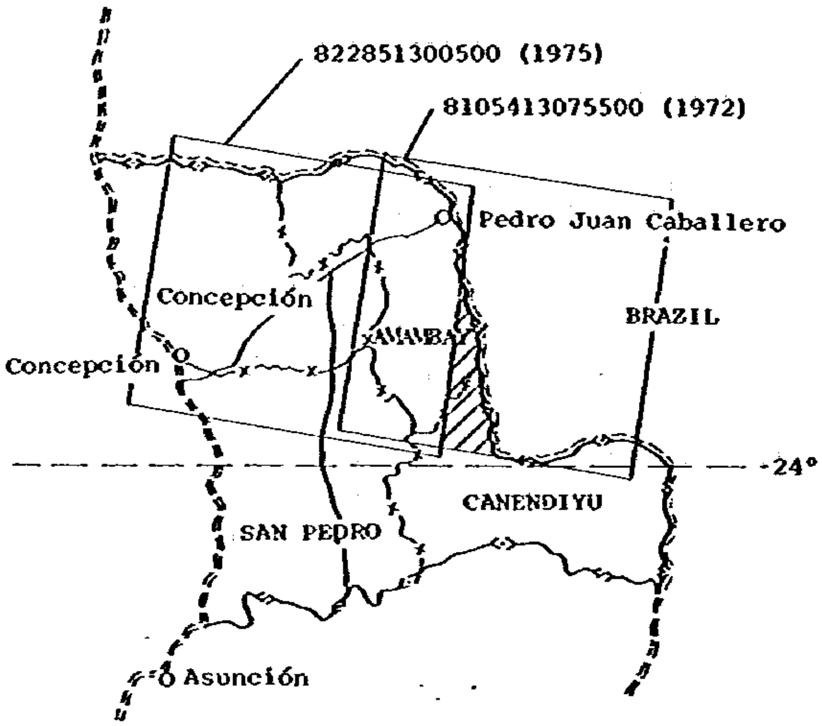


Figure-7. Location of study area and Landsat data

ii) PRE-PROCESSING

The Landsat data normally has some distortion due to fluctuation of the orbit or a mechanical problems in the detectors. It needs to be corrected for an appropriate classification by pre-processing.

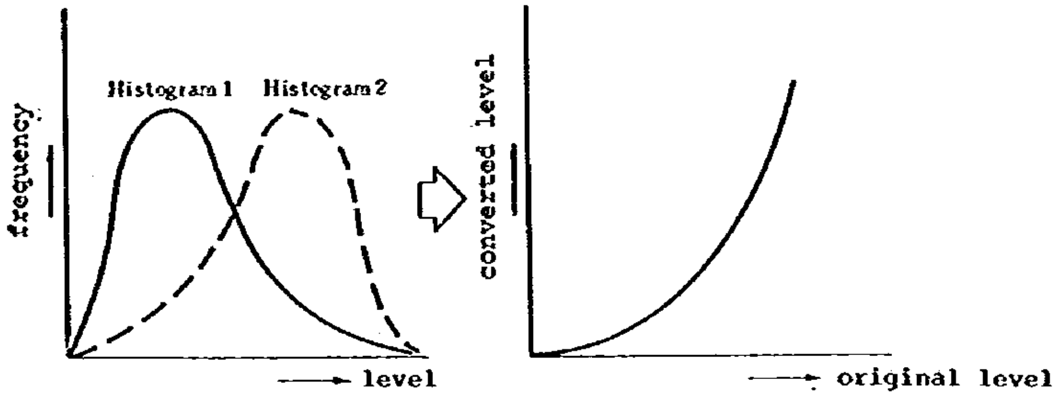
There are two types of computer-aided corrections, a radiometric correction and a geometric one.

RADIOMETRIC CORRECTION

The six parallel detectors in each of the four bands of the Landsat can catch reflection of the ground surface simultaneously. Then, an imagery of the six parallel lines can be recorded simultaneously in one scan. In the next scan, the Landsat spacecraft has moved just six lines (about 480 m, see Figure 5). The CCT's (computer compatible tape) of a scene has, therefore, 2,340 lines on the image taken from 390 scans. These six parallel detectors have almost the same sensitivity. However, these sensitivities are sometimes not the same. This is due to what we call SCAN-

NING NOISE. This is typical of radiometric distortion. In fact, the scanning noise not only prevents viewing, but also causes errors on the statistical computer-aided analysis.

One method of eliminating scanning noise is the " "HISTOGRAM EQUALIZATION" method. The conception behind this method is that each of the six parallel detectors views the same object on a scene. Thus, each of the six parallel detectors probably has the same statistical characteristics for the radiometric data. This method uses histograms for the statistical characteristics. Now, six histograms for each of the six parallel detectors can be calculated respectively. One standard histogram can be selected among them at random. The other five histograms can be nonlinearly converted to distribution level of the standard histogram. (Figure 8)



an example of histogram

a curve for converting levels from histogram 2 to histogram 1

Figure-8. Histogram equalization

In fact, though the Landsat data of 8228513005500 November 3, 1975, which was used for the classification in this study area, had heavy scanning noise, these scanning noise could be perfectly eliminated by the "HISTOGRAM EQUALIZATION" method. Therefore, we believes that this method can eliminate any scanning noise later. Figure 9 shows the different patterns of histogram on band 7 for the six parallel detectors.

GEOMETRIC CORRECTION

Geometric distortions depend on the orbit of the satellite, the oscillation of the spacecraft itself, a skew in rotation with respect to the Earth, and a difference ratio between the vertical and horizontal interval of a pixel after processing the digital data. Distortion depending on the orbit and the oscillation can seriously influence the imagery, but, those resulting from skew and different ratios are not so serious.

The geometric correction can be generally done by the "RESAMPLING" method, which adopts a linear or non-linear function for converting co-ordinates, for example, polynomial, etc. The linear function can easily correct the co-ordinates, but, the accuracy will be lower than for an non-linear function. However, the non-linear function requires complex calculation. In any case, for the resampling method, two functions can be made as follows;

$$L = f\ (l,p)$$
$$P = g\ (l,p)$$

where;

L: the number of lines of the original image which is not corrected yet.

P: the number of pixels of the line L of the original image which is not corrected yet.

f: a function for a converting co-ordinates of the row

g: a function for a converting co-ordinates of the column

l: the number of lines after the corrected image

p: the number of pixels of the line l after the corrected image

L and P will be calculated as a decimal, but, not as an integral number: this does not perfectly correspond to the original co-ordinate (l,p) which is an integral number. Therefore, the original co-ordinate (l,p) can be represented for the pixelas near as possible to the original co-ordinate, or for the average of some density of pixels neighboring the

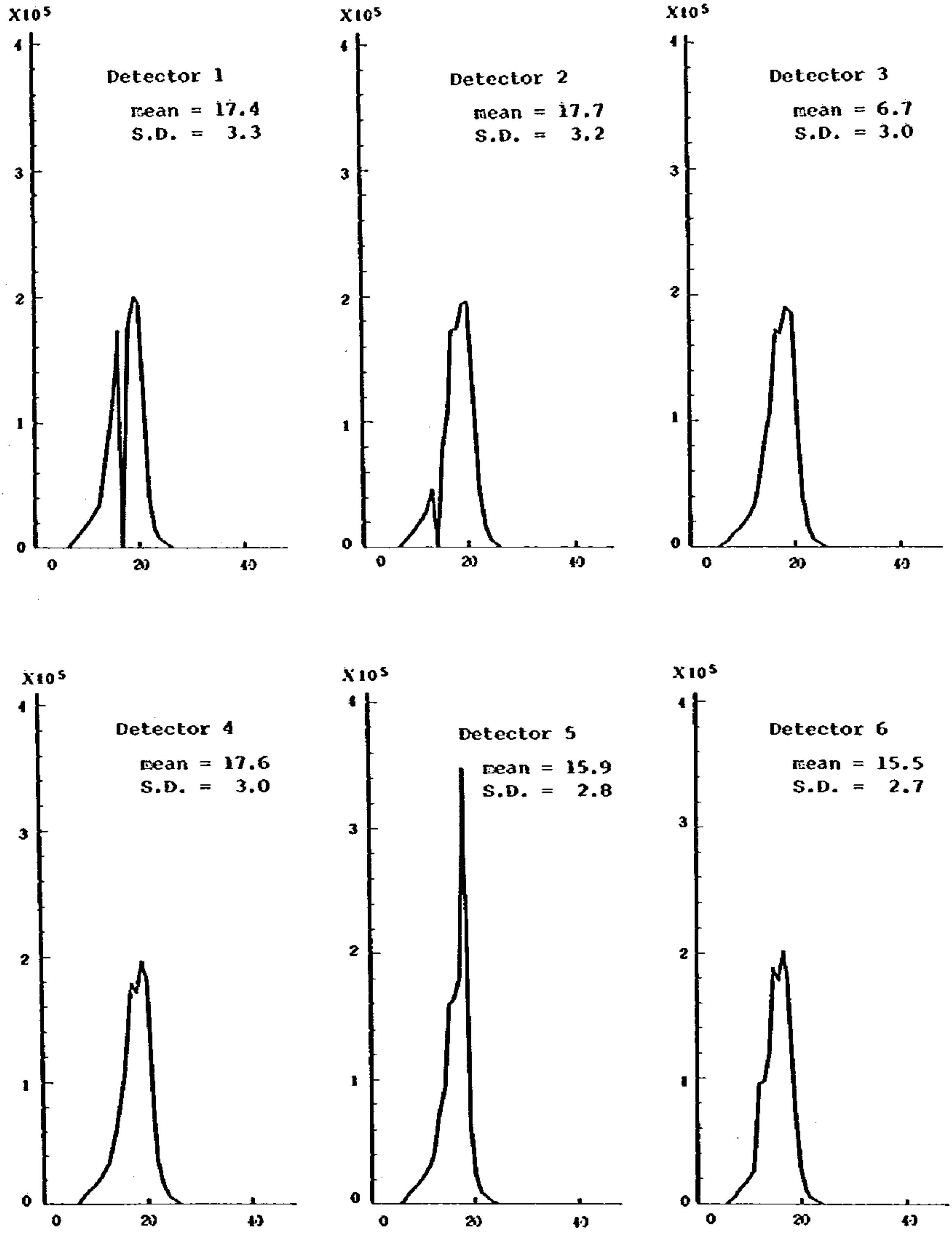


Figure-9. Histograms on band 7 for the six parallel detectors original one.

The former method is popularly used recently. (Figure 10)

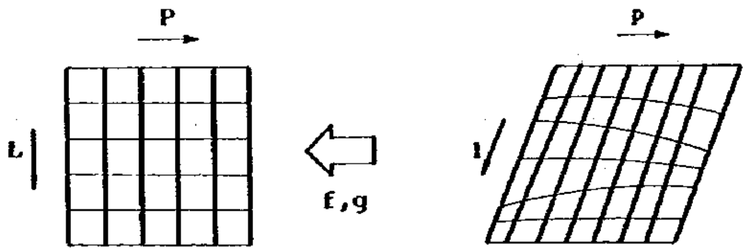


Figure-10. A resampling of imagery

iii) CLASSIFICATION

We have adopted the supervised method for the computer-aided classification, because we obtained the aerial photographs in 1968 and 1980 for the "Ground Truth". The procedure for the classification is shown in Figure 11.

SELECTING CATEGORIES

We interpreted the aerial photographs and divided them into twelve categories as follows;

(1) tall forest-type A
(2) tall forest-type B
(3) tall forest-type C
(4) medium forest-type A
(5) medium forest-type B
(6) dense crown forest
(7) mixed forest
(8) low forest
(9) pasture or cultivated area
(10) unused area
(11) natural grass land
(12) low grass land

where,

A tall forest probably has a high timber volume, because it includes mainly tall trees. Types A, B, and C depend on the density of the tall trees. A medium forest may have a timber volume of less than the tall forest, but, the crown diameter is relatively larger than the tall forest. Types A and B of the medium forest depend on the composition of tree species. A dense crown forest is a forest whose crowns are closely touched. A mixed forest includes tall and low trees. A low forest has an negligible timber volume. Pasture or cultivated area cannot be distinguished from pasture and crop land, because we do not know the crop calender. An unused area is mostly grass, but it is not natural grass land, and has few trees. A low grass land may be wet, and have short grass.

PRELIMINARY TRAINING AREA

Training areas, which the Landsad data should be selected for each category as the "Ground Truth", can be located on two color composite prints from Landsat images in 1975 and 1972 (Figure 12). Table 2 shows the range from lines and pixels of the image and the twelve categories for each number of training area.

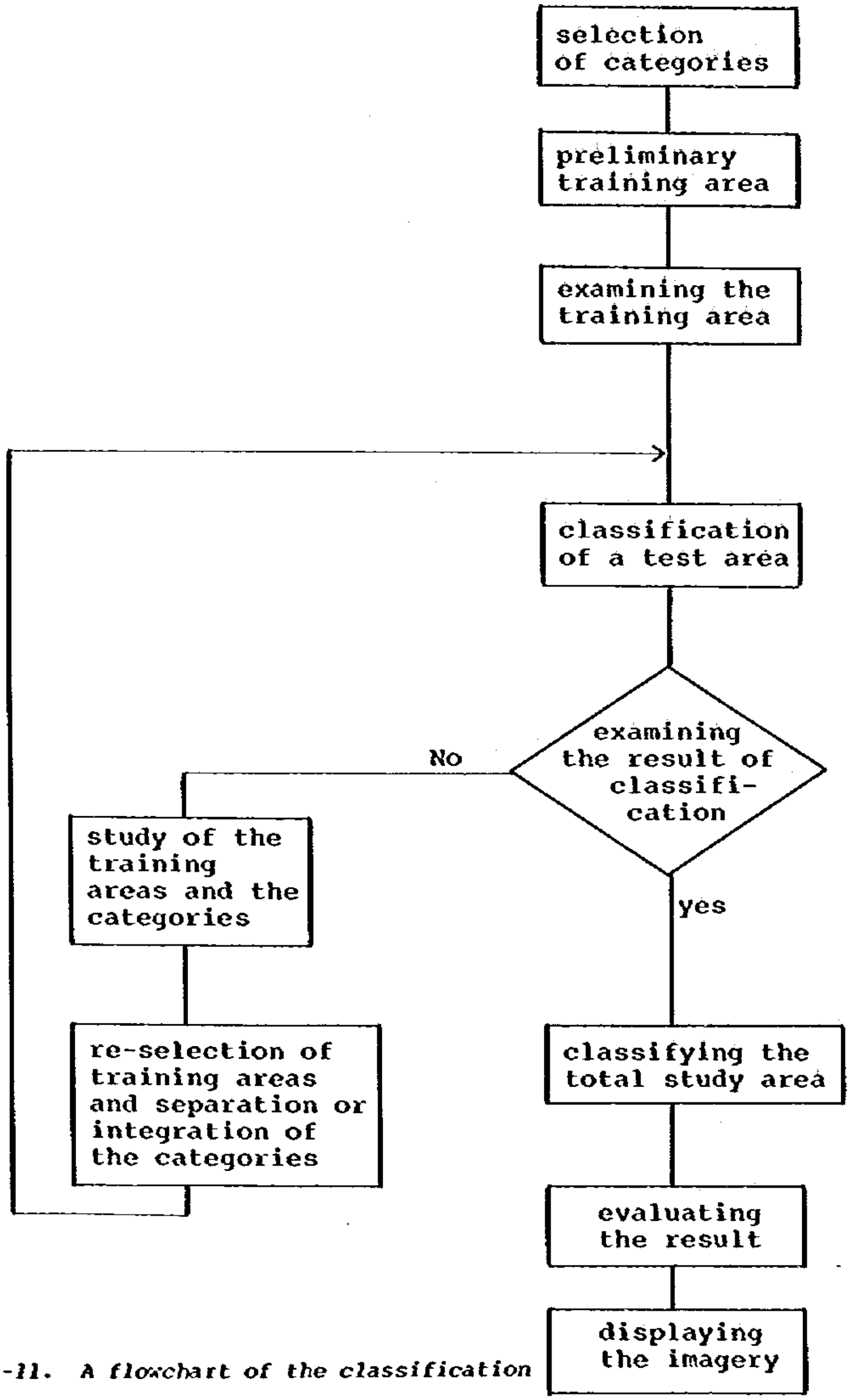


Figure-11. A flowchart of the classification

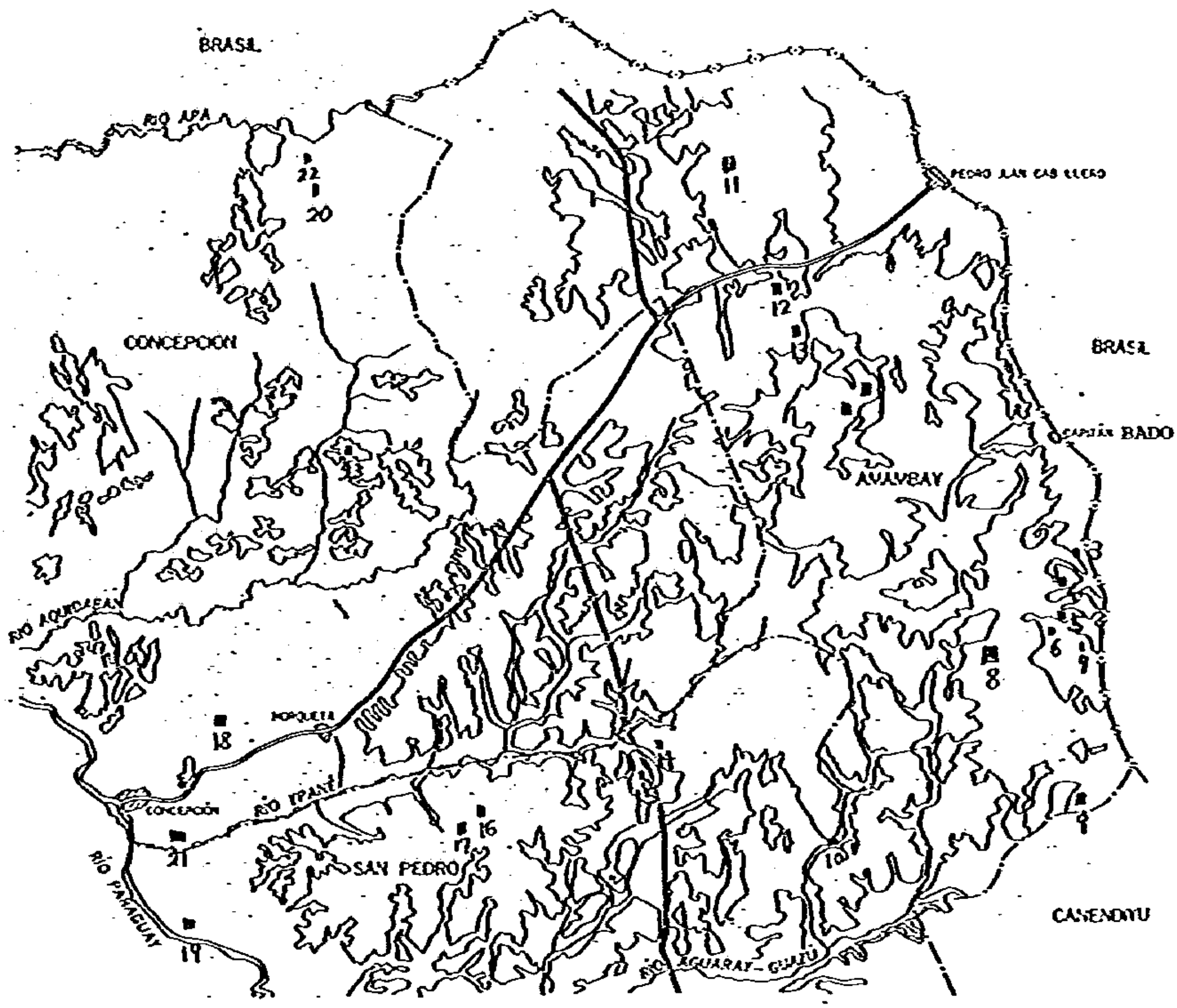


Figure-12. Sites of training areas

Category		Symbol	No. of training area	Line		Pixel	
Tall forest	Type A	C	11	199	212	2294	2313
	Type B	D	12	555	572	2446	2462
			13	650	677	2543	2573
	Type C	E	1	781	802	2786	2816
			2	786	816	2712	2746
Medium forest	Type A	G	15	1760	1771	2083	2094
	Type B	H	16	1847	1875	1569	1599
			17	1874	1902	1510	1560
Dense crown forest		F	14	1669	1680	2125	2157
Mixed forest		P	23	928	957	1082	1127
Low forest		O	22	118	130	1109	1123
Pasture or cultivated area		J	18	1665	1690	745	795
Unused area		K	19	2098	2104	535	554
Natural grass land		L	20	248	265	1140	1166
Low grass land		M	21	1870	1880	549	562

Table-2-a. Category and training area (main)

Category		Symbol	No. of training area	Line		Pixel	
Tall forest	Type A	C	8	1607	1643	831	873
	Type B	D	12	674	696	2446	2462
			13	777	807	134	166
	Type C	E	1	920	953	395	422
			2	937	969	298	329
			4	1392	1424	1080	1116
			5	1493	1518	1101	1133
Dense crown forest		F	9	1965	2006	1183	1227
Low forest		O	6	1540	1549	1051	1027
Pasture or cultivated area		J	3	1338	1374	1141	1174
Natural grass land		L	7	1584	1600	1181	1201
Low grass land		M	10	2075	2078	375	394

Table-2-b. Category and training area (complementary)

EXAMINING THE TRAINING AREAS

An examination of the training areas is necessary for two reasons. One is that it is not certain whether the training areas for categories on the photographs can be located on the Landsat digital data. The other is that if patterns of the digital data for two categories are similar or close, it is impossible or difficult to distinguish them.

The former will be clear from the histograms, which will have more than two frequency peaks, although a histogram normally has only one frequency peak.

In the other case, all of the training areas should be selected for easily separation of each category in the computer-aided classification, because the computer-aided classification is dependant on the spectral features mentioned before. If two categories have similar spectral features (or patterns), they should be combined into one category or training areas within them may be misselected for other areas of the same category. You can see the spectral features for each category in Figure 13. Figure 13 shows the normalized spectra for each band. It may be difficult or mistaken to separate categories of a similar pattern in the computer-aided classification. For example, types B and C of the tall forest have quite similar patterns to each other. We can then calculate the so-called "SEPARABILITY", made from a complex equation by using mean and standard deviations for all of the bands (Table 3) and matrices of variance and co-variance (Table 4). Table 5 shows the "SEPARABILITY" for each pair of categories, which means that the maximum range is 2,000, and they may be precisely separated with more than 1,000, but it may be impossible or difficult to separate them with less than 500.

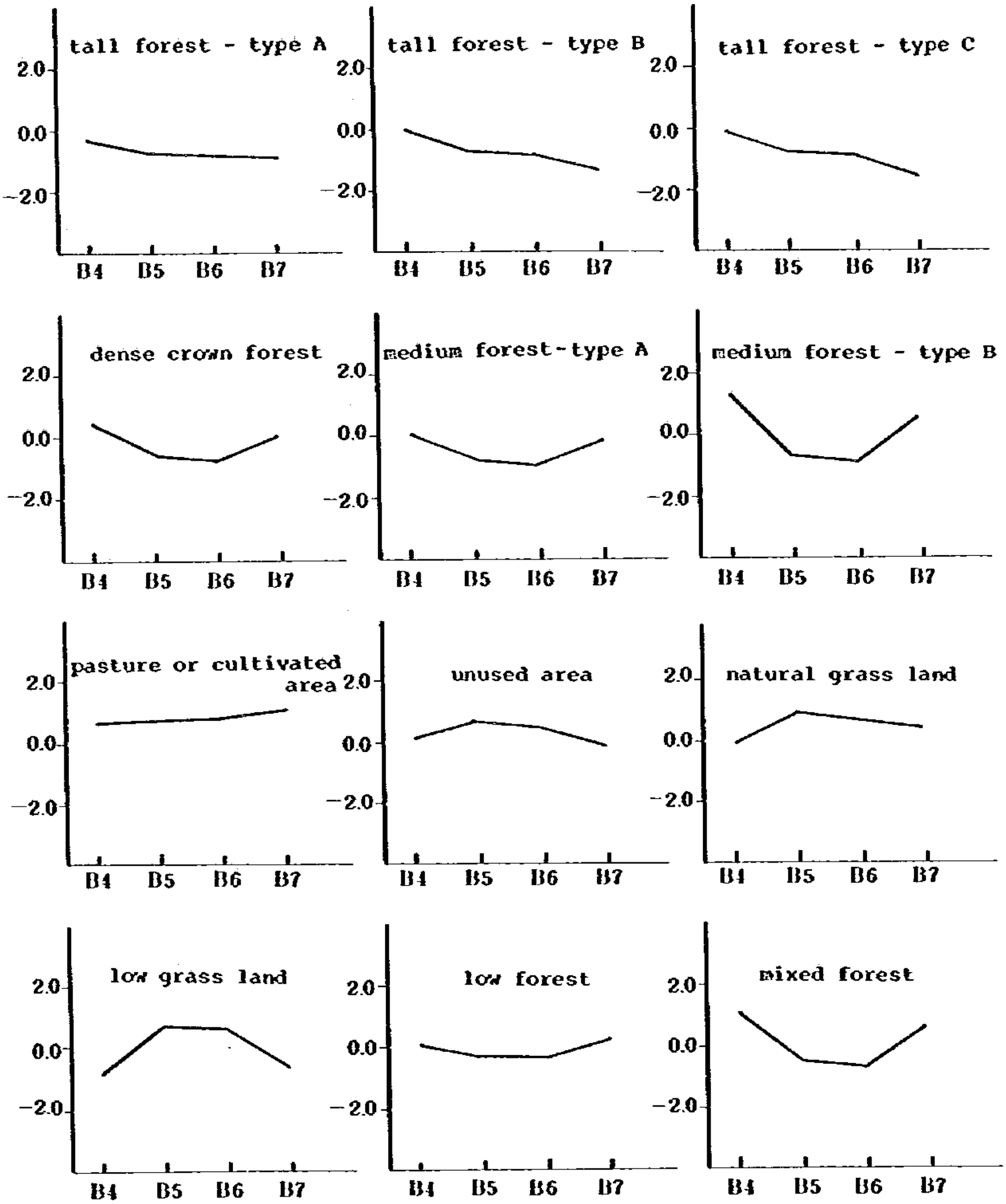


Fig.-13 Spectral features for each category

Category		BAND 4		BAND 5		BAND 6		BAND 7	
		mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
Tall forest	Type A	28.5	2.7	13.2	0.5	9.3	0.7	31.3	1.7
	Type B	26.5	3.4	13.1	0.6	9.4	1.1	29.9	1.7
	Type C	25.8	2.9	12.7	0.6	8.8	1.1	29.1	1.6
Medium forest	Type A	27.2	1.6	12.9	0.5	8.7	0.9	30.6	0.7
	Type B	33.7	2.1	13.3	0.6	9.0	0.8	32.9	1.4
Dense crown forest		29.6	1.8	13.6	0.6	9.9	1.1	31.3	1.1
Mixed forest		32.3	1.8	13.9	0.5	10.0	0.9	32.8	1.3
Low forest		26.9	3.6	14.6	0.7	12.5	1.5	31.7	1.4
Pasture or cultivated area		30.6	5.2	17.9	1.8	21.2	6.6	34.3	2.7
Unused area		27.4	4.4	17.9	1.3	19.2	3.3	30.5	2.4
Natural grass land		25.7	1.9	18.5	0.9	20.4	2.2	32.2	1.6
Low grass land		21.5	2.0	17.8	1.0	20.0	1.7	28.6	1.0

Table-3 Means and standard deviations for all of the categories and the bands

Category			B4	B5	B6	B7
Tall forest	A	B4	7.31	-0.07	-0.19	0.46
		B5	-0.07	0.25	0.04	0.20
		B6	-0.19	0.04	0.55	0.25
		B7	0.46	0.20	0.25	2.84
	B	B4	11.50	0.27	0.34	1.61
		B5	0.27	0.38	0.22	0.41
		B6	0.34	0.22	1.23	0.43
		B7	1.61	0.41	0.43	2.86
	C	B4	8.52	0.03	-0.05	0.38
		B5	0.03	0.39	0.20	0.04
		B6	-0.05	0.20	1.12	-0.55
		B7	0.38	0.04	-0.55	2.48
Medium forest	A	B4	2.55	0.07	0.20	0.46
		B5	0.07	0.27	0.10	0.05
		B6	0.20	0.10	0.78	0.23
		B7	0.46	0.05	0.23	0.55
	B	B4	4.39	0.19	0.26	1.31
		B5	0.19	0.31	0.08	0.21
		B6	0.26	0.08	0.60	0.25
		B7	1.31	0.21	0.25	2.03
Dense crown forest		B4	3.39	0.36	0.73	0.73
		B5	0.36	0.36	0.25	0.26
		B6	0.73	0.25	1.13	0.51
		B7	0.73	0.26	0.51	1.14
Mixed forest		B4	3.26	-0.02	0.03	0.19
		B5	-0.02	0.25	0.02	0.13
		B6	0.03	0.02	0.74	0.20
		B7	0.19	0.13	0.20	1.74
Low forest		B4	12.89	0.29	1.47	1.08
		B5	0.29	0.55	0.35	-0.02
		B6	1.47	0.35	2.35	-0.69
		B7	1.08	-0.02	-0.69	1.93
Pasture or cultivated area		B4	27.32	0.49	3.11	3.03
		B5	0.49	3.11	8.89	0.10
		B6	3.11	8.89	43.64	-2.38
		B7	3.03	0.10	-2.38	7.05
Unused area		B4	19.63	-1.67	-6.66	5.00
		B5	-1.67	1.73	2.94	-0.70
		B6	-6.66	2.94	10.62	-3.85
		B7	5.00	-0.70	-3.85	5.62
Natural grass land		B4	3.54	0.01	0.34	0.42
		B5	0.01	0.88	1.12	0.43
		B6	0.34	1.12	5.02	0.70
		B7	0.42	0.43	0.70	2.72
Low grass land		B4	3.90	0.35	0.33	0.17
		B5	0.35	0.93	0.60	0.42
		B6	0.33	0.60	2.96	0.70
		B7	0.17	0.42	0.70	1.08

Table-4 Matrices of variance and co-variance

Category		Tall forest			Medium forest		Dense crown F.	M.F	L.F.	P.C.A.	U.A	N.G.L	L.G.U
		A	B	C	A	B							
Tall forest	A		387	842	854	1066	622	1114	1826	2000	2000	2000	2000
	B			315	981	1512	849	1525	1525	1999	1999	1999	1999
	C				1162	1722	1331	1844	1863	2000	1999	1999	1999
Medium forest	A					1724	1331	1728	1895	2000	2000	2000	2000
	B						1399	716	1952	2000	2000	2000	2000
Dense crown forest								806	1650	1999	1999	1999	2000
Mixed forest									1759	2000	1999	2000	2000
Low forest										1991	1888	1984	1998
Pasture or cultivat-ed area											1222	1595	1994
Unused area												942	1706
Natural grass land													1665
Low grass land													

Table-5 The "SEPARABILITY" for each category

CLASSIFICATION OF A TEST AREA

We classified two test areas shown in Figure 14 and the result of the classification output from the line printer of a computer with symbolized categories is given in Table-2-a. Figure 15 shows the result of the classification in a part of the test area. All of the results are highly satisfactory, and the forest and other areas are perfectly distinguished. Therefore, we judged that most of the categories can be adopted from computer-aided classification for the total study area.

However, both types A and B of the tall forest, and the dense crown forest and the mixed forest are sometimes confusing, and the pasture or cultivated area and the unused area are also mixed up. In addition, unclassified areas occured more than we expected previously because of cloud cover. However, we discovered that these unclassified areas, apart from cloud cover, may be bare land or burned areas. It should, therefore, be added as a new category.

INTEGRATING THE CATEGORIES

Table 6 shows percentages of the classified pixels for the categories in all the training areas, with the new category, the bare or burned area mentioned above. In Table 6, types A and B of the tall forest are frequently mistaken in classifying them strictly. In addition, the dense crown forest and the mixed forest are somewhat confusing. Therefore, they might be better combined into one category.

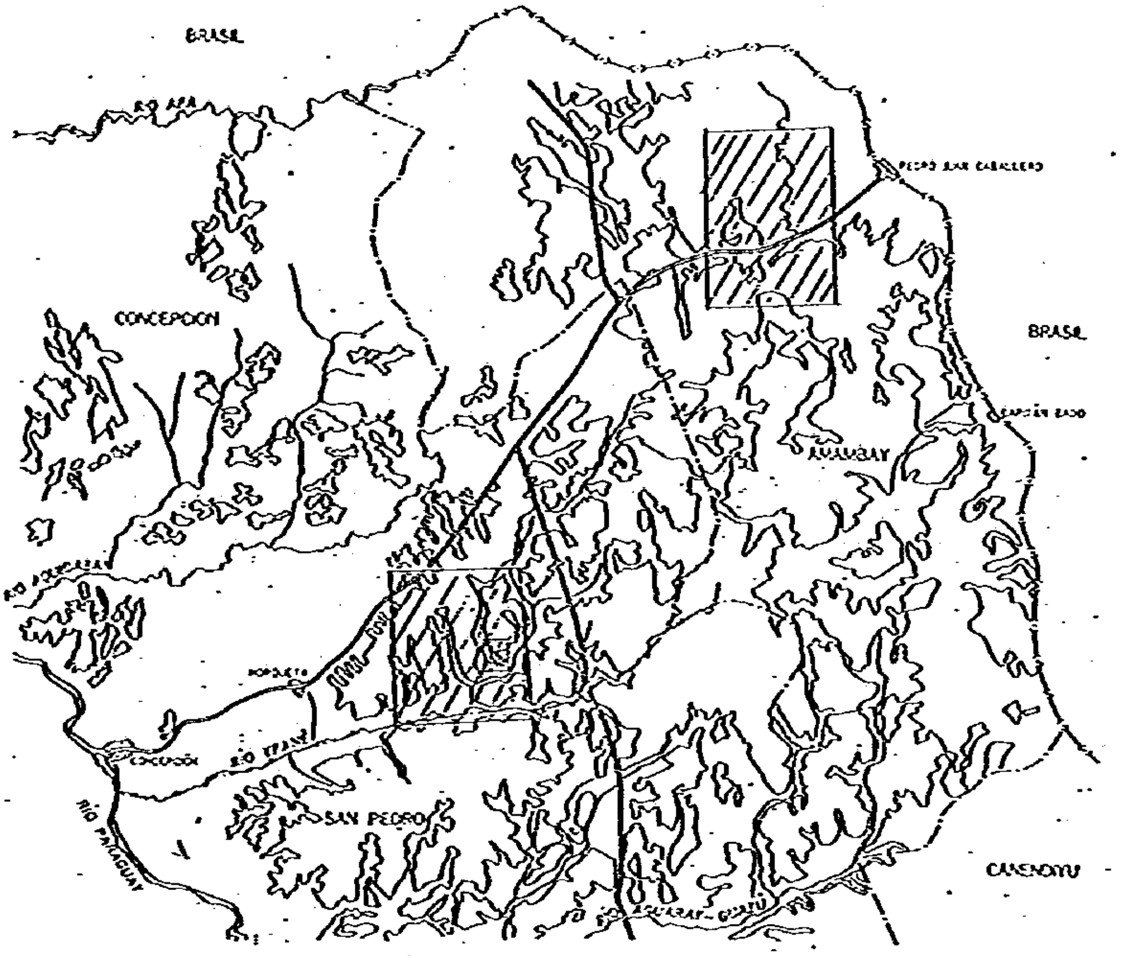
In the detailed forest resources inventory which we will make in the future, we first need to make boundaries, such as strata which can represent the averages and variances of the timber volumes by investigating sample plots on the ground. Conventionally, these strata can be made from interpreting aerial photographs. However, because of the huge study area, it will be a tremendous amount of work and will be very time-consuming. Then, the strata for types A and

B of the tall forest made from the computer-aided classification will be available as first rough boundaries for strata before we interpret the aerial photographs. Types A and B of the tall forest are similar in surface appearance, but they may be different in timber volume.

The dense crown forest and the mixed forest are also mixing, but these forests are basically so different types of forest that they must have different timber volumes since the mixed forest has a far smaller timber volume than the dense crown forest. Therefore, they should not be combined into a category despite of the mixing, and we should wait until the interpretation of aerial photographs or the field survey has been done. We can correct the boundaries later.

In the other case, the unused area is also misclassified slightly. In fact, this area cannot be distinguished on the ground as to whether it belongs to pasture, cultivated area, or natural grass land. Therefore, we judge that this unused area classified by computer is better than by interpreting the aerial photographs.

Finally, we decided that none of the categories should be combined for classifying in the total study area.



test area

site of an example in figure 15

Fig.-14 Sites of test areas

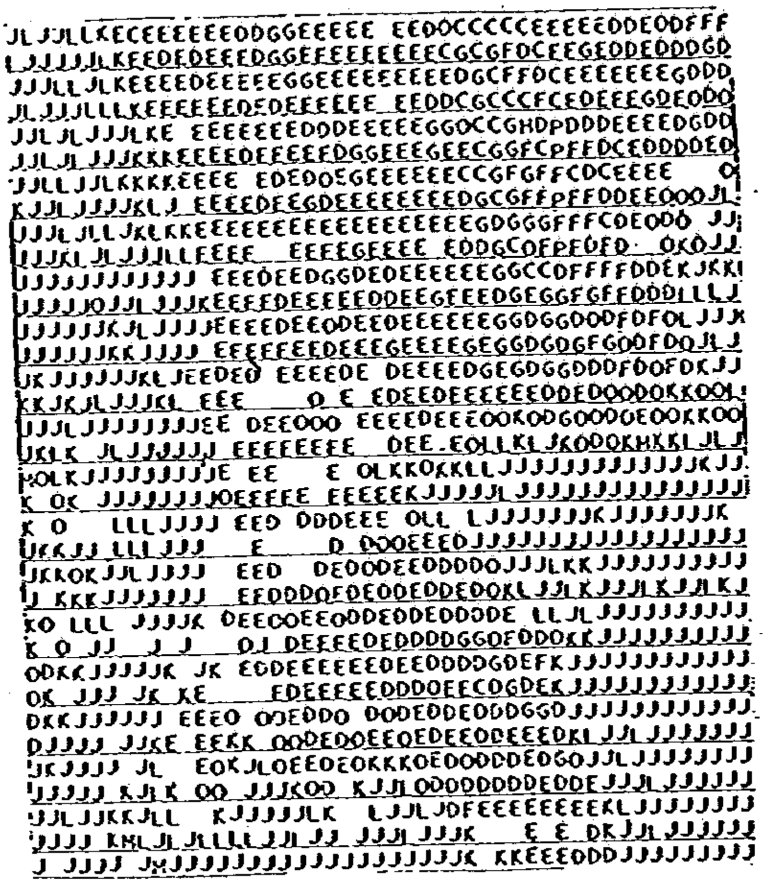


Fig.-15 An example of the results of the classification output with the line printer

(See table-2-a as the symbolized categories)

Category		Tall forest			Medium F.		D.C.F	M.F.	L.F.	P.C.A	U.A.	N.G.L	L.G.L	B.B.A	Un-class
		A	B	C	A	B									
Tall forest	A	35	5	10	20	13	14	5	1	0	0	0	0	0	0
	B	11	19	31	17	3	10	4	5	0	0	0	0	0	0
	C	5	6	60	22	1	3	0	1	0	0	0	0	0	2
Medium forest	A	5	1	6	74	1	13	0	0	0	0	0	0	0	0
	B	4	0	0	1	78	3	14	0	0	0	0	0	0	0
Dense crown forest		9	3	1	20	2	48	12	5	0	0	0	0	0	0
Mixed forest		3	0	0	0	15	16	65	1	0	0	0	0	0	0
Low forest		0	0	0	0	0	3	2	91	0	4	0	0	0	0
Pasture or cultivated A.		0	0	0	0	0	0	0	3	71	13	12	1	0	0
Unused area		0	0	0	0	0	0	0	0	10	64	16	10	0	0
Natural grass land		0	0	0	0	0	0	0	0	7	8	84	1	0	0
Low grass land		0	0	0	0	0	0	0	0	0	0	3	97	0	0
Bare or burned area		0	0	0	0	0	0	0	0	0	0	0	0	100	0

Table-6 Percentages of the classified pixels for the categories in all the training areas

CLASSIFYING THE TOTAL STUDY AREA

The result of the classification on the total study area is shown in a supplementary map of 1 : 500,000 sale. This supplementary map (called the FOREST TYPE and LAND USE map) is color-coded for each category. For example, types A, B, and C of the tall forest are colored with yellow-green, green and whitish green respectively. Table 7 shows the ratios of color composite for each category. For example,type A of the tall forest is displayed with the yellow-green projected 255 degrees in green and 127 degrees (half of the 225 degrees) of blue.

Table 8 shows hectares and percentages of the category to the Landsat main image (822851300500 November 3, 1975). In table 8, the forest area is 1,722,351 ha (50.3%), and the forest expected to produce timber products, except for the low forest, is 1,193,455 ha (34.9%). However, as the total study area includes part of the complementary Landsat image (8105413075500 September 15, 1972), all of the forest area in the North-Eastern region of Paraguay should be added to these forests.

We estimated that the total forest area is approximately 2,500,000 ha.

Category			light strength		
			red	green	blue
1	Tall forest	A	0	255	127
2		B	0	255	0
3		C	127	255	0
4	Medium forest	A	0	255	191
5		B	0	0	127
6	Dense crown forest		0	127	0
7	Mixed forest		191	255	0
8	Low forest		255	255	0
9	Pasture or cultivated A.		127	127	127
10	Unused area		255	127	0
11	Natural grass land		255	191	0
12	Low grass land		0	0	255
13	Bare or burned area		0	0	0
14	Unclassified		255	255	255

Table-7 Ratios of color strength for each category

Category			Hectare	percentage(%)
1	Tall forest	A	109,408	3.2
2		B	169,670	4.9
3		C	320,530	9.4
4	Medium forest	A	169,122	4.9
5		B	135,512	3.9
6	Dense crown forest		144,965	4.2
7	Mixed forest		144,248	4.2
8	Low forest		528,896	15.5
9	Pasture or cultivated A.		512,164	15.0
10	Unused area		493,362	14.4
11	Natural grass land		333,617	9.7
12	Low grass land		226,815	6.6
13	Bare or burned area		2,452	0.07
14	Unclassified		131,739	3.8
Total			3,422,500	100.0

Table 8. Hectares and percentages for each category

6. ESTIMATION OF DEFORESTED AREAS

Recently, it is reported that the forest land in the study area is decreasing every year, and besides, due to a new economic situation in the world, especially in Brazil, the forest area is very rapidly decreasing at a couple of years along changing timber prices. Both the National Forest Service of Paraguay and we ourselves wanted know how much area of forest had been lost and how much forest will be lost before the forest resources inventory is carried out, because an estimation of the amounts of deforested areas greatly influence a planning and a forest policy in the future. For this reason, it is first necessary to know how much area has been deforested in the previous years.

i) INTERPRETATION OF THE COLOR COMPOSITE PRINTS OF THE LANDSAT

We interpreted the color composite prints as follows;

a. 82100412292x0- 22 Oct. 1977

b. 8228513005500- 03 Nov. 1975

c. 8123513144500- 15 Mar. 1973

d. 8105413075500- 15 Sep. 1972

Though it is difficult to measure precisely the forest and deforested areas on a color composite print scaled to 1: 1,000,000, the interpretation can be done exactly, because a forest appears in bright red, and the deforested area in whitish red color. In addition, the boundary of the deforested area mostly appears as a non-curved pattern. This interpreted area must be divided into two regions; One is the western region where we interpreted deforested areas between November 3, 1975(b) and March 15, 1973(c). The other one is the eastern region which was interpreted between October 22, 1977(a) and September 15, 1972(d).

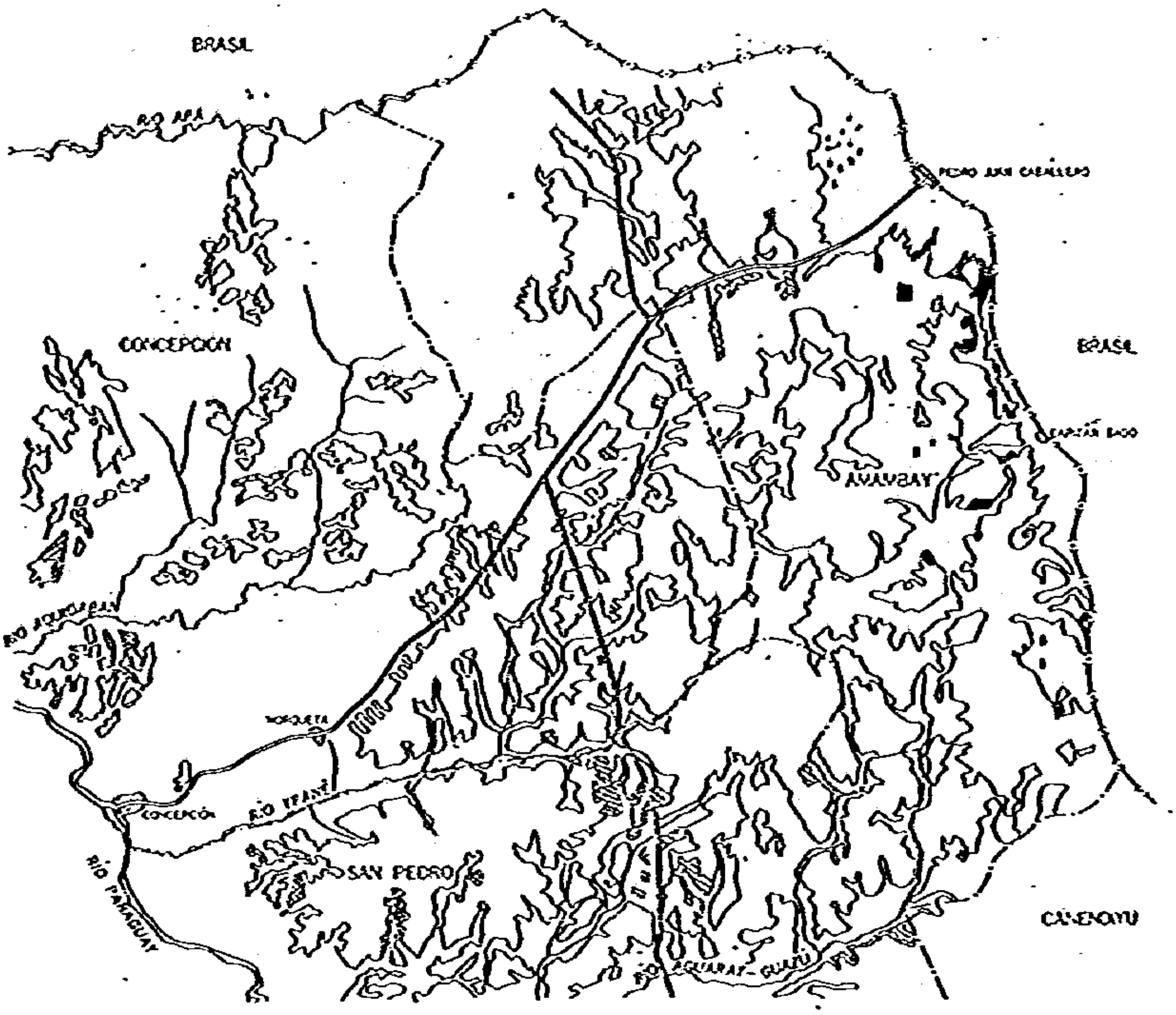
Figure 16 shows the deforested areas which changed over 2 years and 8 monthes, and over 5 years and one month. We measured these deforested areas by using the 1 mm -dot-plate on which there are many dots at 1 mm intervals in the horizontal and vertical directions on a transparency.

Consequently, the forest and deforested area are respectively 7,712 dots and 296 dots over the 2 years and 8 monthes, and 2,098 and 143 dots over the 5 years and a month. This result means that 29,600 ha in the western region was deforested during the 2 years and 8 monthes, and 14,300 ha of the forest in the eastern region was lost during the 5 years and a month. On the other hand, 3.70 and 6.38 percents to the previous forest areas were respectively deforested in the western and eastern region.

Therefore, as these percentages are simply divided by the 2 years and 8 monthes and the 5 years and a month, the forest has been losing about 1.25 to 1.44 percent every year in the study area. (Table 9)

	Period	Forest area	Deforested area	Deforested percentage	Every year (%)
West region	Nov.3, 1975 to Mar.15,1973	771,200	29,600	3.70	1.39
East region	Oct.22,1977 to Sep.15,1972	209,800	14,300	6.38	1.26
Total area		981,000	43,900		

Table-9 Deforested areas interpreted on the Landsat images



deforested area between Nov.3, 1975 and Mar.15, 1973

deforested area between Oct.22, 1977 and Sep. 15, 1972

Fig.-16 Deforested areas interpreted on the Landsat images

ii) INTERPRETATION OF THE AERIAL PHOTOGRAPHS

We interpreted the aerial photographs scaled 1 : 60,000, taken in 1968, for a test area for which we surveyed the field in 1980 and already interpreted the aerial photographs scaled 1 : 20,000, taken in 1980 as a test area of 52,500 ha (525 sq.km). (Figure 17)

In this test area, it was mostly expected that the forest had decreased rapidly because of easy logging as neighboring the High-way route 5 and the Brazilian boundary.

Table 10 shows the land use classification already interpreted with the aerial photos, taken in 1980 mentioned above, in the test area. Figure 18 shows the comparison of the forest areas between 1980 and 1968. The tall forest, which herein means the total forest expected to produce timber products, except the low forest, had lost 12,556 ha (27.47%) and the low forest had lost 638 ha (17.22%) during the twelve years. Therefore, these percentages of the deforested area to the previous forest in 1968 are simply divided by the twelve years, and 2.29 percents of the tall forest and 1.44 percents of the low forest are deforested every year. This result means that the test area is losing more forest than the total study area mentioned 6-i).

However, we obtained Landsat images in 1975 and 1973 as mentioned before. The head prints show enlarged colore composite prints of the Landsat in the test area. We interpreted these color composite prints, and obtained the result that the forest area did not begin to change so greatly until 1975 (Figure 19). Figure 20 shows the deforested area in 1980, 1975, 1973, and 1968 respectively in the test area.

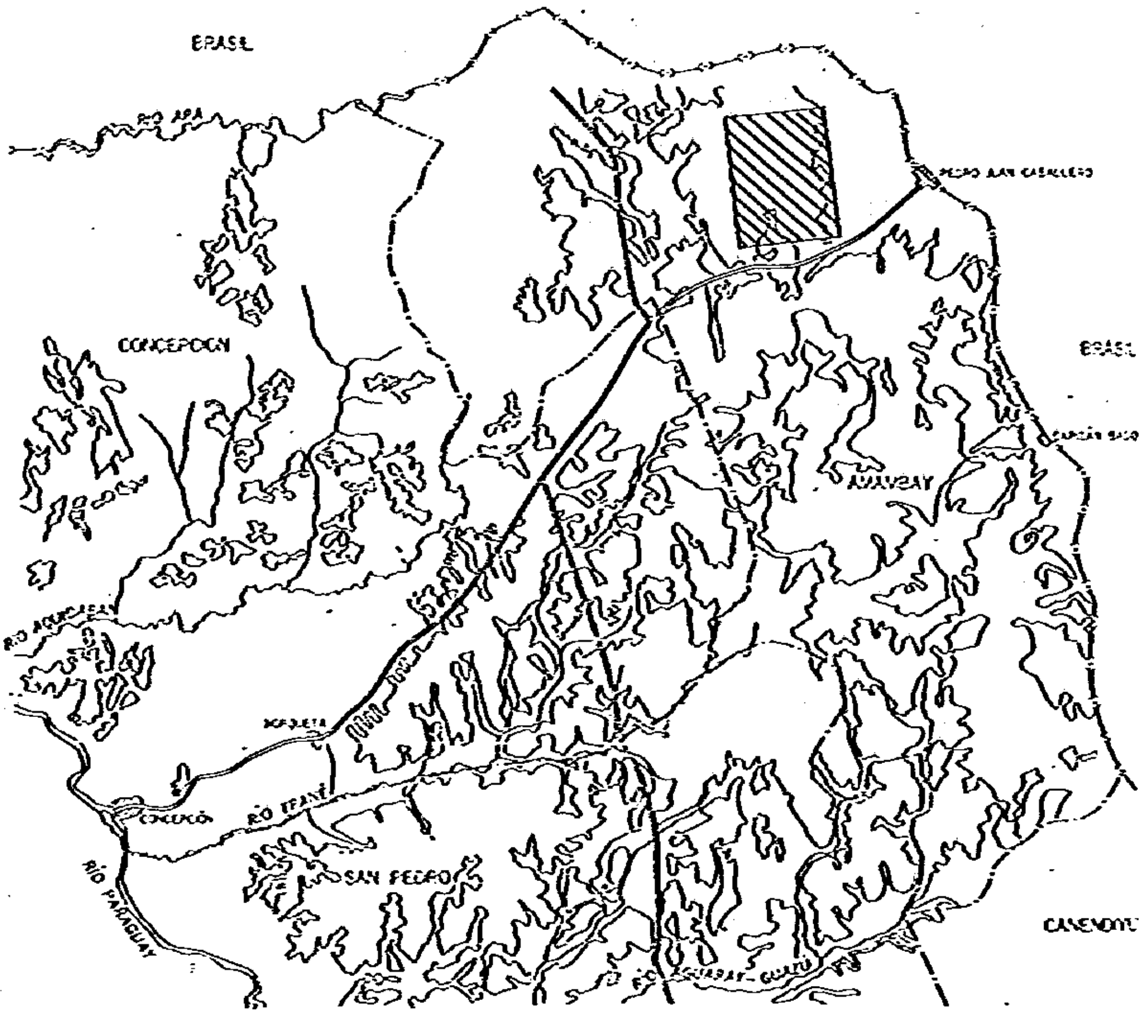


Fig.-17 A test area for interpreting the aerial photographs of deforested areas

Category	hectare	percentage
Tall forest A	5,535	10.5
Tall forest B	9,764	18.6
Tall forest C	11,703	22.3
Medium forest	6,145	11.7
Low forest	3,066	5.8
Cutting area	7,209	13.7
Pasture	4,755	9.1
Cultivated area	1,830	3.5
Grass land	1,303	2.5
Others	1,190	2.3
Total	52,500	100.0

Table-10 The land use classification in the test area

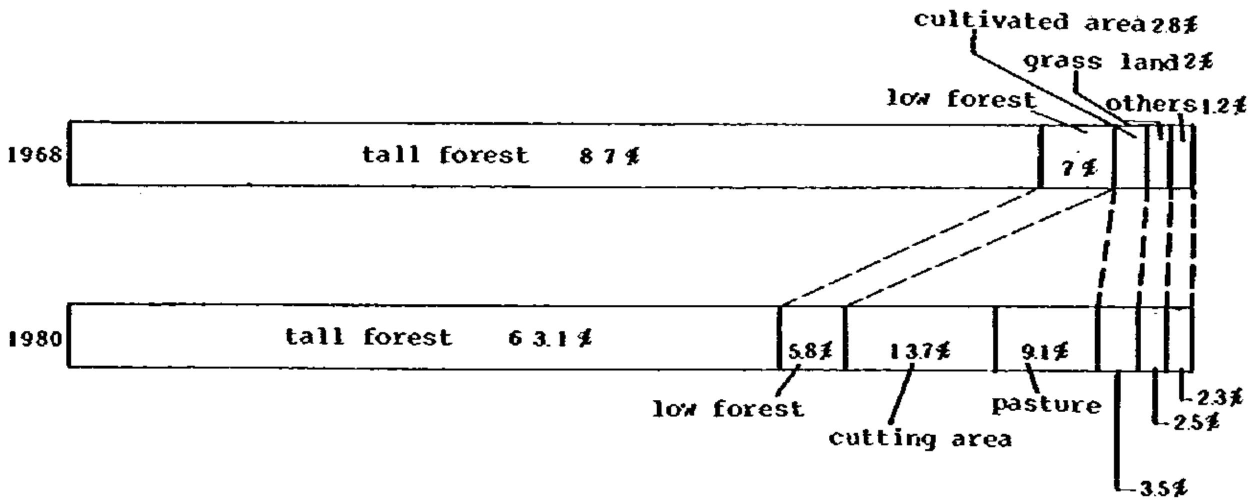


Fig.-18 Comparison between 1980 and 1968

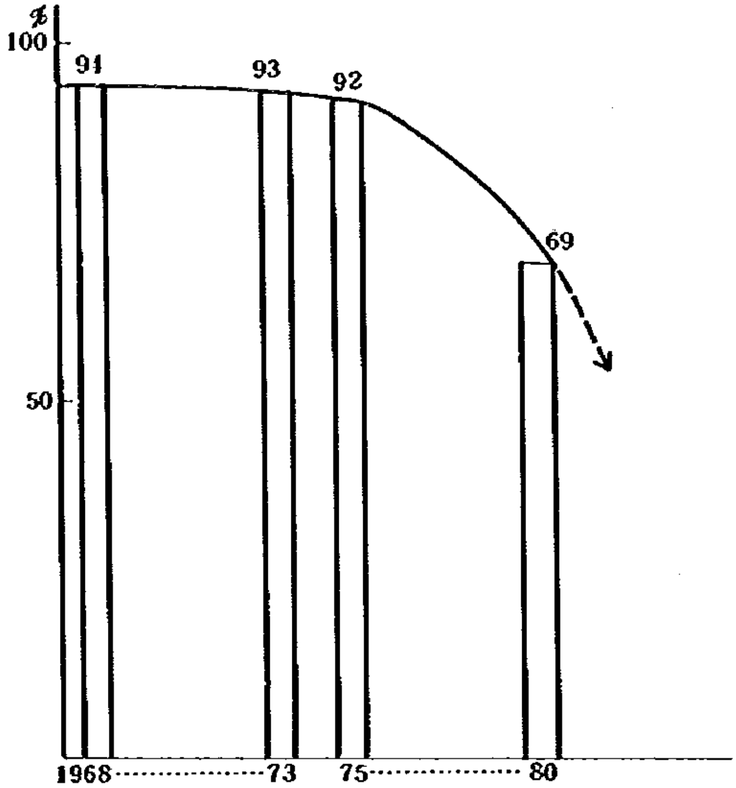


Fig.-19 Pattern of changing forest area

7. RESULTS AND DISCUSSION

This report answered three very important questions relative to the forest resources inventory being prepared for 1983.

(1) What is the geographic distribution of forest resources and land uses ?

(2) How much land area is covered by which forest types ?

(3) How much forest area will be deforested by 1983 ?

The Landsat digital analysis provided the geographic distribution of the various forest types and land use for the North-Eastern region of Paraguay and the results were output as THE FOREST TYPE and LAND USE MAP scaled to 1 : 500,000 with color print.

Table 8 answered how much area is covered by various forest types and we estimated that forest occupied 2,500,000 ha on the total study area in 1975.

Last question; Though it is very difficult to answer, Figure 19 indicates that the forest will lose a considerable area by 1983. In Figure 19, the forest had lost a little up to 1975, and it had rapidly deforested a large area between 1975 and 1980. Supposing that the ratio of decrease of the deforested area for every year during the last five years continues until 1983, the forest will be deforested over 25,830 ha (49.2%) in 1983. This means that the forest may lose 28.7 percent by three years afterward. Therefore, we earnestly hope that an appropriate policy or forestry plan will be drown up quickly as the same time as a forest resources inventory, and believe that this report will be very useful for preparing the inventory, and that other computer-aided classification analysis using the new Landsat digital data is needed in future.

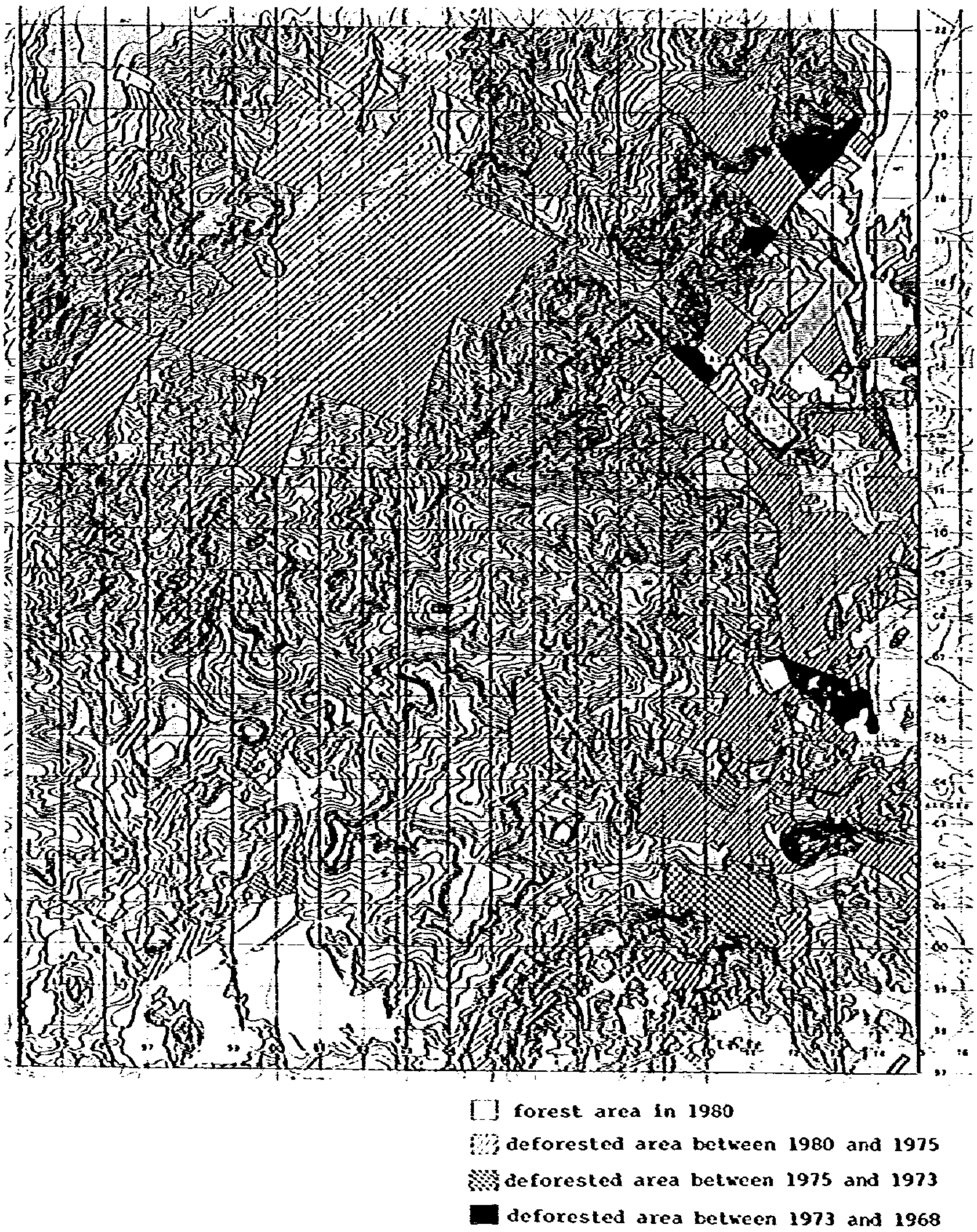
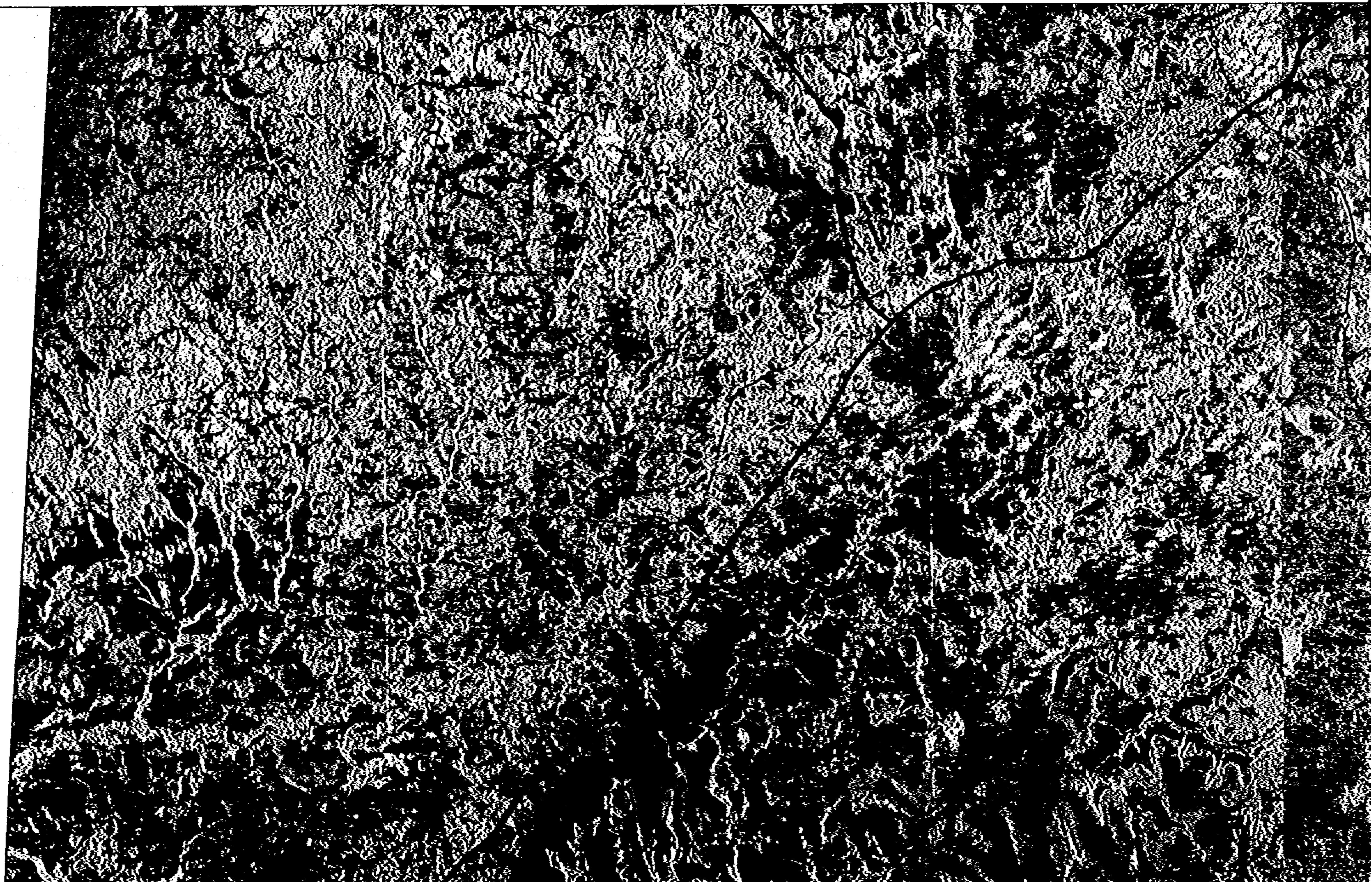


Fig.-20 Sites of deforested areas in the test area

THE FOREST TYPE AND LAND USE MAP

(IN THE NORTH-EASTERN REGION OF PARAGUAY)

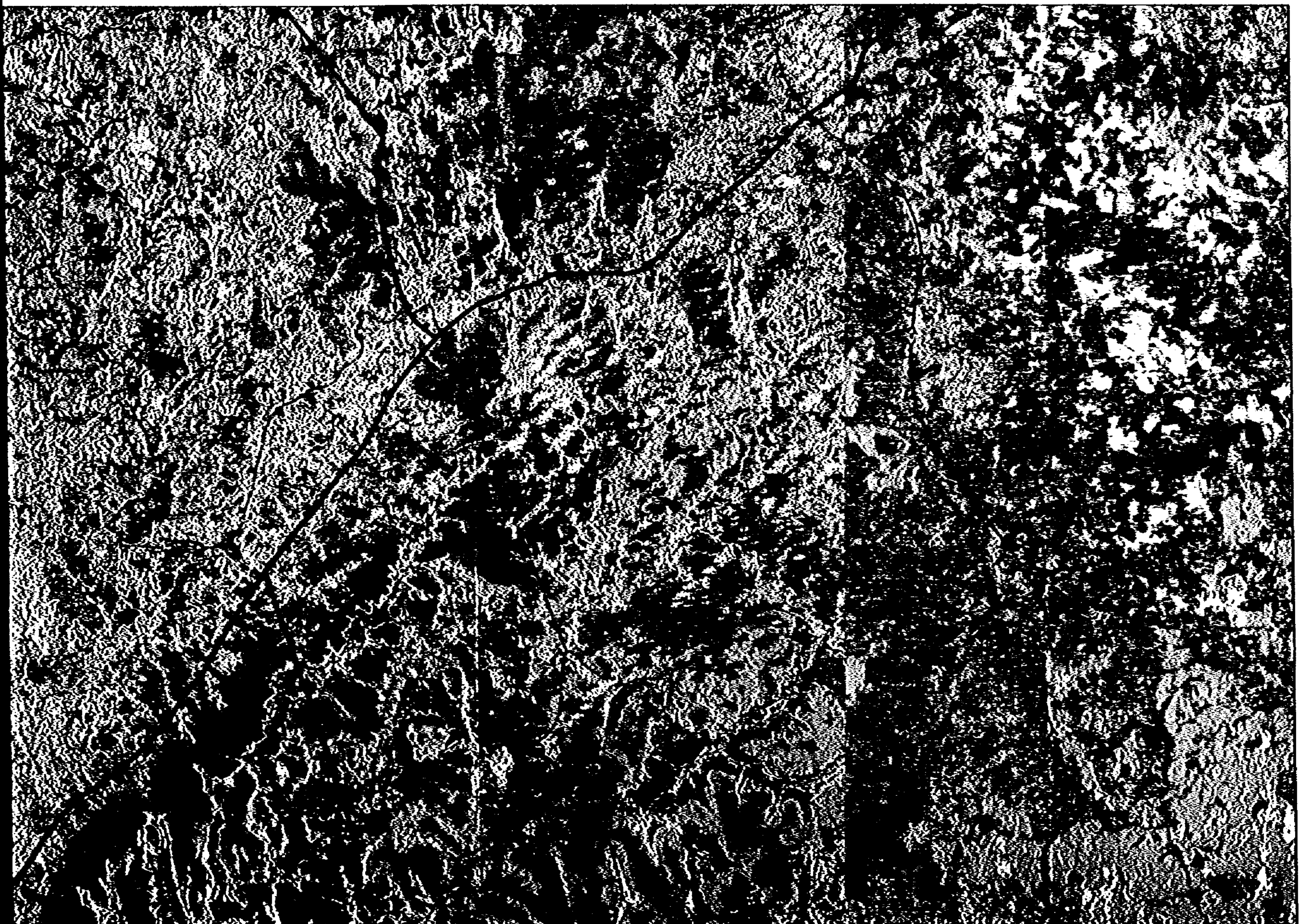


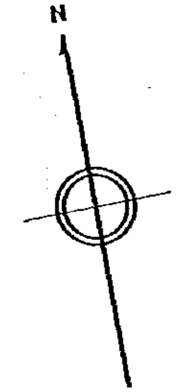
THE FOREST TYPE AND LAND USE MAP

(IN THE NORTH-EASTERN REGION OF PARAGUAY)

FOREST TYPE AND LAND USE MAP

(IN THE NORTH-EASTERN REGION OF PARAGUAY)



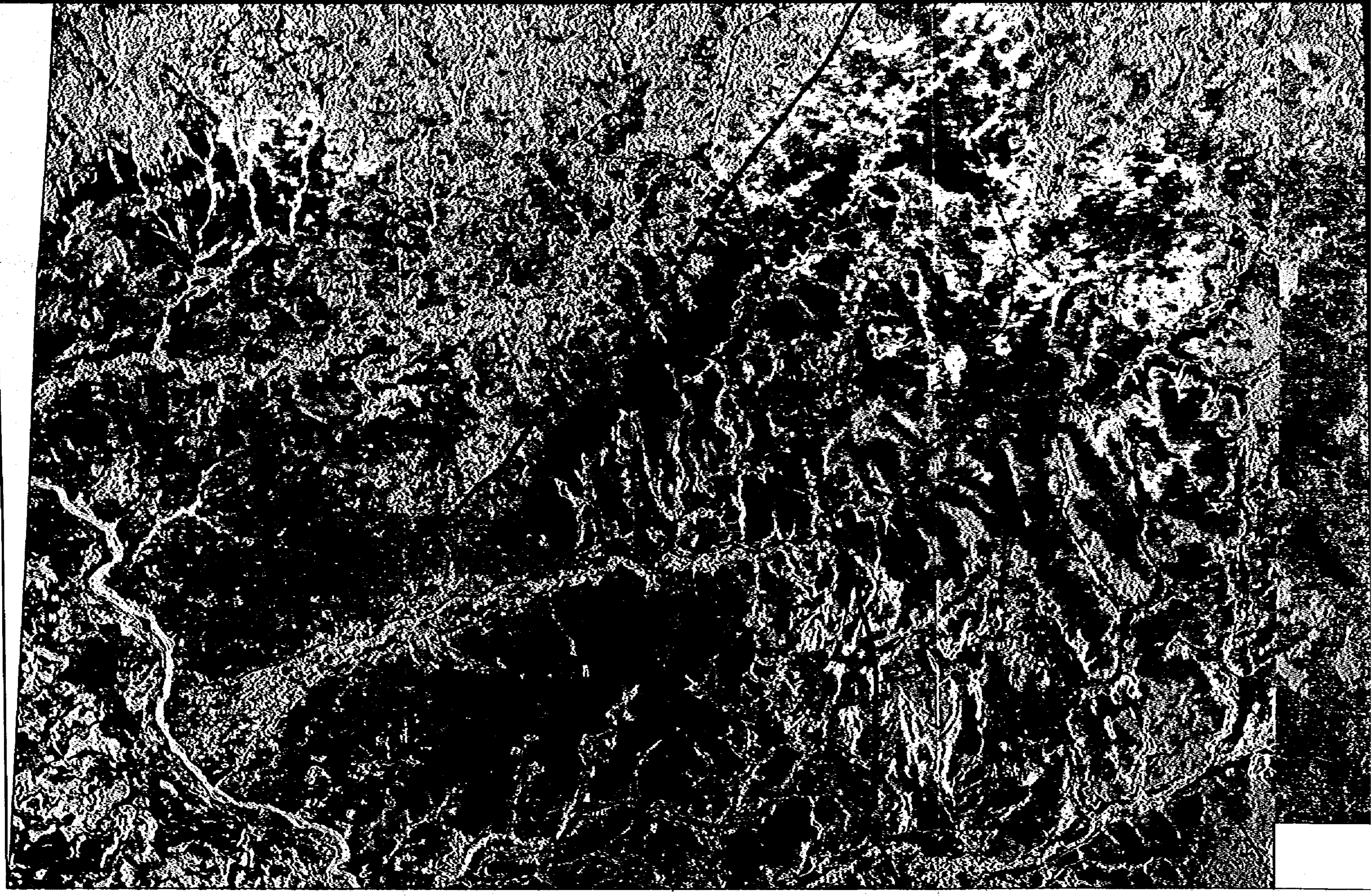


NOTE

- Tall forest type A
- Tall forest type B
- Tall forest type C
- Medium forest type A
- Medium forest type B
- Dense crown forest
- Mixed forest
- Low forest
- Pasture, cultivated area
- Unused area

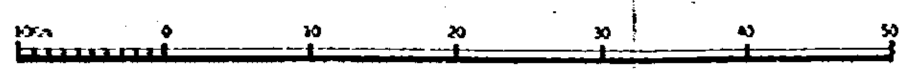
FOREST TYPE AND LAND USE MAP

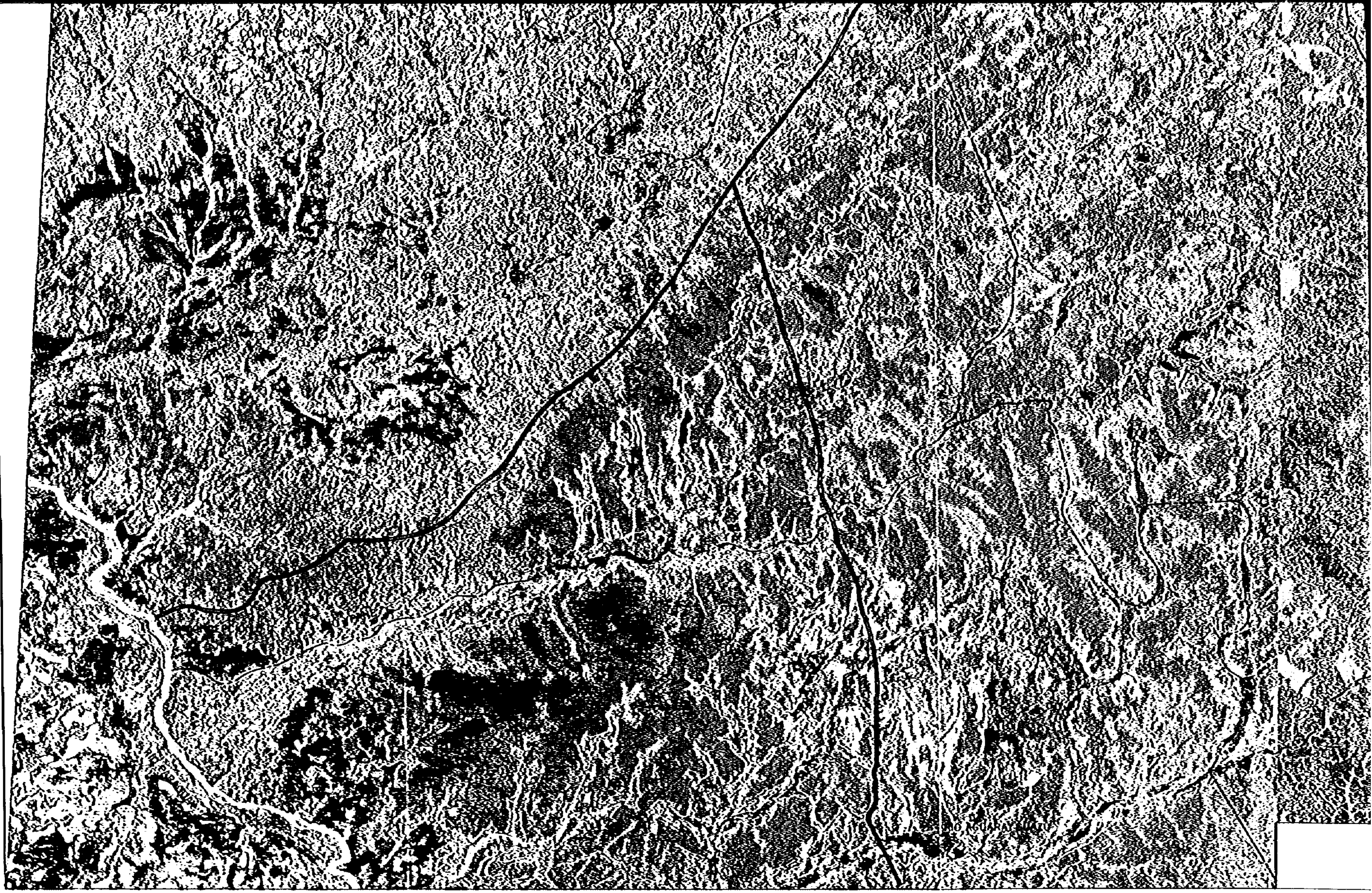
(IN THE NORTH-EASTERN REGION OF PARAGUAY)



MAIN PART on 3 NOV. 1975 by LANDSAT-II 8228513005500
COMPLEMENTARY PART on 15 SEP. 1972 by LANDSAT-I 8105413075500

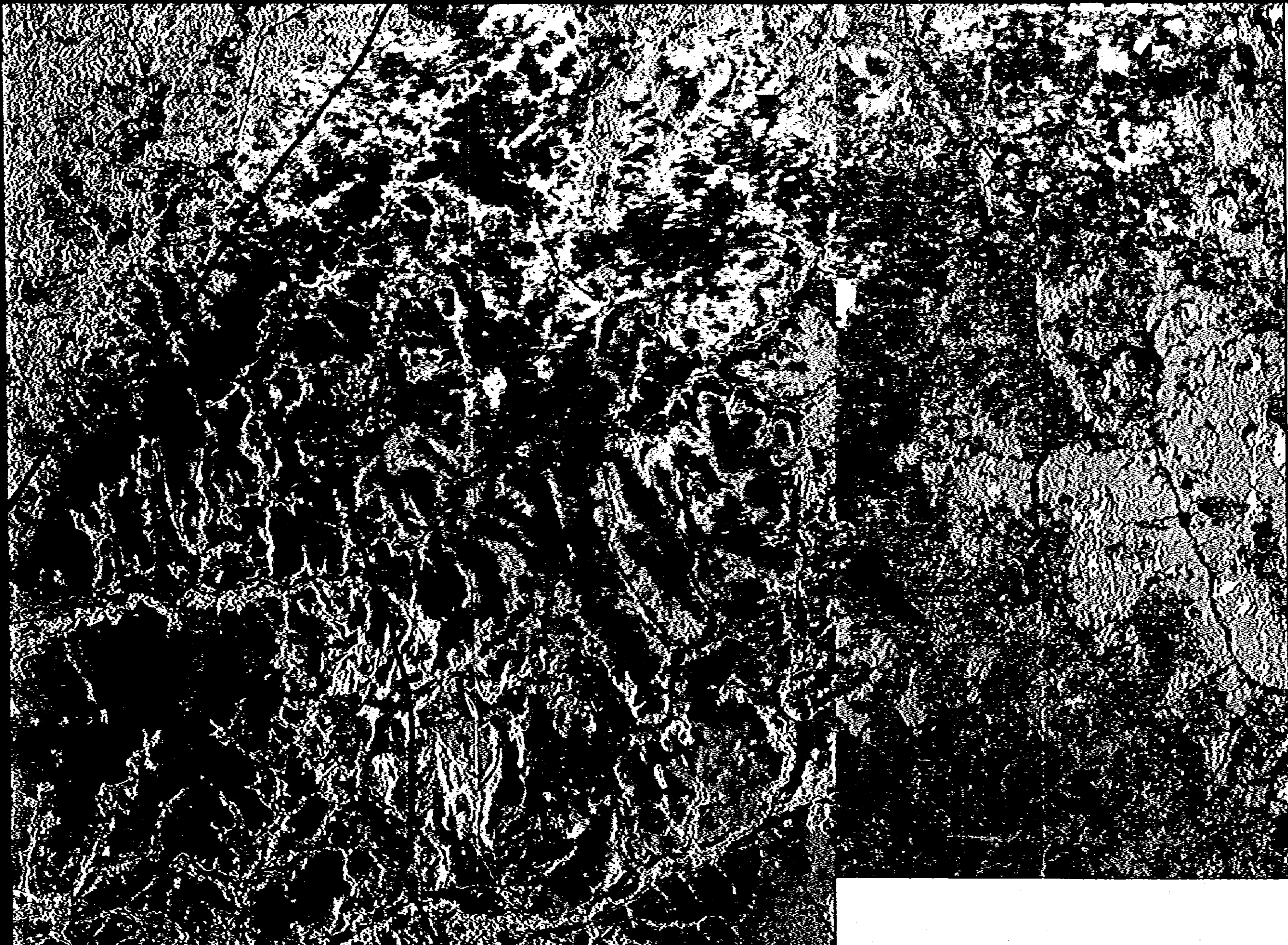
1:500,000





MAIN PART on 3 NOV. 1975 by LANDSAT-II 8228513005500
COMPLEMENTARY PART on 15 SEP. 1972 by LANDSAT-I 8105413075500

1 : 500,000



Tall forest type A
Tall forest type B
Tall forest type C
Medium forest type A
Medium forest type B
Dense crown forest
Mixed forest
Low forest
Pasture, cultivated area
Unused area
Natural grass land
Low grass land
Others
Unclassified

1:500,000

JAPAN INTERNATIONAL COOPERATION AGENCY

1:500.000

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